Electric, Hybrid & Fuel Cell Light Commercial Vehicles 2021-2041

COVID adjusted regional sales, penetration, battery demand and market value forecasts for electric, plug-in hybrid and fuel cell light commercial vehicles 2021-2041. Europe, China, and the US: players, technology, and drivers for electrification.

Dr David Wyatt, Luke Gear

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Today, Luke speaks regularly both at IDTechEx events and external events, sharing the latest insights on electric vehicle and battery trends. He has provided keynote presentations and technical masterclasses across three continents.

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1. Executive Summary

Imminent Boom in eLCVs

Diesel and petrol combustion engines are yesterday's technology: today, all major light commercial vehicle (LCV) manufacturers are investing in zero-emission technology, for fear of being left behind.

Electric LCVs (eLCVs) offer the possibility of zero point-of-use emissions that immediately protects cities from harmful particulate matter (PM) and Nitrous Oxide (NOx) emissions. Whilst the burden of decarbonisation is passed on to electricity generation, grids get greener every year as renewable energy installations increase. As major cities around the world establish low or zero emission zones, fleet operators will be increasingly pushed towards electric vehicles as the most cost-effective solution for their business.

Today the eLCV market is at a nascent stage: it is much smaller than the electric car market and few models are available for purchase. The next few years will see companies conducting large pilot projects to establish that eLCVs meet their operational range, load capacity, payload and reliability requirements. As experience and trust in electric technology grows, widespread replacement of ageing diesel LCVs with eLCVs will begin.

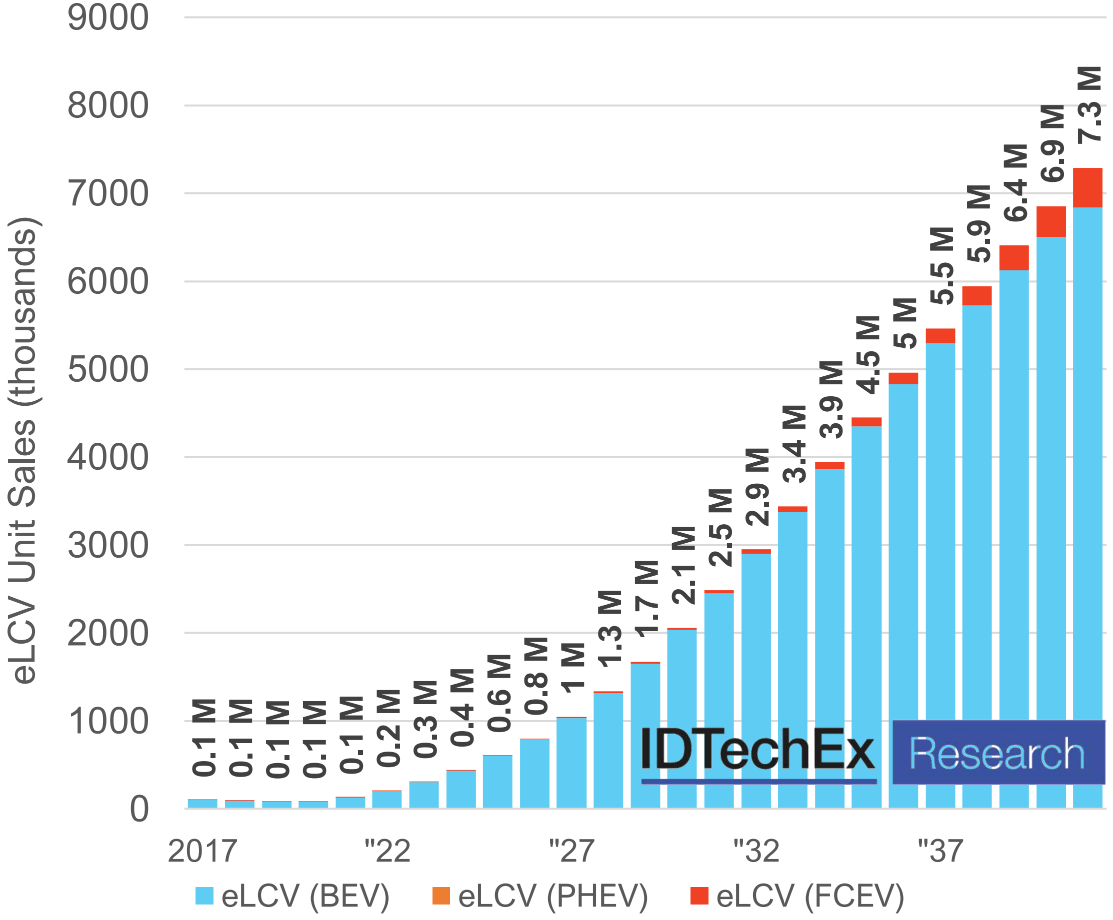
Electrification is also driven by increasing demand for freight delivery as the retail industry grows its online sales platforms, and consumers gradually abandon private car ownership for mobility as a service (MaaS) platforms.

Electric LCV Unit Sales BEV, PHEV, FCEV 2017-2041

As electricity provides a cheap source of fuel, our analysis finds that battery-electric LCVs already offer TCO parity with diesel in many scenarios. It is therefore expected that BEVs will attract more support than fuel cells, where hydrogen as a fuel remains expensive and lacks infrastructure. Despite the early cost advantage, in the short term the eLCV market will need subsidy support to grow initial trust in the technology. It will also need significant investment for the installation of charging / re-fuelling infrastructure.

As battery cost and eLCV prices fall, the cost of selling and running diesel LCVs is likely to increase as tightening impending fines force improvement of engine efficiency / cleaning exhaust gases.

We are not optimistic about PHEV LCVs. BEVs are the best value option to the fleet operator and the environment because battery-electric ranges are currently at an acceptable level (100 miles); in contrast, PHEVs are the worst of both worlds, with more complex, emitting powertrains at a high price. The lack of available PHEV models announced / currently on the market reflects this position.



Electric LCVs and Covid-19

The eLCV forecasts in this report account for the impact of the covid-19 pandemic.

China

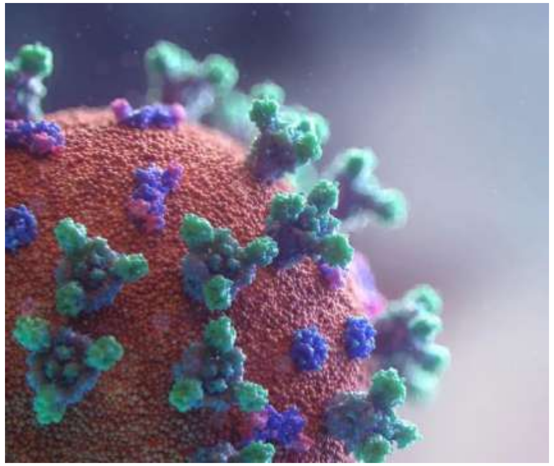
In China, auto production had resumed to 80% - 90% of December levels by mid-February, 2 - 3 months after the outbreak began in December 2019 but only 2 - 3 weeks after the normal shutdown would have ended in January due to Chinese New Year. With lockdowns eased, vehicles are being produced and consumer demand is returning. LCV sales in China in the first half of 2020 were at the same level as H1 2019 as a result of a recovering logistics sector, a boom in e-commerce and the government mandated replacement of old diesel vehicles.

Europe and the US

The situation is worse in Europe and the US, where covid-19 has had a deeper impact. By March 24, 2020, every auto plant in Europe was closed, with the situation similar in the US. Although production has now largely resumed (Sep 2020), there is increasing risk of further stalls due to lack of consumer demand (against the backdrop of a prolonged recession) and supply chain constraints as further local lockdown restrictions are imposed.

eLCVs

The fall in global eLCV sales between 2017 and 2019 was as a result of subsidy adjustments in China. We feel that the current eLCV sales in China now reflect genuine demand with the subsidy reductions. Whilst the total addressable market for LCVs will likely be affected by the pandemic over the next 3-5 years, IDTechEx believe that it will have a more limited impact on the nascent eLCV market and in fact may act as a boon to its growth: the lockdown restrictions with the resultant reduction in road traffic have provided clear evidence of urban air quality improvement that could be delivered with electric vehicles. In addition, covid-19 has pushed huge expansion of the e-commerce sector and several governments are promoting automotive electrification as a mechanism for stimulating their economies post covid-19 (e.g. France and Germany).



Visualisation of covid-19
Source: Fusion Medical Animation

LCV Sales Jan-Jun 2020

	2020 H1	H1 YoY
Europe LCV (<3.5t)	758,166	-33.8%
US LCV (<6.35t) Class 1-3*	170,142	-28.9%
China LCV (<6t)	1,617,819	1.0%

*Excluding Pickups

Plug-in hybrid LCVs

- Ford, Mitsubishi and LEVC are offering (or will offer) plug-in hybrid light commercial vehicles. The rational behind them lies in the greater flexibility that PHEV architecture offers; as an ICE engine within the vehicle powertrain is able to act as a generator to charge the battery, increasing the vehicles range and decreasing its dependence on available charging infrastructure. They also offer a short zero-emission range, which, to a degree, future proofs them against emission / congestion charges in urban centres. However there are a number of reasons why we feel that PHEV technologies are not suited to the LCV market and hence why PHEV LCV will have limited penetration.

  - **PHEVs are not a zero-emission solution:** countries looking to impose sales bans on ICE vehicles may in the future prevent the sale of all ICE vehicles whether the powertrain is hybrid or not, creating uncertainty for those developing PHEVs. The emission reduction potential of PHEVs, 15-55% compared to conventional vehicles, is unlikely to be as attractive as BEV LCV models to fleet purchasers, where their goal is to reduce CO2 emission to meet internal company targets. As a consequence, no major LCV OEMs outside of Ford offer (or as far as IDTechEx are aware, are developing) a PHEV LCV model.
  - **Fleet operators understand their daily duty requirements**: in many LCV applications there is little need for the flexibility of extra range (unlike cars, taxis, and long-haul trucks). Research suggests that a significant percentage of the LCV market have a daily range requirement of less than 100 km per day and depart from and return to a depot. In short range applications where a PHEV LCV would almost exclusively use only the electric range, then they would be needlessly carrying the extra weight of an ICE engine, and the demand could be met by a BEV. Moreover, LCV fleet operators have the data to plan their operations and charging schedule to optimise the use of battery-only LCVs. In the case where the range cannot be met, the operator will likely continue to purchase an ICE LCV until a ban prevents this, by which time (in most countries) battery and charging technologies (and potentially in the longer term FCEV technology) will have advanced enough to deliver longer daily duty ranges.
  - **Hybrid systems are complex:** as PHEV powertrains combine both EV and ICE parts this requires maintenance and servicing of both technologies. Therefore PHEVs will not offer the same reduced maintenance benefit that BEVs offer over ICE vehicles and given the complexity could potentially be more expensive and less reliable than ICE LCV.

- The current niche for PHEV LCV appears to be for those operators who do more than 100 km a day and regularly drive through city centres with low-emission zones. We believe is a very small percentage of the LCV market which will dwindle as powertrain technology improves range in the coming years. The proof will be in the sales performance of the Ford PHEV. We are not aware of any other major OEMs currently developing PHEV LCVs, all others have transition from ICE straight to BEVs.

Global Forecast Takeaways

This report contains forecast lines describing eLCV uptake (excluding passenger pickup trucks) in Europe (EU +EFTA+UK), China, and the US along with forecasts for the rest of the world (RoW). These four regions are aggregated to provide a global outlook for eLCV. Forecasts have been calculated from 2020 to 2041, for each region, detailing vehicle sales, market penetration (%), market revenue ($) and battery capacity requirement (GWh). Separate forecast lines for battery electric (BEV), plug-in hybrid (PHEV) and fuel cell (FCEV) are provided for each region. The report also includes a detailed look at the markets within Europe, providing individual 2020-2041 eLCV sales and market penetration figures for all countries with over 75,000 annual LCV sales.

Region	Key Takeaways
Global	• Total global sales of eLCV (BEV, PHEV & FCEV) is forecast to rise from 78 thousand units in 2019 to 2.06 million units in 2030 (excluding pickup trucks) and 7.3 million units in 2041. • In 2030, 41.7% of sales are in China, 37.5% in Europe, 5.5% in the US (*passenger pickup trucks are excluded) and 15.3% in the RoW (notably Japan, South Korea, India, Brazil). • By 2030 the eLCV market will required 109.8 GWh of batteries. • The market for eLCV reaches $58 billion in 2030, rising to $203 billion in 2041.

Forecast Takeaways

Region	Key Takeaways
Europe	• By 2030 electric penetration into the European LCV market is forecast to be 33.3%. Sales of eLCV rise to approximately 772.4k units by 2030, as legislation is enacted by several countries that bans the sale of new ICE LCV. By the end of the decade there is a TCO advantage for eLCV in all small, medium and large LCV segments where the battery size meets the required daily duty cycle. • In 2030, 37.5% of global eLCV revenue is forecast to be from the European eLCV market (≈ $27.7 billion)
US	• Addressable market for LCV in the US rises from 574k units in 2020 to 620k units in 2030 (excludes passenger pickup trucks, which are incorporated into IDTechEx's analysis of electric cars, due to significant private rather than commercial use in the US) • Forecast 2030 US sales of eLCV are 112.9k units, with an eLCV market share of 18.2% and market value of $4.5 billion • Early uptake of eLCV primarily in California due to policy supporting the uptake of EVs, wider adoption expected as other states follow suit. • Electrification of the LCV fleet in the US is likely to be driven in the short-term by global companies (Amazon, UPS, FedEx, etc.) with their own internal GHG emission reduction targets.
China	• China is forecast to have the largest share of sales, 0.85 million eLCV p.a. in 2030 (41.7% of global sales). • Strong government support for the manufacture eLCV and its supply chain, along with policy for air quality improvement in urban areas see the eLCV market share in China forecast to reach 24.5% by 2030. • In 2030, it is forecast that 29.1% of global eLCV revenue will be in the Chinese market (≈ $16.9 billion).
RoW	• In 2019, 34.9% of all LCV (all fuels) were sold outside of the Chinese, US and European markets, this is forecast to rise to 36.1% in 2030, and 38.2% in 2041. There are significant LCV markets in Japan, India, Thailand, Brazil and South Korea. • The forecast 2030 eLCV share in the RoW markets is 8.7%, with 315k units p.a. but uptake of eLCVs will vary greatly by individual country. • The market value of eLCV in the RoW is forecast to rise to $9 billion in 2030.

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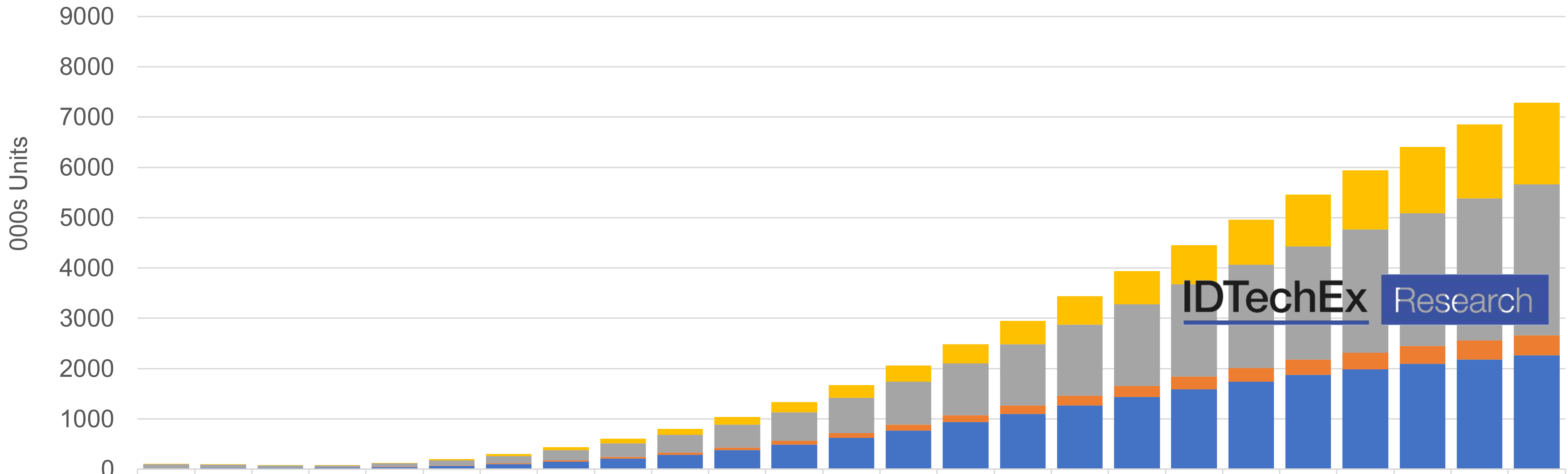
eLCV (BEV, PHEV, FCEV) sales by region 2017-2041 (000s units)



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
RoW	0	0	1	1	11	25	41	62	89	120	157	201	254	315	387	469	561	665	779	902	1034	1174	1320	1473	1630
China	82	71	48	47	69	104	147	203	274	355	453	569	704	858	1030	1217	1417	1625	1836	2046	2251	2448	2638	2819	2994
US	0	0	0	0	3	8	14	22	31	43	56	73	91	113	137	163	190	219	248	276	304	330	355	379	401
EU + EFTA + UK	16	23	29	31	46	69	104	152	210	283	376	490	623	772	934	1101	1269	1434	1591	1739	1873	1989	2092	2184	2264
eLCV Total	99	95	78	79	130	206	307	439	604	801	1042	1333	1672	2058	2487	2949	3438	3942	4453	4963	5462	5941	6406	6854	7289

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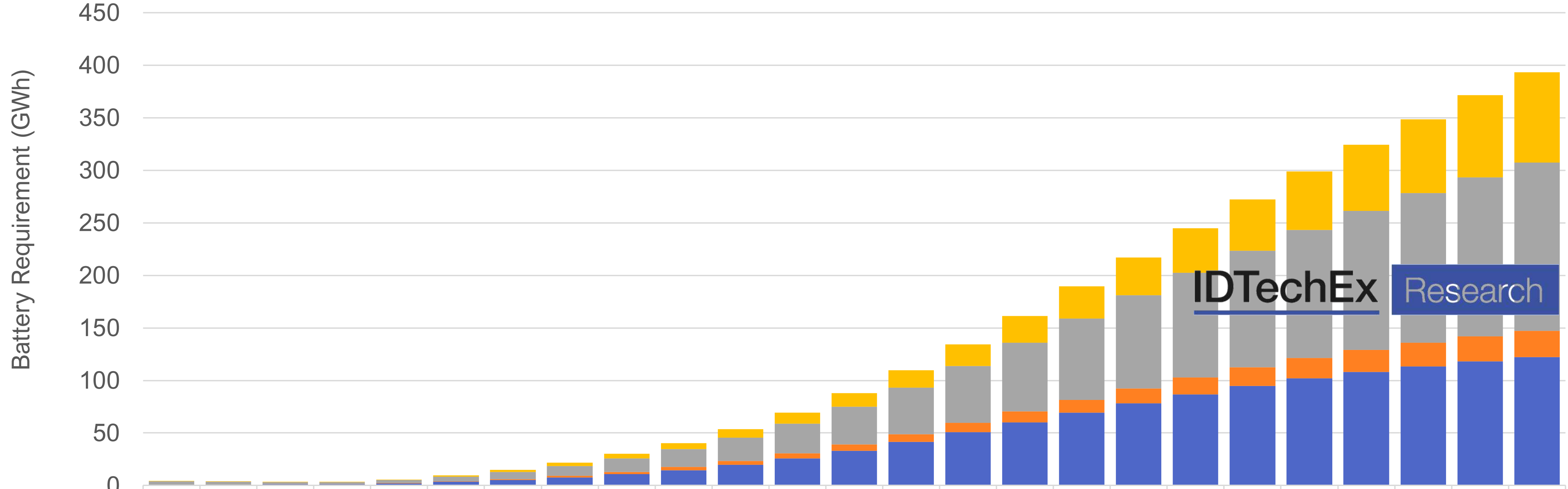
eLCV (BEV, PHEV, FCEV) battery forecast by region 2017-2041 (GWh)



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
RoW	0.0	0.0	0.0	0.0	0.5	1.2	2.0	3.0	4.3	5.9	7.9	10.3	13.1	16.5	20.6	25.2	30.5	36.0	42.1	48.7	55.6	62.9	70.5	78.2	86.0
China	3.3	2.9	2.0	2.0	3.0	4.5	6.6	9.3	12.8	17.0	22.1	28.3	35.7	44.4	54.3	65.3	77.4	88.6	100.0	111.2	122.1	132.5	142.3	151.5	160.1
US	0.0	0.0	0.0	0.0	0.2	0.6	1.0	1.5	2.1	2.9	3.8	4.8	6.0	7.4	8.9	10.5	12.2	14.0	15.9	17.6	19.3	21.0	22.5	23.9	25.2
EU+EFTA+UK	0.6	0.8	1.1	1.2	2.0	3.4	5.2	7.7	10.8	14.7	19.7	25.9	33.2	41.5	50.7	60.2	69.4	78.3	86.9	94.8	102.0	108.1	113.5	118.1	122.1
eLCV Total	3.9	3.7	3.1	3.2	5.7	9.7	14.8	21.5	30.1	40.5	53.5	69.3	88.1	109.8	134.4	161.2	189.4	217.0	244.8	272.3	299.1	324.5	348.7	371.7	393.4

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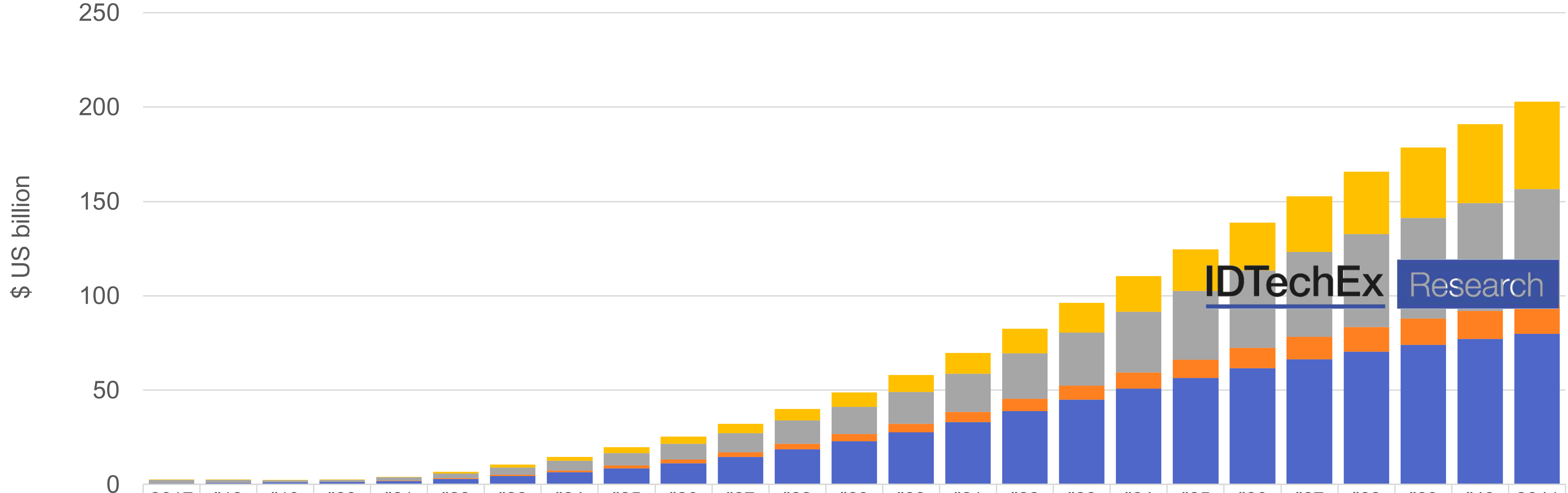
eLCV market revenue forecast by region 2017-2041 ($US billion)



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
RoW	0.0	0.0	0.0	0.0	0.4	0.8	1.5	2.1	2.9	3.9	4.9	6.1	7.4	9.0	10.9	13.2	15.8	18.8	22.0	25.5	29.3	33.3	37.5	41.8	46.2
China	1.7	1.5	1.1	1.1	1.7	2.6	3.9	5.2	6.7	8.4	10.2	12.3	14.5	16.9	20.3	24.0	28.0	32.2	36.5	40.8	45.1	49.3	53.3	57.3	61.1
US	0.0	0.0	0.0	0.0	0.2	0.4	0.7	1.0	1.4	1.9	2.4	3.0	3.7	4.5	5.4	6.4	7.5	8.6	9.7	10.8	11.9	12.9	13.8	14.7	15.5
EU+EFTA+UK	0.6	0.9	1.1	1.2	1.9	2.9	4.5	6.4	8.6	11.3	14.6	18.6	23.0	27.7	33.1	39.0	44.9	50.8	56.4	61.6	66.4	70.4	74.1	77.2	79.9
eLCV Total	2.3	2.4	2.2	2.4	4.1	6.8	10.5	14.7	19.7	25.4	32.2	40.0	48.7	58.0	69.6	82.6	96.3	110.4	124.6	138.8	152.6	165.9	178.7	191.0	202.8

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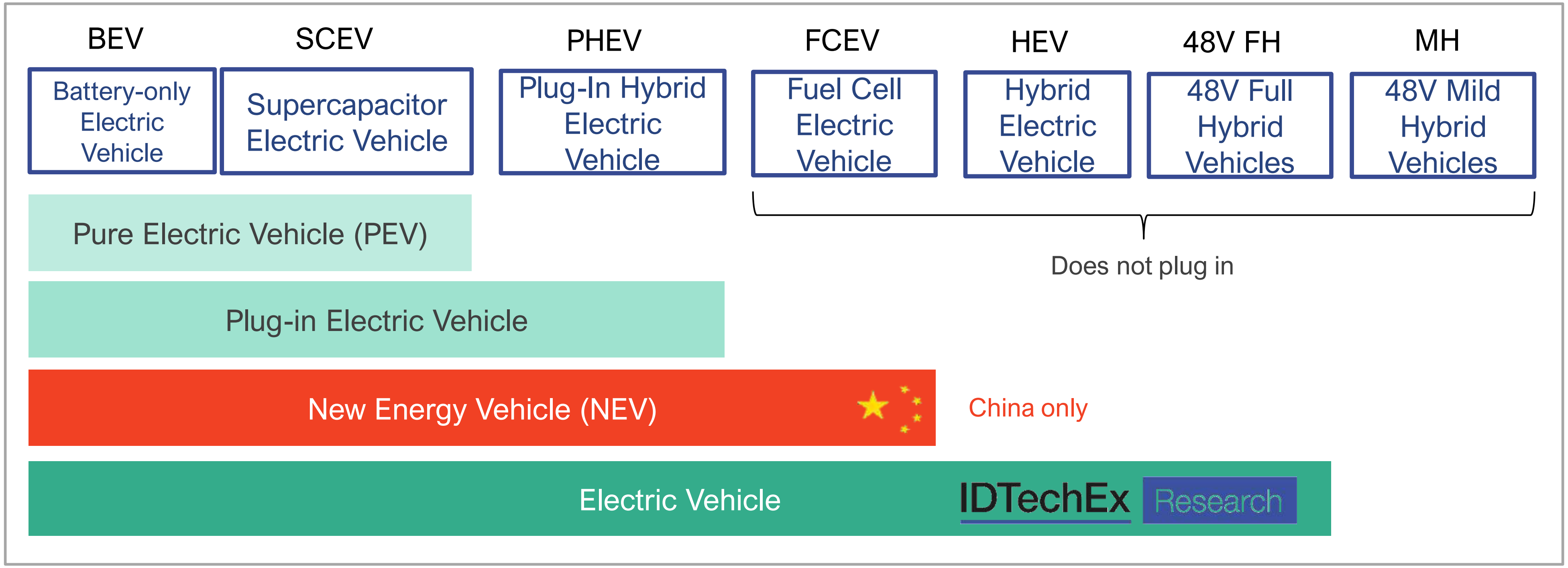
2. Introduction

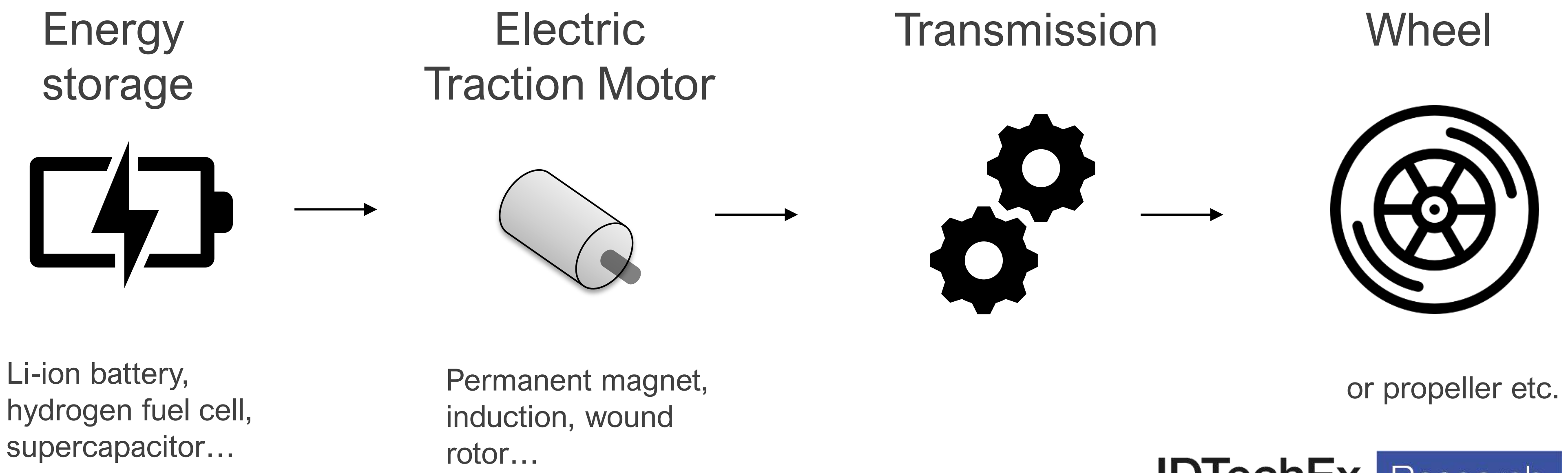
Electric Vehicle Terms

An electric vehicle (EV) is an umbrella term for any vehicle that has pure electric modes for emissions-free operation. There are different levels within this, including battery-electric vehicle (BEV), plug-in hybrid electric vehicle (PHEV), high-voltage hybrid electric vehicle that does not plug in (HEV) and low-voltage full hybrid electric vehicles that do not plug in (48V FH). 48V mild-hybrid (MH) vehicles are not included under the definition because they do not have engine-off modes, although they improve fuel economy. ‘Electric Vehicle’ is also technology agnostic to the onboard energy storage device: fuel cell electric vehicles (FCEV) and supercapacitor electric vehicles (SCEV) are also ‘electric vehicles’ in addition to those powered by Li-ion batteries. China has a separate umbrella term, ‘New Energy Vehicle’, which is similar but excludes strong hybrids (HEVs).



Electric Vehicles: Basic Principle

In their simplest form, an electric vehicle consists of a Li-ion battery which powers one front-mounted electric traction motor (‘motor’) which turns the wheels or propeller via a transmission. They tend to have only a few moving parts, with the powertrain requiring almost no maintenance over its lifetime. In fact, the most regular maintenance required for the BEV car is replacing air filters. This is in stark contrast to the internal combustion engine with hundreds of moving parts requiring constant maintenance and repair, with multiple points of failure as they age. The first point of failure in the electric car is usually the battery, with the body, power electronics and motors having potential to last 20-30 years.



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Electric Vehicles: Typical Specs

Below we show the typical spec ranges of the different electric car powertrains, based on our cars model database and OEM disclosures.

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Vehicle	Powertrain	Battery Capacity (kWh)	Voltage (V)	Combined Motor Output (kWp)
Car	BEV	30-150	200-900	100-200
Car	PHEV	10-20	200-400	100-200
Car	HEV	< 10	200-400	80
Car	48V Full Hybrid	< 5	48	< 80
Bus	BEV	100-250	400V-1000	200-300
LCV	BEV	30-150	200-400	50-200
Truck	BEV	150-1000	400V-1000	200-300

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LCV Definition

Source: Renault.ie

LCVs (LCV)

EU LCV Classification:

N1 – Used for the carriage of goods, having a maximum mass not exceeding 3.5 tonnes.

US, China, RoW LCV Classification:

Cargo LCV < 3,856 kg (8,500 lb – Class 2a)
Delivery Truck < 6,350 kg (14,000 lb – Class 3)

* This analysis excludes passenger pickup trucks

Different segments of goods transportation by land

- M&HDT: Medium- & Heavy-duty trucks
- Mass > 3500 kg
- Long range
- Drives on highways
- Automation is easier
- Electrification is difficult

- LCV: LCV
- Mass < 3500 kg
- Short / medium range
- Drives in cities
- Automation is difficult
- Electrification is easier

Types of popular on-road truck

Terminology varies across the world. Using common US definitions, three volume types are as shown, with official subdivisions.

Type	Examples	Weight	Comment
Light Commercial Truck (LCV)	• Minivans • Passenger trucks (typically pickups)	1–14000 lb (1–6350 kg)	Light trucks have powertrains similar to cars. Upfront price, appearance and total cost of ownership can be issues. In the US the trend is for consumers to buy pickup trucks and drive them like a car, hence ‘passenger truck’. In the US, light trucks can include SUVs. In this report we do not include SUVs or passenger pickup trucks. Light trucks are easiest to electrify viably.
Medium trucks (MDT)	• Box truck • Motorhome • Platform truck	14001–26000 lb (6351–11793 kg) *A heavy goods vehicle (HGV), also large goods vehicle (LGV) or medium goods vehicle, is the EU term for any truck with a gross combination mass (GCM) of over 3,500 kilograms*	Except for motorhomes, these are mainly corporate purchases where total cost of ownership and intensive use often in cities with frequent stop start and emissions are key issues.
Heavy truck (HDT)	• Haul truck • Tank truck • Tractor unit • Lorry	26001 to over 33000 lb (11794 to over 14969 kg)	Corporate purchases where total cost of ownership and intensive inter city use are key issues. Heavy trucks have to be the primary focus of government pressure to electrify for emission control in US.

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LCV fleet description by region

Comparison of LCV specifications in different regional markets. The US LCV fleet contains pickup trucks and four-wheel drive SUVs

Light commercial vehicle fleet	China (2012*)	EU-28 (2015)	India (2014)	Japan (2013)	Mexico (2014)	Saudi Arabia (2012)	South Korea (2014)	U.S. (2015)
Sales (million)	2.6	1.7	0.3	0.8	0.2	0.4	0.2	10.3
Engine displacement (L)	1.7	1.9	1.6	1.0	2.7	3.7	2.3	3.8
Engine power (kW)	46	86	33	-	135	173	-	211
Curb weight (metric tons)	1.4	1.8	1.3	1.1	1.7	2.0	1.9	2.2
Footprint (m^2)	3.5	5.2	3.6	-	4.6	4.6	-	5.2
Fuel consumption - NEDC (l/100km)	8.7	7.2	6.8	6.5	9.6	10.7	8.9	9.7
CO_2 emission - NEDC (g/km)	202	168	158	151	224	251	209	226
Petrol	48%	3%	0%	94%	95%	-	0%	98%
Diesel	51%	97%	89%	6%	5%	-	96%	2%
Hybrid-electric	0%	0%	0%	0%	0%	-	0%	1%
Others	1%	1%	11%	0%	0%	-	4%	0%
Manual transmission	100%	96%	100%	-	65%	-	28%	1%
Automatic transmission	0%	4%	0%	-	35%	-	72%	99%

* China sales reflects 2014 fleet, footprint reflects 2010 fleet

Source: ICCT, CATARC

The Core Driver: Climate Change

The Intergovernmental Panel on Climate Change's fifth assessment report (AR5) established that anthropogenic greenhouse gas (GHG) emissions are responsible for the period of global warming observed over the past few decades, CO2 imparting the largest impact. If emissions continue at current levels (without growth), the resultant warming is likely to induce devastating changes to the climate with dire consequences for the most vulnerable communities and ecosystems around the world. As road transportation is a major source of made-made GHG emissions, this is the core driver for electrification.

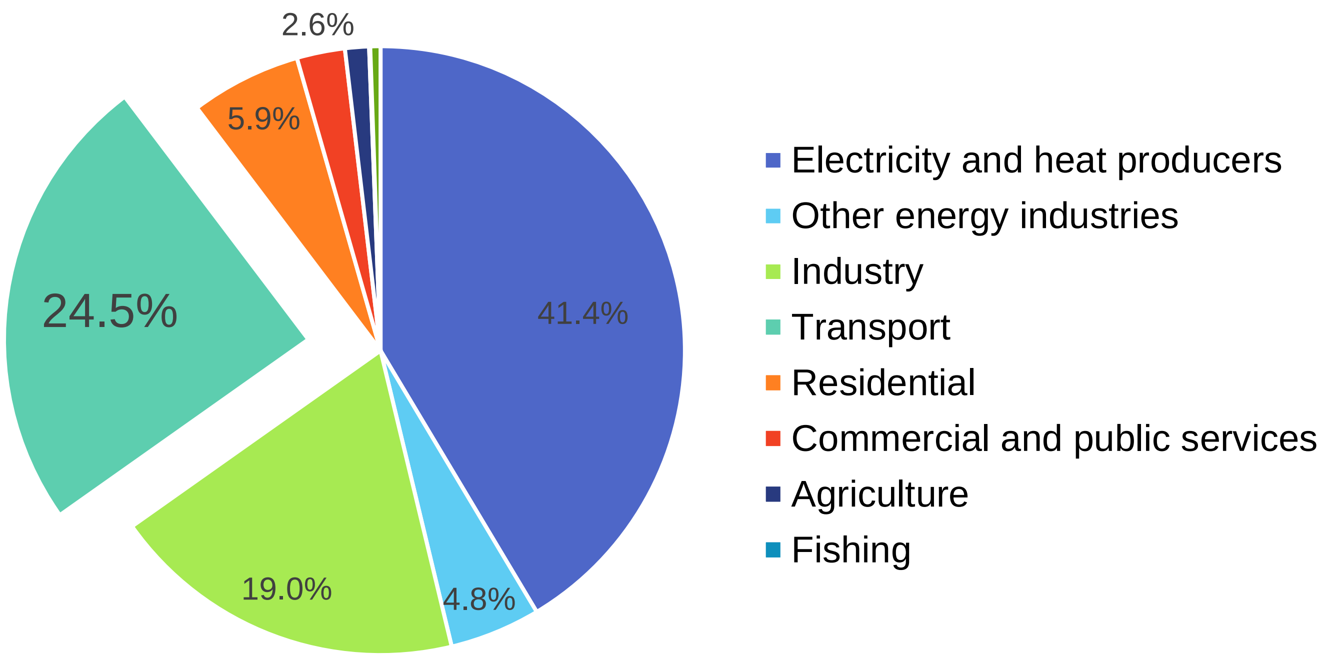
In response to this threat, many countries around the world have made commitments towards reducing their GHG emissions. In 2015, the signing of the 'Paris Agreement' by 195 countries put into place "the first-ever universal, legally binding global climate deal". The goal of the agreement is to see global GHG emissions peak "as soon as possible" in order to meet a long-established target of limiting global warming to less than two degrees Celsius. As part of the agreement, many countries around the world have made strong commitments towards reducing their GHG emissions through formally submitted Intended Nationally Determined Contributions.

Global CO_2 emission from transport

Research conducted by the International Energy Agency (IEA) suggests that global fuel combustion resulted in 32.8 Gt of CO2 emission in 2017. China (9.3 Gt), the US (4.8 Gt) and Europe (3.2 Gt) between them, generated 55.6% of this emission.

Overall the transport sector contributed 8.0 Gt (24.5%), with the US (1.7 Gt), Europe (0.9 Gt) and China (0.9 Gt) responsible for 44.0% of all transport related CO2 emissions from fuel combustion.

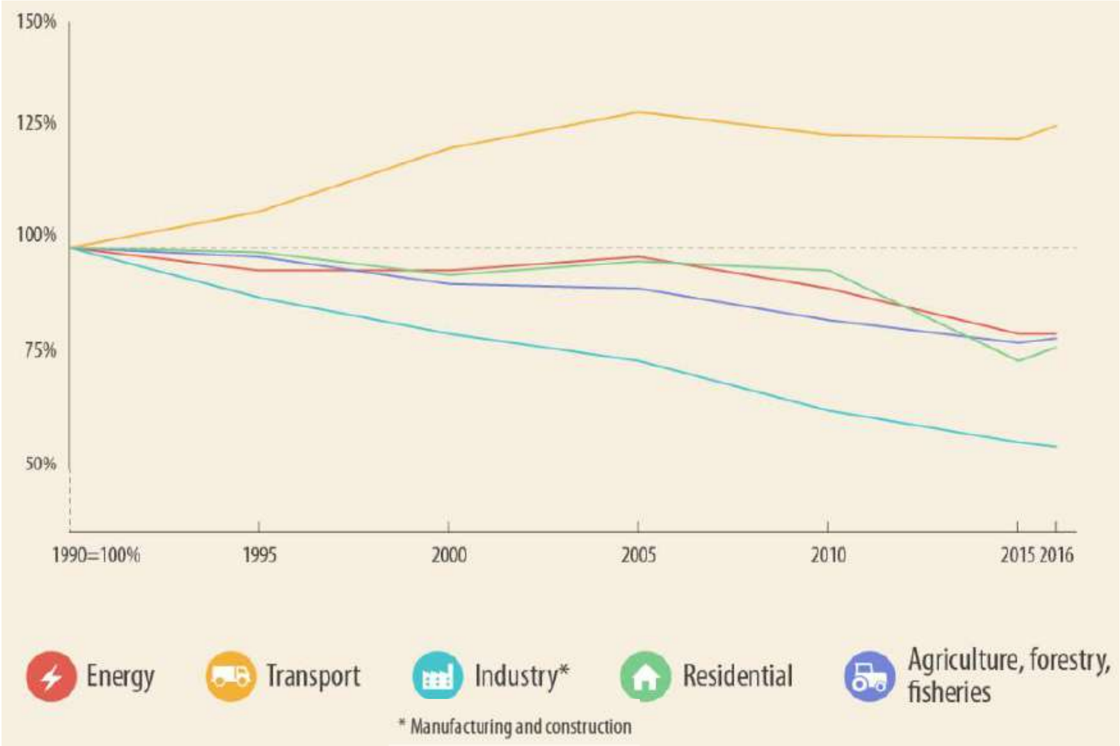
Global CO_2 Emissions from Fuel Combustion by Sector



Source: iea.org

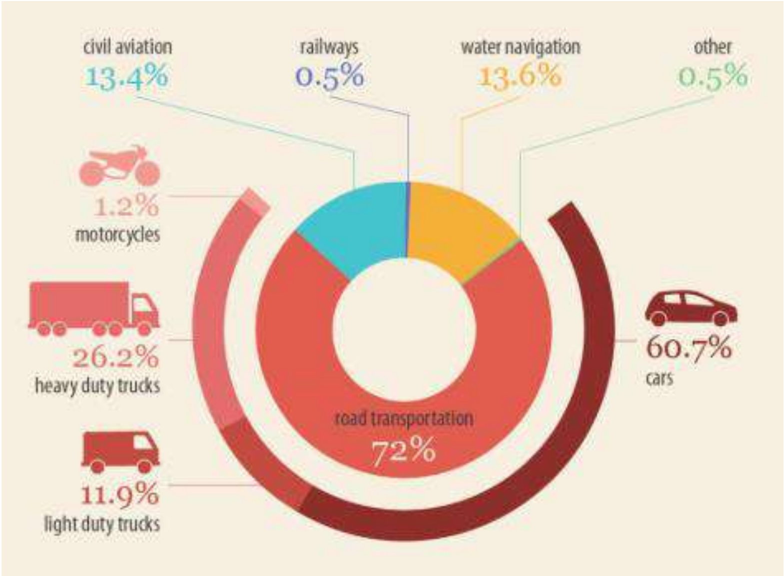
CO_2 emissions from the LCV sector

Europe: Change in CO_2 Emissions by Sector (1990-2016)



Whilst every other sector in Europe has seen a CO_2 reduction against the 1990 level of CO_2 emission, total emissions from the transport sector have not, despite efforts to improve fuel efficiency

Europe: CO_2 emissions by transport mode (2016)



Source: EEA

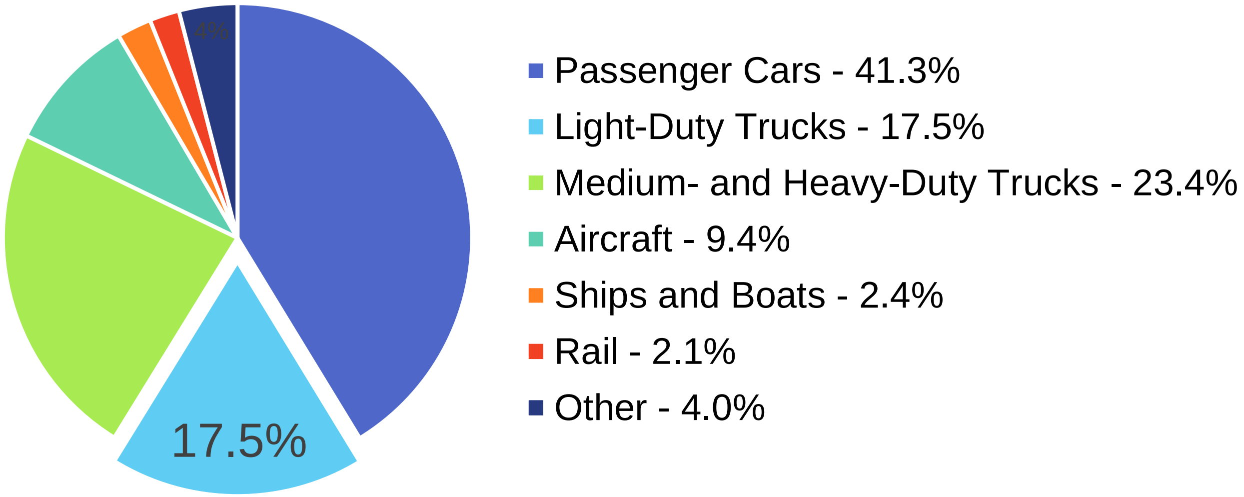
- Transport contributed **30% of Europe's total CO_2 emissions**
- 72% comes from on-road transportation
- 11.9% of the EU's road transport emission is from light duty trucks (81 Mt CO_2)
- Therefore, **2.6%** of Europe's total CO_2 emissions is generated by LCVs

CO_2 emission from the LCV sector

In the US 17.5% of transport GHG emissions is generated by the light-duty truck sector. Equivalent to 327.3 Mt of CO2e. The US definition of light-duty truck also includes SUVs, minivans and passenger pickup trucks, where there is very significant private rather than commercial usage.

According to Chinese Government statistics the total fuel consumption of their LCV sector is around 7 million tonnes per year, which would be equivalent to approximately 22.4 Mt CO2e, which is about 2.5% of China's total transport related emission from fuel combustion.

Share of US Transport GHG emission by Sector 2017



To meet climate targets there will need to be significant decarbonisation of the LCV sector

Source: nepis.epa.gov, gov.cn

Urban air quality

The European Environment Agency (EEA) define air pollution as “the presence of pollutants in the atmosphere at levels that harm human health, the environment and / or cultural heritage (e.g. by damaging buildings, monuments and materials)”.

Over the past decade it has become increasingly clear that road transportation is an important source of some of the most harmful air pollutants, in particular emission of Nitrogen Oxides (NOx) and Particulate Matter (PM).

Whilst in absolute terms air pollution emissions from other sources such as power plants and industrial facilities may be greater, the proximity of transport emissions to large populations, especially in congested urban areas, mean that emissions from road transport are much more likely to be the source of dangerously high levels of air pollution.

The World Health Organization (WHO) suggest that an estimated 3.7 million premature deaths can be attributed to air pollution, with poor air quality increasing the risk for heart and lung disease, cancer, diabetes, preterm birth and cognitive decline.

Smog in Shanghai, China. Credit: Holger Link

Smog in Mumbai, India. Credit: Abhay Singh

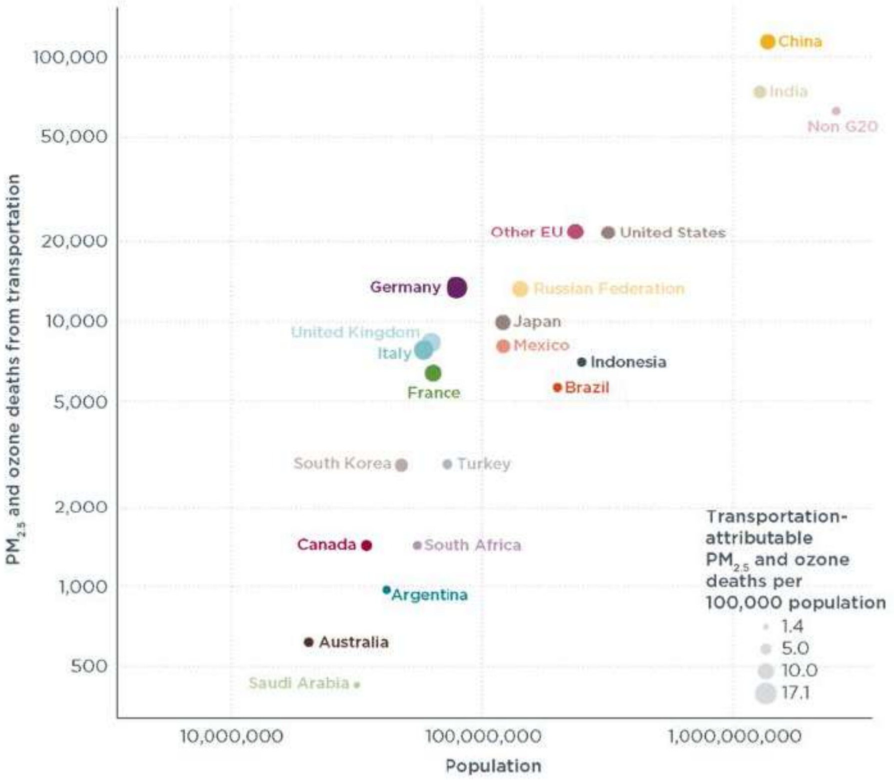
Urban air quality

Air pollution-related deaths and illness are linked closely to exposure to small particulate matter (PM) emissions of less than 10 or 2.5 microns in diameter (PM_{10} and $PM_{2.5}$). Small particulates bypass the body's defences against dust, penetrating deep into the respiratory system. They also comprise a mixture of health-harming substances, such as heavy metals, sulphurs, carbon compounds, and carcinogens including benzene derivatives.

Nitrogen dioxide (NO_2) is associated with asthma incidence among children and acts as an irritant to the human respiratory system. NO_2 is also responsible for the formation of secondary $PM_{2.5}$ and ozone.

A study by the International Council on Clean Transportation in 2019 directly linked vehicle exhaust emissions of $PM_{2.5}$ and ozone to ~361,000 premature deaths worldwide in 2010 and ~385,000 in 2015, estimating the cost of transportation-attributable health impacts at approximately $1 trillion in 2015.

Exhaust emission from on-road diesel vehicle was found to be responsible for nearly half of the premature deaths.



Source: WHO, Hindustan Times, kcrw.com, ICCT

Urban air quality

The ICCT study found that urban areas with the highest number of transportation-attributable air pollution deaths in 2015 were Guangzhou, Tokyo, Shanghai, Mexico City, Cairo, New Delhi, Moscow, Beijing, London, and Los Angeles.

EU regulations mandate that sites must not exceed a maximum NO_2 concentration of 200 µg/m3 for more than 18 hours over a whole year; between 2010 and 2017 London exceeded this level within the first six days of each year. In 2018 it was exceeded by the end of January, but in 2019 the regulation was not breached until the 25th of July.

The improvement in London's air quality has been attributed to investment in new lower pollution buses and lower exhaust emission from new trucks.

A study done in 2016 at Columbia University, found that replacing diesel buses with electric in New York City would have a benefit to the heath of the population (reducing respiratory and other diseases) that equated to $150k per bus (over the lifetime of the bus) in reduced hospitalization, emergency room treatment and missed days of work.

Despite the improvement in London, the Mayor of London's office released a press release in April 2019 saying that 2 million Londoners, including 400,000 children live in areas exceeding legal air pollution limits.

theguardian

London reaches legal air pollution limit just one month into the new year

South China Morning Post

Pollution makes Beijing almost 'uninhabitable for human beings'

New study ranks Beijing second worst in terms of living environment among 40 major world cities

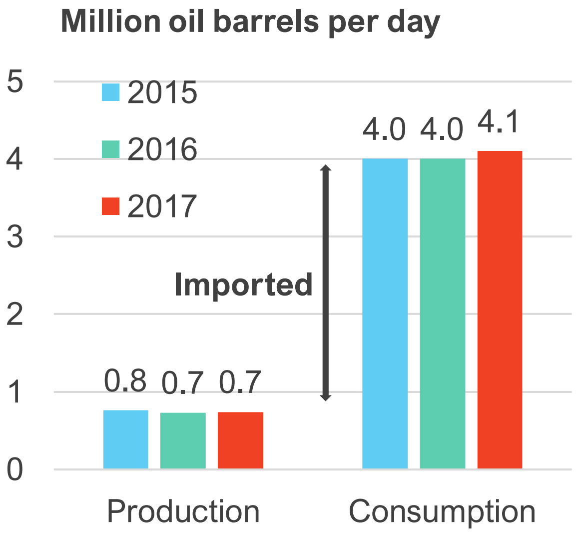
The New York Times

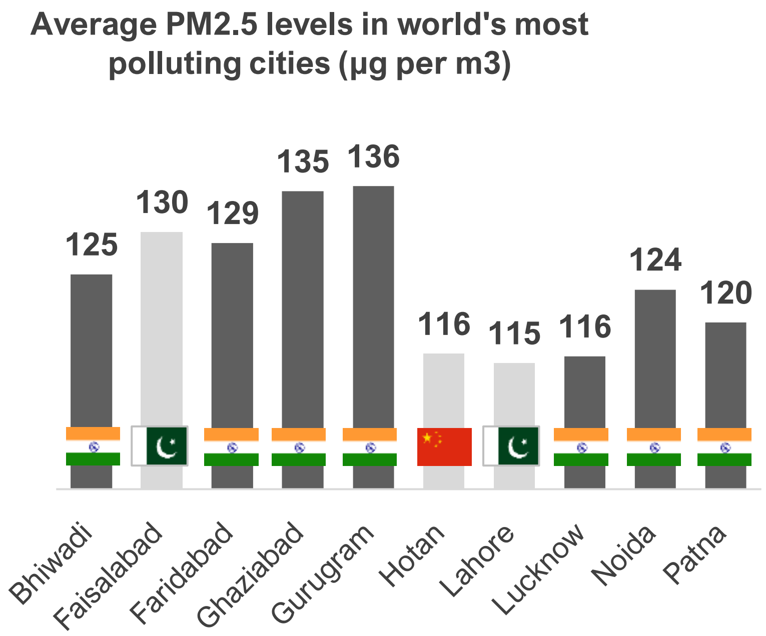
Delhi to Limit Use of Cars in an Effort to Control Pollution

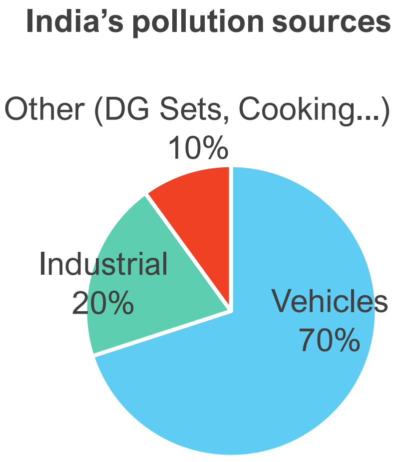
Source: ICCT, The Guardian, airqualitynews.com, London.gov.uk

Pollution in India

India is highly dependant on oil imports and has seven of the world's top ten most polluted cities. Roughly 70% of pollution comes from vehicle emissions, and 81% of vehicle sales were two-wheelers in fiscal year 2020 (SIAM). Energy independence and emissions reduction are key drivers for electrification.







Smog in Mumbai, India. Credit: Abhay Singh

Data sources: Society of Manufacturers for Electric Vehicles (SMEV)

Road transport the main source of urban NOx

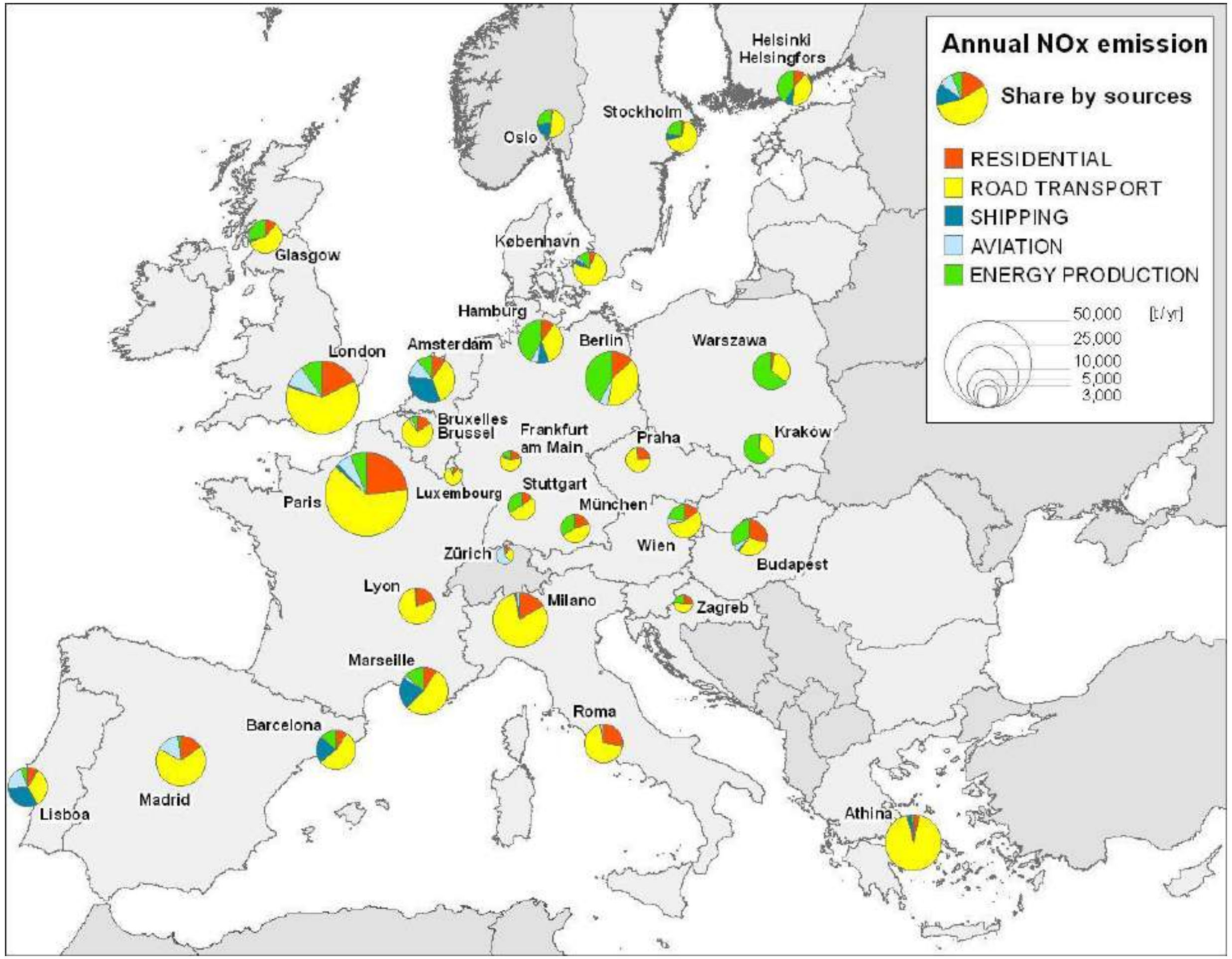
The urban nitrogen dioxide (NO2) atlas, put together by the European Commissions Joint Research Centre (JRC) identified the main sources of NO2 within 30 European cities.

This research highlights the contribution road transport makes to overall NOx emission.

The average contribution of road transport was 47%, with Athens and Milan this figure was over 70%.

Research like this makes a strong case for restricting the access of vehicles to populous urban centres, especially diesel vehicles, which are responsible for the bulk of road transport NOx emissions.

As LCVs are commonly used in urban delivery applications, reducing emissions from LCVs will be important in improving urban air quality



Source: EU 2019

Fossil Fuel Bans: Explained

A fossil fuel ban is a ban on gasoline-only or diesel-only vehicles - it does not necessarily exclude hybrids, which have an internal combustion engine with engine-off modes.

An official target is one announced and confirmed by the government. Most official targets do not have legislative backing (which make it illegal to use fossil fuelled vehicles after the target year).

An unofficial target is one where a draft or proposed ban has been reported (typically by local news outlets), but has not been confirmed as official policy by the government.

While at least 16 countries have drafted or proposed fossil fuel vehicle bans, only eight of them are official policy at time of writing, of which three have legislative backing (France, Iceland and Canada). Most do not clarify whether plug-in hybrids (PHEVs), or even strong hybrids (HEVs) are included in the bans.

Official or Legislated Fossil Fuel Bans (National)

Country	Announced	Comments	Vehicle Type	Official Target	Legislative Backing	Includes HEVs	Includes PHEVs	2025	2030	2035	2040	2050
Canada	2017	Target for new light duty vehicle sales to be 100% zero emission vehicles (ZEV) by 2040. PHEVs count as a zero-emission vehicle.	New Cars and LCVs	Yes	Yes	Yes	No	10%	30%		100%	
France	2017	New petrol and diesel car sales. Unclear on hybrids. Former environment minister Nicolas Hulot, who made the announcement, resigned in Sept-2018. Legislation adopted May 2019 (article 26AA).	New Cars	Yes	Yes	Unclear	Unclear				100%	
Iceland	2018	New petrol and diesel car sales are banned under the 'Climate Action Plan'. Unclear on hybrids.	New Cars	Yes	Yes	Unclear	Unclear		100%			
Netherlands	2017	One sentence in the 2017 coalition agreement says the 'aim' is for all new cars to be zero emission by 2030 at the latest.	New Cars	Yes	No	Unclear	Unclear		100%			
Norway	2017	An 'agreement' on a target of zero new fossil-fuel cars sold from 2025, 'no outright ban, but strong actions required'.	New Cars	Yes	No	Unclear	Unclear	100%				
Costa Rica	2019	The National Decarbonization Plan of Costa Rica sets out targets to convert its fleet of public and private vehicles to zero emissions in steps up to 2050.	New Vehicles	Yes	No	Yes	Yes			70%		100%
Singapore	2020	Goal to 'phase-out internal combustion engines by 2040' deputy prime minister mentioned in a budget speech (Feb 2020).	New Vehicles	Yes	No	Unclear	Unclear				100%	
UK	2017 / 2020	The UK government brought forward a 2040 ban on petrol and diesel cars and LCVs (set in 2017) to at least 2035, and clarified that all hybrids would be included.	New Cars and LCVs	Yes	No	Yes	Yes			100%		

Unofficial, Drafted or Proposed Fossil Fuel Bans (National)

Country	Announced	Comments	Vehicle Type	Official Target	Legislative Backing	Includes HEVs	Includes PHEVs	2025	2030	2035	2040
Sweden	2018	Government will investigate a ban of selling new diesel and petrol cars after 2030, a requirement from the coalition partner Green Party (MP).	New Cars	No	No	Unclear	Unclear		100%		
Taiwan	2017	Proposed a ban on new sales of non-electric motorcycles by 2035 and four-wheelers by 2040. In June 2019, it emerged the scooter ban would not be enforced due to pressure from the traditional scooter industry.	New vehicles	No	No	Unclear	Unclear				100%
Slovenia	2017	Draft to ban cars emitting more than 50g of CO_2 per kilometre by 2030, which will be difficult for non-plug in HEV cars to meet.	New Cars	No	No	No	No		100%		
Sri Lanka	2017	All private vehicles (fleet of cars, motorcycles, tuk tuks) must be electric or hybrid by 2040. Government vehicles including buses by 2025.	New and Existing Vehicles	No	No	No	No				100%
Ireland	2018	Draft proposed for 2030 ban; yet to be passed into law and reports of it being unrealistic. However, 'transitioning the car transport fleet to electricity and providing additional charging infrastructure' is a qualitative target in the 2018 national development plan.	New Cars	No	No	Unclear	Unclear		100%		
Israel	2018	Ban on imported diesel and petrol cars only. After the plan was proposed no reports emerged of it being approved as an official target, despite the fact that initial reports said it would be approved before 2019.	New Cars	No	No	Unclear	Unclear		100%		
India	2018	In 2017, a target was drafted for 100% electrification by 2030. In 2018, this was stripped back to 30% by 2030 and is still not official policy. The uncertainty caused some companies to cancel their electrification plans. There are further proposals for a ban on combustion rickshaws by 2023 and two-wheelers by 2025.	New Vehicles	No	No	Unclear	Unclear		30%		
China	2019	Draft targets to ban the internal combustion engine have emerged from China in 2019 but have not materialised into anything official. The latest unofficial target is 25% electric vehicles by 2025 from December 2019. There were also earlier reports of a 60% target by 2035 being considered.	New Cars	No	No	Yes	No	25%		60%	
EU / Denmark	2019	Denmark, backed by 10 other EU countries, called for an EU-wide ban on the sale of diesel and petrol cars by 2040 after its own plans to ban the sale of all fossil-fuel powered cars by 2030 were cancelled due to a breach of EU rules.	New Cars	No	No	Unclear	Unclear				100%

Fossil Fuel Bans (Cities)

Around the world cities are beginning to take action to tackle dangerous air quality and emission from road transport. For example, many European cities are proposing bans on the entry of diesel and petrol vehicles to urban centres: inc. the Fossil Fuel Free Streets Declaration.

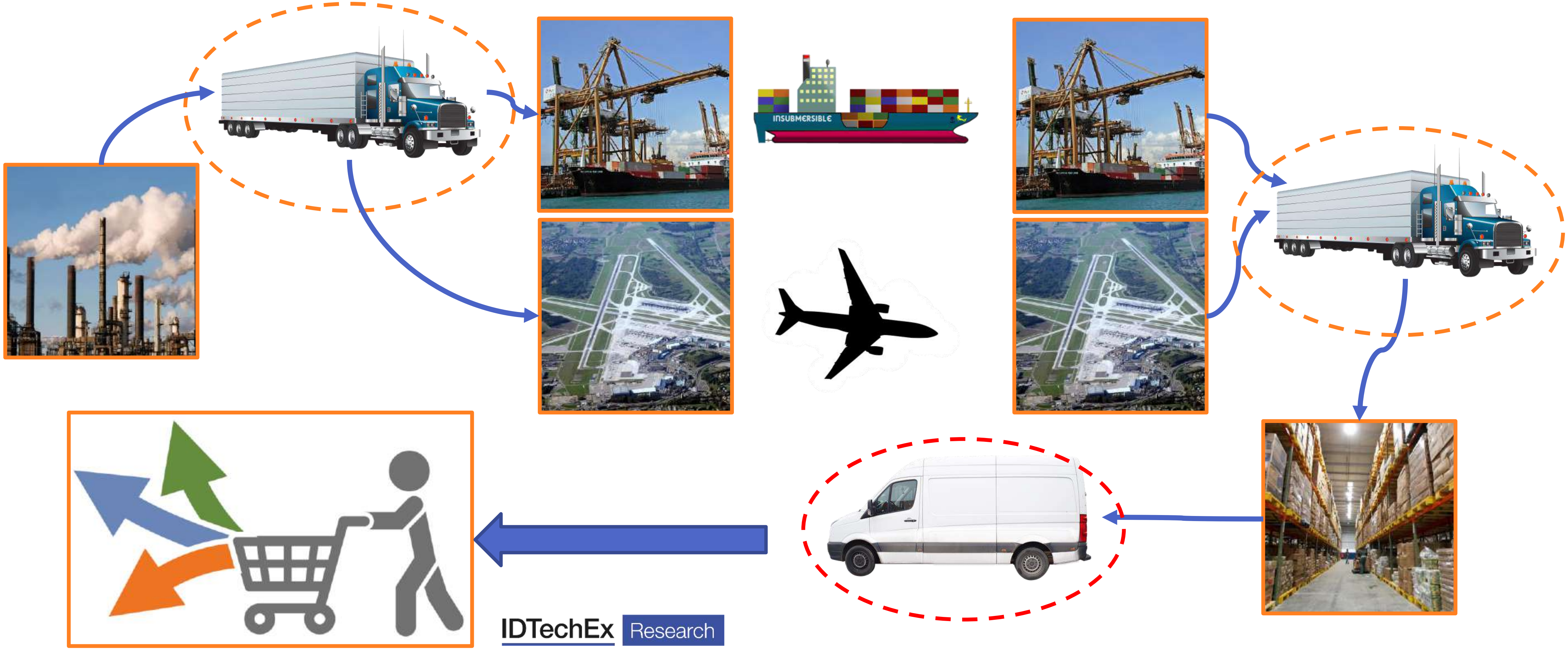


Madrid
Oslo
Paris
Copenhagen
Amsterdam
Rotterdam
Barcelona
Berlin
Heidelberg
London
Manchester
Warsaw
Milan
Rome
Birmingham
Oxford
Liverpool
Athens

Source: Unsplash

IDTechEx

The worldwide freight transport industry



IDTechEx Research

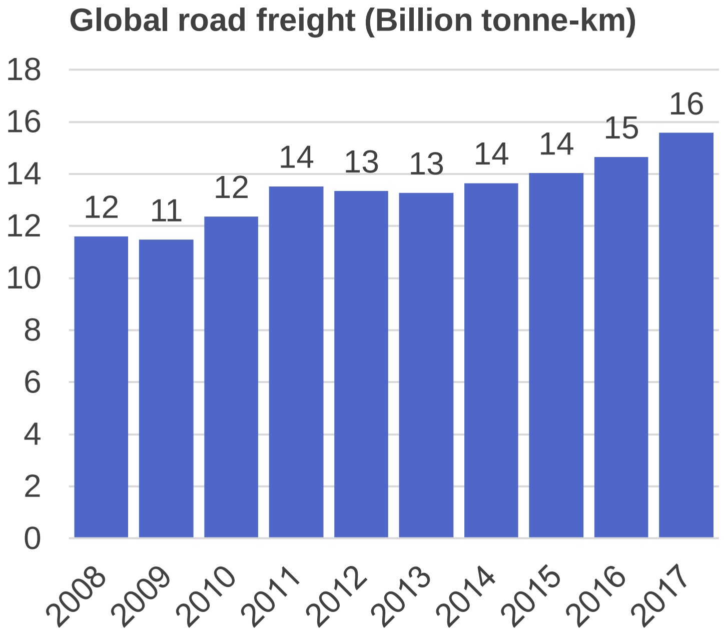
Road Freight Market

Medium and heavy-duty trucks form an integral part of the freight transport industry.

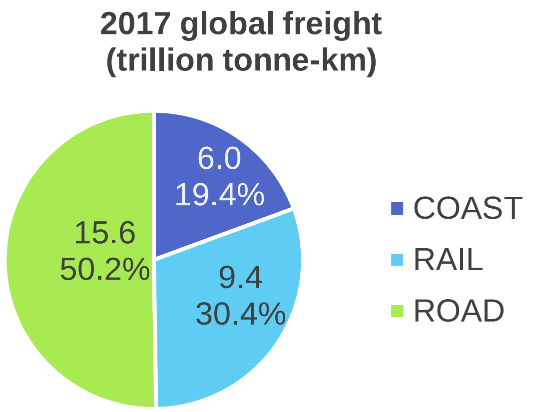
There are approximately 90 million commercial freight vehicles (primarily diesel powered) driving on the roads of the world's main economies. These vehicles are the backbone of those economies, with the movement of goods keeping businesses running.

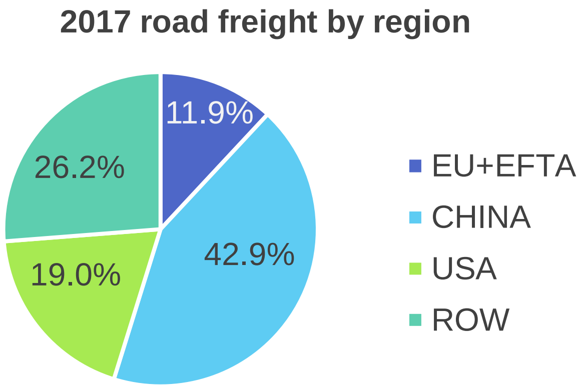
In 2017, 50.2% of the total movement of goods using inland transport was transported by road - moving 15.6 trillion tonne-kilometres of freight.

Rapid expansion of the Chinese economy over the past decade has seen it take the lead in road freight transportation.



Data sources: OECD



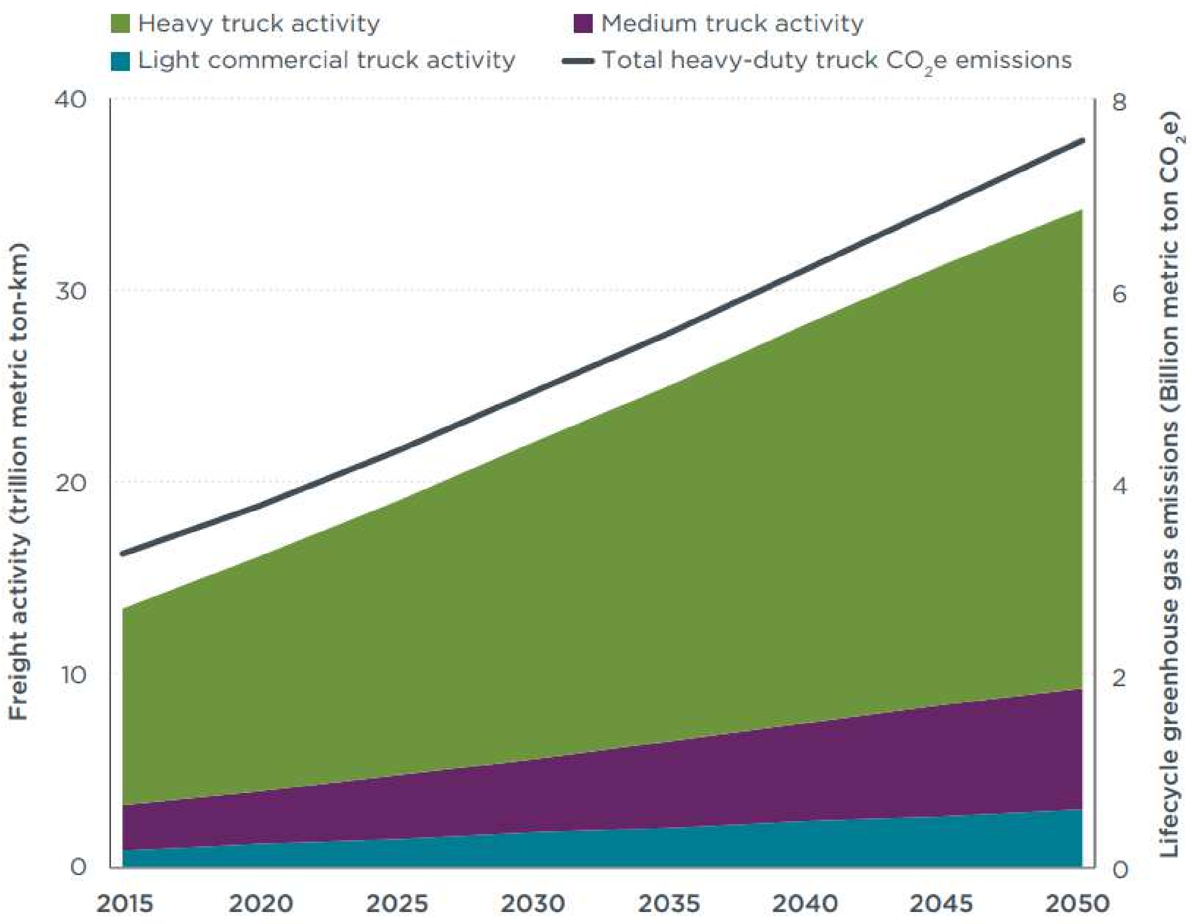


Projected increase in global road freight activity

An International Council on Clean Transportation white paper "Transitioning to Zero-Emission Heavy-Duty Freight vehicles" suggests that freight activity for light, medium and heavy duty trucks will more than double between 2015 and 2050.

Under a business as usual scenario, lifecycle greenhouse gas emissions (including vehicle exhaust emission and the emissions to produce the trucks' fuels) could also increase to approximately 7 billion tonnes CO2e.

Part of the increase in demand for freight is the huge growth o e-commerce, where the customers no longer need drive to a shop, but can order online and have the product delivered to their home.



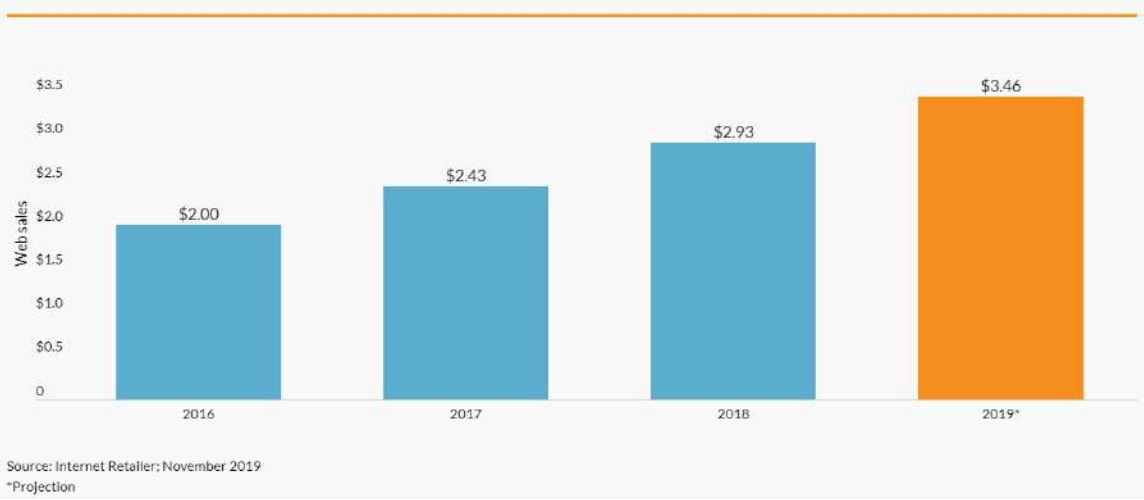
Source: ICCT

The rise of e-commerce: increased freight demand

Global e-commerce was estimated at $3.46 trillion in 2019 (16.4% of global retail sales)

Source:
Casaleggio associate and in-house elaboration

Global retail sales, in $ trillions



Top 10 global e-commerce leaders – ranked by 2018 web sales

Global Rank	Retailer	Web Sales Growth	Country	Merchant Type	Merchandise Category
1	Amazon.com Inc.	20.0%	United States	Web Only	Mass Merchant
2	JD.com Inc.	29.8%	China	Web Only	Mass Merchant
3	Suning Commerce Group Co. Ltd.	32.3%	China	Retail Chain	Mass Merchant
4	Apple Inc.	20.0%	United States	Consumer Brand Manufacturer	Consumer Electronics
5	Walmart Inc.	38.8%	United States	Retail Chain	Mass Merchant
6	Dell Technologies Inc.	4.0%	United States	Consumer Brand Manufacturer	Consumer Electronics
7	Vipshop Holdings Ltd.	14.5%	China	Web Only	Mass Merchant
8	Gome Electrical Appliances Holding Ltd.	14.9%	China	Retail Chain	Mass Merchant
9	Macy's Inc.	14.3%	United States	Retail Chain	Apparel/Accessories
10	Otto Group	-0.6%	Germany	Retail Chain	Mass Merchant

Source: digitalcommerce360, ponyzero, Casaleggio associate

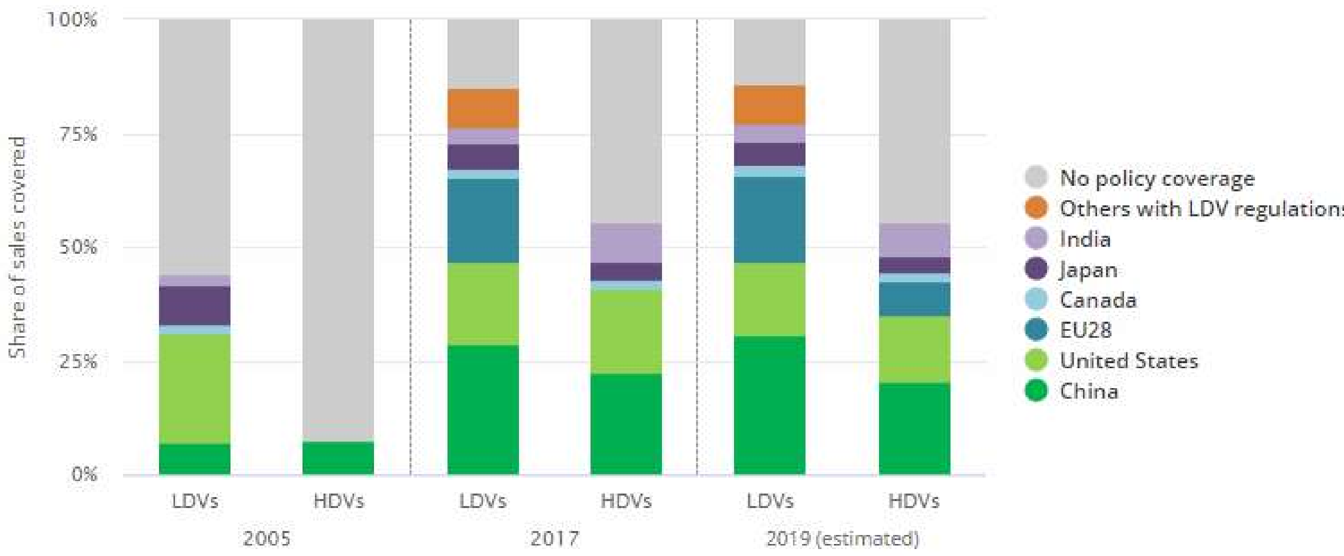
Fuel / emissions regulation for new LCVs

Recognising that the current level of emissions from LCVs are contributing to climate change and are having very serious impacts on human health in urban areas, combined with forecast growth in demand for freight activity, means that policy makers around the world are having to seriously address the emissions from LCVs.

One mechanism governments are employing is mandatory fuel economy / emission standards, which force manufacturers to reduce pollutant emissions.

The G20 countries collectively account for 80% of global energy demand and more than 90% of global new vehicle sales; the policies relevant to the transport sector in these countries largely dictate the impacts of the sector globally on air quality, climate change, and energy consumption.

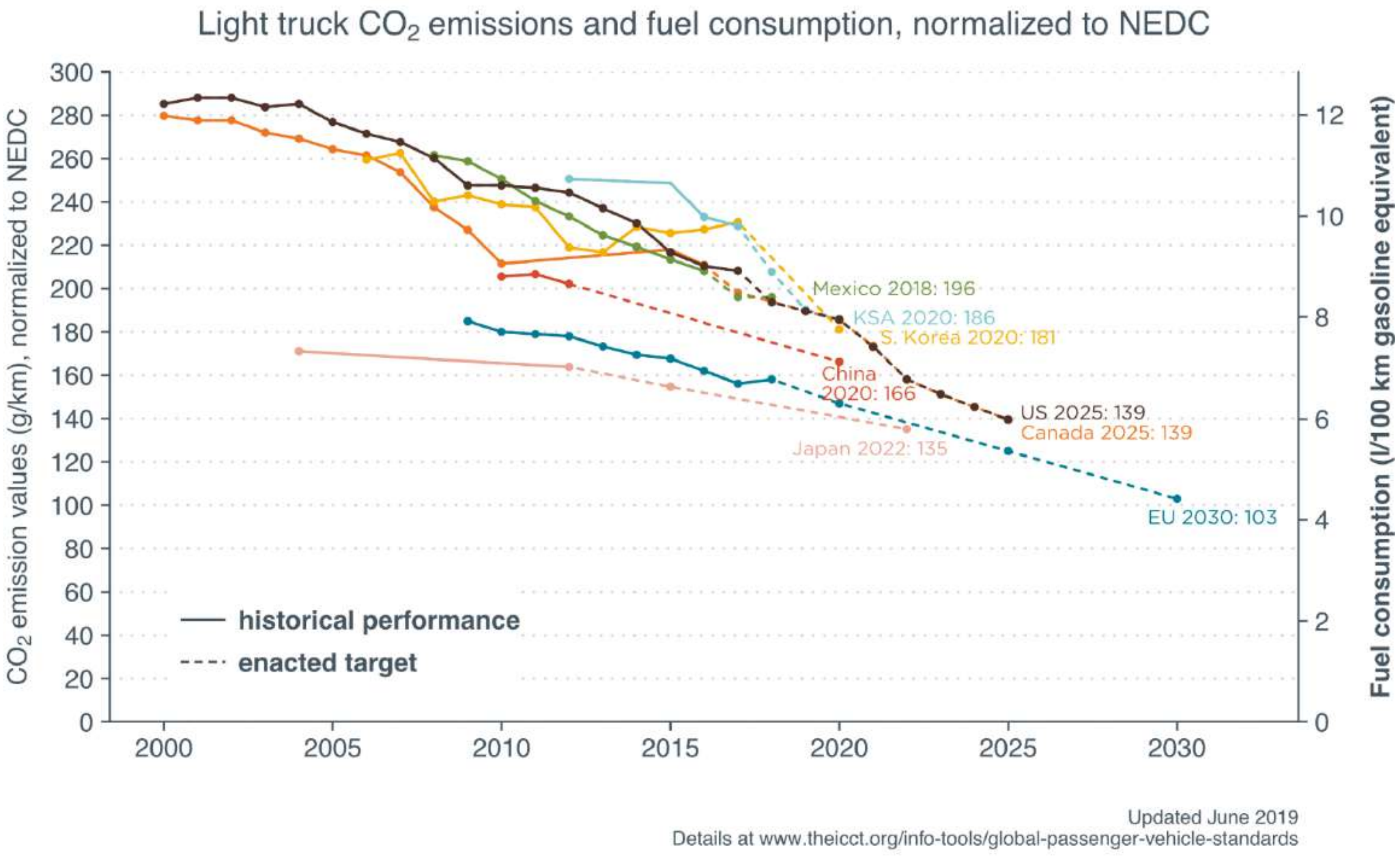
Share of sales in countries with adopted fuel economy or GHG/CO_2 standards



There is strong policy coverage for light duty vehicles, about 85% of cars and LCVs sold in 2018 were covered by fuel economy standards.

Source: IEA

GHG emission from LCVs



Source: ICCT

- Around the world, tightening fuel consumption standards have forced OEMs to improve the CO2 emission from their LCVs.
- Likewise, standards for other exhaust pollutant species such as NOx and PM are gradually making exhaust emissions cleaner.
- In some regions the fuel consumption targets are reaching a critical point where they are difficult to meet using traditional ICE technologies.
- OEMs have the option of either continuing to invest in increasingly expensive ICE technologies to get to the required fuel efficiency or invest in EV technologies, where weighted credit systems allow manufacturers to offset emissions from their ICE vehicles with sale of low or zero emission vehicles.
- Eventually a point will be reached where the legislation makes it impossible to use petrol or diesel as a fuel for on-road transportation.

Europe Emissions Standards: LCVs

LCVs

- **2017 to 2019: 175g CO_2 per km (NEDC):** average point of use emissions of all new car sales between 2017 and 2019 must be below 175g CO_2 per km. This target was achieved in 2013 using NEDC driving standards.

- **2021 onwards: 147 CO_2 per km (WLTP):** the 2019 value is lowered to 147g CO_2 per km. The 2018 average was 157.9g CO_2 per km (NEDC).

- **Penalty:** 95 euros for each CO_2 g per km of exceedance.

- Cars reaching lower than 50g CO_2 per km are awarded ‘super credits’: they are credited as two vehicles in 2020, 1.67 in 2021 and 1.33 in 2022. Leading automakers can pool or sell their credits to those with less. Electric LCVs do not receive ‘super credits’.

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Drivers for LCV Electrification

The International Energy Agency's (IEA) Global EV Outlook 2020, suggests that, by the end of 2019, there were around 380,000 eLCVs on the road worldwide. When this figure is compared to the more than 9.3 million sales of LCV in 2019 alone (*figure excludes passenger pickup trucks), the currant dominance of the internal combustion engine in the LCV market is clear.

However, the eLCV segment is of interest because a number of factors are coming together to drive the LCV market toward a zero on-road emission solution, including:

- Commitments from governments and businesses around the world to **tackle climate change** and **health implications of poor air quality**.
- Increasingly **stringent vehicle exhaust emission / fuel efficiency regulation.**
- Proposed **road-use restrictions** for diesel and petrol vehicles, with many large cities looking to introduce zero emission zones, that will affect urban deliveries.
- The **increasing price competitiveness of EV** against combustion vehicles, with reducing battery cost and economies of scale in the greater production of electric vehicles.

As a result IDTechEx believe the LCV sector is likely to see a significant transition to electric powertrains over the next couple of decades.

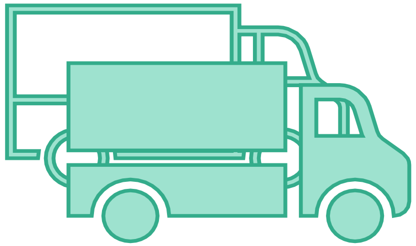
eLCV Market Drivers

There is a strong case for the relatively rapid electrification of the LCV sector:

- Businesses govern purchase decisions by the total cost of ownership rather than the upfront purchase price. Our research shows that the TCO is already at parity for small LCVs in some scenarios and will be at parity for larger LCVs by the mid 2020s. This is driven by decreasing battery pack prices and the cheaper price of electricity.
- LCVs are commonly employed in urban delivery, with short duty cycles over relatively fixed routes returning to a central hub, making it possible to build charge time into the daily schedule, ensuring sufficient range.
- Growing concern about NOx and PM emission from road transport in urban areas will see diesel vehicles gradually phased out from congested urban areas.
- Increasing demand for home delivery, with increased urbanisation and decreased private car ownership, sustain or potentially increase demand for LCV, but these vehicles will need to meet increasingly strict emission standards.
- Quieter operation of eLCV opens up possibilities of deliveries outside of peak driving hours, either overnight or early in the morning, with the prospect of reducing peak congestion.

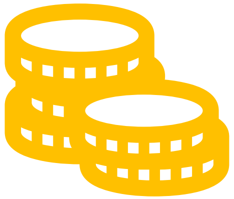
Considerations for eLCV adoption

Operational



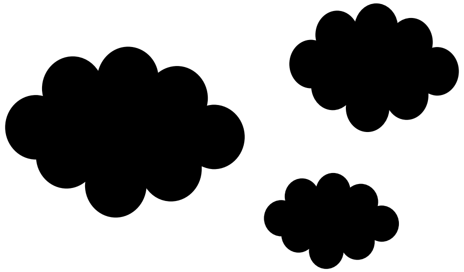
- Duty cycle range
- Payload weight and volume
- Charging infrastructure / scheduling
- Reliability, servicing, maintenance
- Staff training

Financial



- Initial capital investment
- Operational costs
- Total cost of ownership
- Purchase vs leasing
- Incentives for eLCV

Environmental

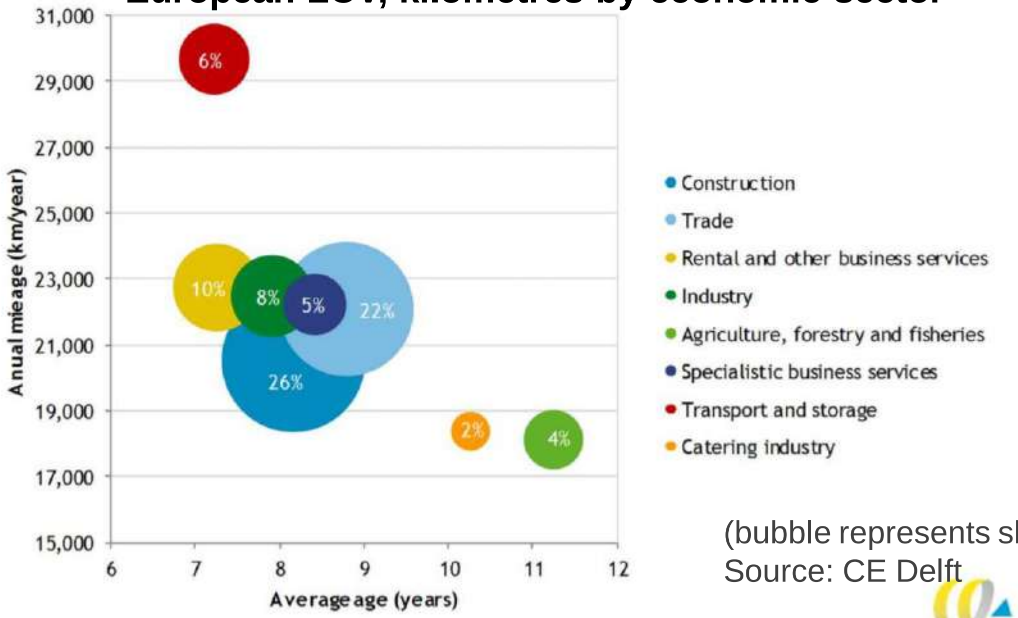


- Clean air / congestion / low emission zone charging / exemption
- Fleet future-proofing (CO_2 and other exhaust pollutant legislation)
- Environmental goodwill
- Vehicle noise

Do eLCVs offer sufficient range?

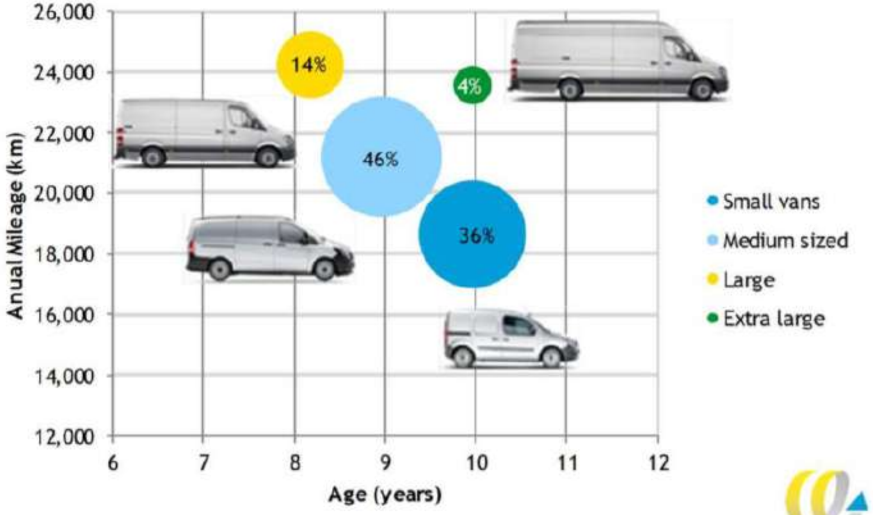
Research from a number of OEMs, including Renault and Mercedes, suggests that although the range of eLCVs is shorter than the equivalent diesel LCVs it is sufficient to meet the daily duty demand in a large percentage of use cases. A stakeholder survey conducted by CE Delft, suggests that a range of 150 km is sufficient to meet the needs of the majority of LCV users. Smaller LCVs were found to have the shortest duty cycles. An annual mileage of 25,000 km/year, is an average daily duty cycle of around 100 km per day.

European LCV, kilometres by economic sector



(bubble represents share in total kilometres)
Source: CE Delft

LCV-size classes and mileage in the Netherlands

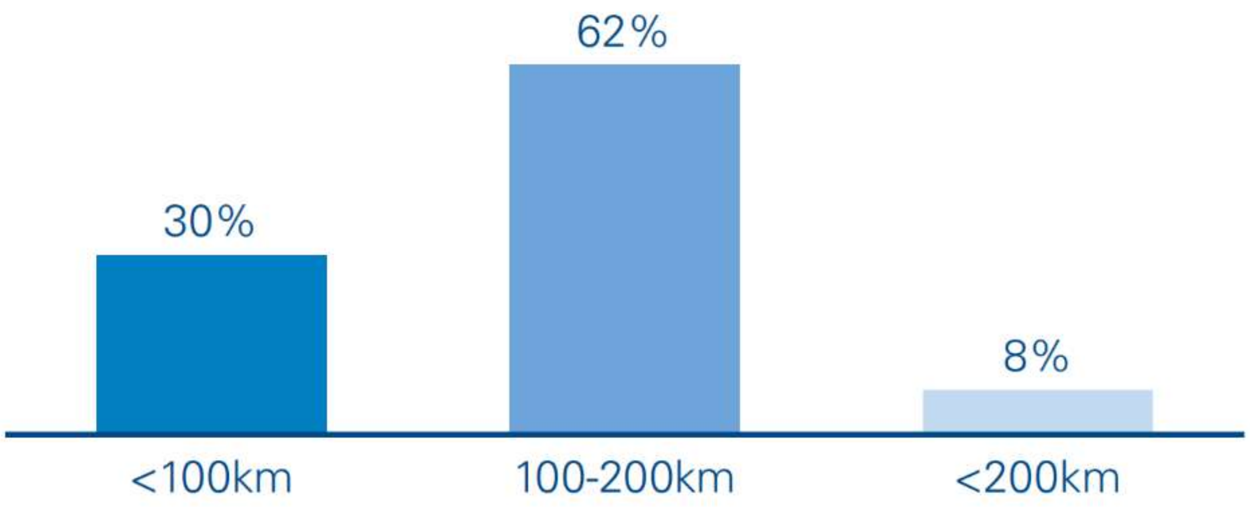


Source: CE Delft

Do eLCVs offer sufficient range?

- The reported CE Delft LCV daily range requirements are in agreement with several other sources.
- A 2019 report by Arthur D Little into eLCV in Germany suggests that 92% of fleet LCVs cover less than 200km daily.
- Renault's in-house research suggests that urban delivery vehicles in Europe require only around 50km range per day.
- A report by Oak Ridge National Laboratory, for the US department of energy into the electrification of Class 2b-3 commercial vehicles in the US reported a wide range of duty cycles for LCV and an average annual mileage of around 24,000 km per year (≈100 km/day). Many of the applications the report identified for LCV required a short daily driving range, but some large Class 3 trucks in the US are used in haulage for daily round trips of up to 200 miles.
- These range requirements are possible with today's battery technology, which makes BEVs an attractive value proposition for fleet operators.

Typical daily driving ranges of an LCV in a fleet



Source: Arthur D. Little research

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Do eLCVs offer sufficient range?

An International Energy Agency (IEA) report into the future of trucks investigated the average annual mileage requirement of different sectors of the freight industry.

Their research highlights the significantly shorter average annual mileage for LCVs in comparison to medium-freight trucks (MFTs) and heavy-freight trucks (HFTs).

This is likely reflected in considerably shorter daily range demands for LCV which can be met by electric powertrains.

Average mileage in thousand kilometres of annual travel

Country/Region	LCVs	MFTs	HFTs
Africa	9	18	29
ASEAN	11	39	47
China	8	25	36
EU28	18	51	73
India	9	29	38
Japan	9	31	43
Latin America	11	30	51
Mexico	17	50	69
Middle East	15	47	59
Russia	12	36	50
United States	20	63	90
World average	*13*	*37*	*52*

Notes: Average mileages are estimated on the basis of calibration across many variables, including national automotive gasoline and diesel consumption as estimated in the IEA Energy Balances (IEA, 2017b) as well as national and regional statistics on truck stocks, sales and road freight activity (vkm and tkm). The resulting estimates are for the average mileage of each truck category over its entire lifetime and, as such, are lower than the mileages in the first two to five years of operation (especially for HFTs).

Source: IEA

Do eLCVs offer sufficient range?

A 2018 paper from the Institute of Transport Economics in Oslo detailed a colour coding scheme, devised by Renault of Norway, to help purchasers determine the suitability of eLCV in replacing diesel LCVs in Norway.

The basis for the schemes is that in summer the range of an eLCV can be 30% less than the official range (air conditioning), and in winter the range can be 50% less than the official range (loss of battery performance in cold weather, increased driving resistance of winter tires, increased air drag, and cabin heating).

The ideal case for eLCV is that the battery is of sufficient size to meet the required daily duty cycle in the very worst conditions, but is not excessively large, adding unnecessary extra weight. Long range demand can be met with a larger batteries, however, if 'top-up' charging is instead incorporated during the day, the range can be delivered with a smaller battery capacity. Charging strategies to minimise the battery weight and therefore the overall weight of the vehicle, whilst still delivering the required range would optimise the vehicles km/kWh ratio, resulting in lower overall energy use.

The potential spread of values in the deliverable driving range of eLCV necessitates that eLCV manufacturers work with their customers pre-sale, to understand if their vehicle meets their customer's needs, in the conditions specific to that customer's daily duty cycle requirements. Consideration of the worst-case scenario for eLCV performance, optimal charging strategy and optimal battery size (where the manufacturer offers modular battery system) will require manufacturers to share their real-world performance data and customers to share (and understand) their specific requirements.

Renault of Norway, eLCV suitability for vehicle with official range of 170 km

Distance driven day of maximum driving	Original Renault scheme
Always under 51 km	Vehicles can be replaced
51-80 km	
81-120 km	Vehicles can potentially be replaced, depending on road-type, driving style, speed, cargo, topography, temperature, charging
Over 120 km	Not compatible unless possible to charge during day

Source: Institute of Transport Economics, Oslo

3. IDTechEx TCO Calculations

Total Cost of Ownership

The Total Cost of Ownership (TCO) is a calculation that helps Light Commercial Vehicle (LCV) fleet owners determine the complete costs of owning and operating a commercial vehicle. TCO looks at both initial capital cost of purchasing a vehicle along with the operational expenses incurred running the vehicle. A TCO analysis examines not only the price of the LCV, but also its long-term costs over time.

The TCO is very important for LCV fleet operators and will be the determining factor in the uptake of eLCVs. Whilst there is a degree of goodwill to be gained to be seen operating environmentally friendly vehicles, when it comes down to purchasing decisions, fleet managers of commercial vehicle fleets understand the nuts and bolts of their business, and in a market where the margins are very tight, will not run the risk of compromising the competitiveness of their company.

However, once there is demonstrable evidence that eLCVs

- Offer a cost saving over the useful lifetime of the vehicle
- Meet all the vehicle operational requirements in terms of range, payload, load volume, and reliability.

then, there is likely to be a rapid uptake of eLCV, as it becomes a competitive advantage for companies to run eLCVs over traditional ICE.

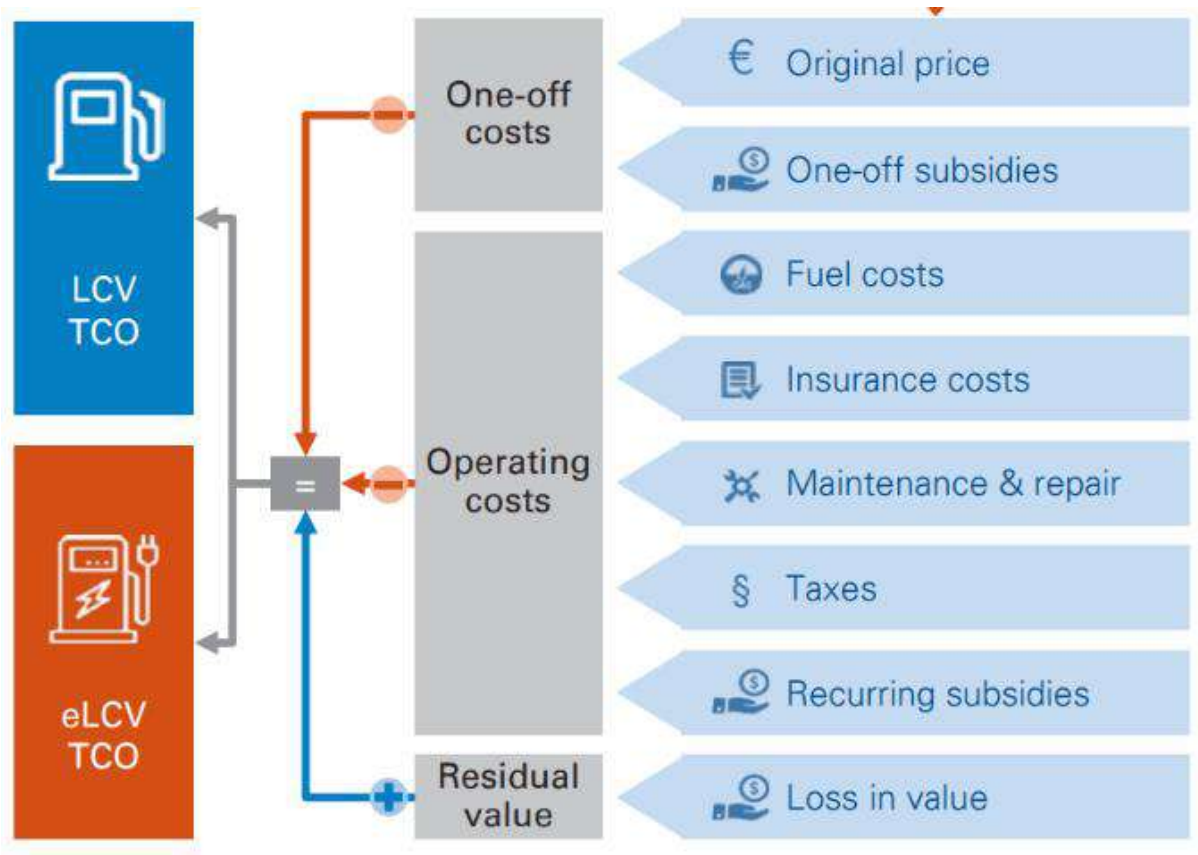
Source: Unsplash/OmidArmin

Environmental goodwill insufficient for uptake of eLCV

- The total cost of ownership (TCO) is a calculation that helps LCV fleet owners determine the complete costs of owning and operating a commercial vehicle. TCO looks at both initial capital cost of purchasing a vehicle along with the operational expenses incurred running the vehicle. A TCO analysis examines not only the price of the LCV, but also its long-term costs over time.
- The TCO is very important for LCV fleet operators and will be the determining factor in the uptake of eLCVs. Whilst there is a degree of goodwill to be gained to be seen operating environmentally friendly vehicles, when it comes down to purchasing decisions, fleet managers of commercial vehicle fleets understand the nuts and bolts of their business, and in a market where the margins are very tight, will not run the risk of compromising the competitiveness of their company.
- However, once there is demonstrable evidence that eLCVs
    - Offer a cost saving over the useful lifetime of the vehicle
    - Meet all the vehicle operational requirements in terms of range, payload, load volume, and reliability.

  then, there is likely to be a rapid uptake of eLCV, as it becomes a competitive advantage for companies to run eLCVs over traditional ICE.
- In the short-term, Government incentives for zero emission vehicles, alongside financial penalties for ICE vehicles, will drive uptake of eLCVs.
- As battery prices drop, electric drivetrain efficiencies improve and significant economy of scale savings on the cost of electric components and vehicle manufacturing are realised, the financial incentives will no longer be required to balance the TCO calculations. Whilst eLCVs become cheaper, diesel LCVs will become increasingly expensive, requiring more expensive exhaust systems to meet stricter pollutant regulations.
- IDTechEx's research suggests that small and medium size electric vans can, if well utilised (driving around 100km each work day), already offer a significant cost saving to operators over the vehicle lifetime without purchase incentives. This is not yet the case for large van models, where the premium on electric powertrains over diesel is still too great to made up through fuel savings without government financial support.

TCO considerations for eLCV

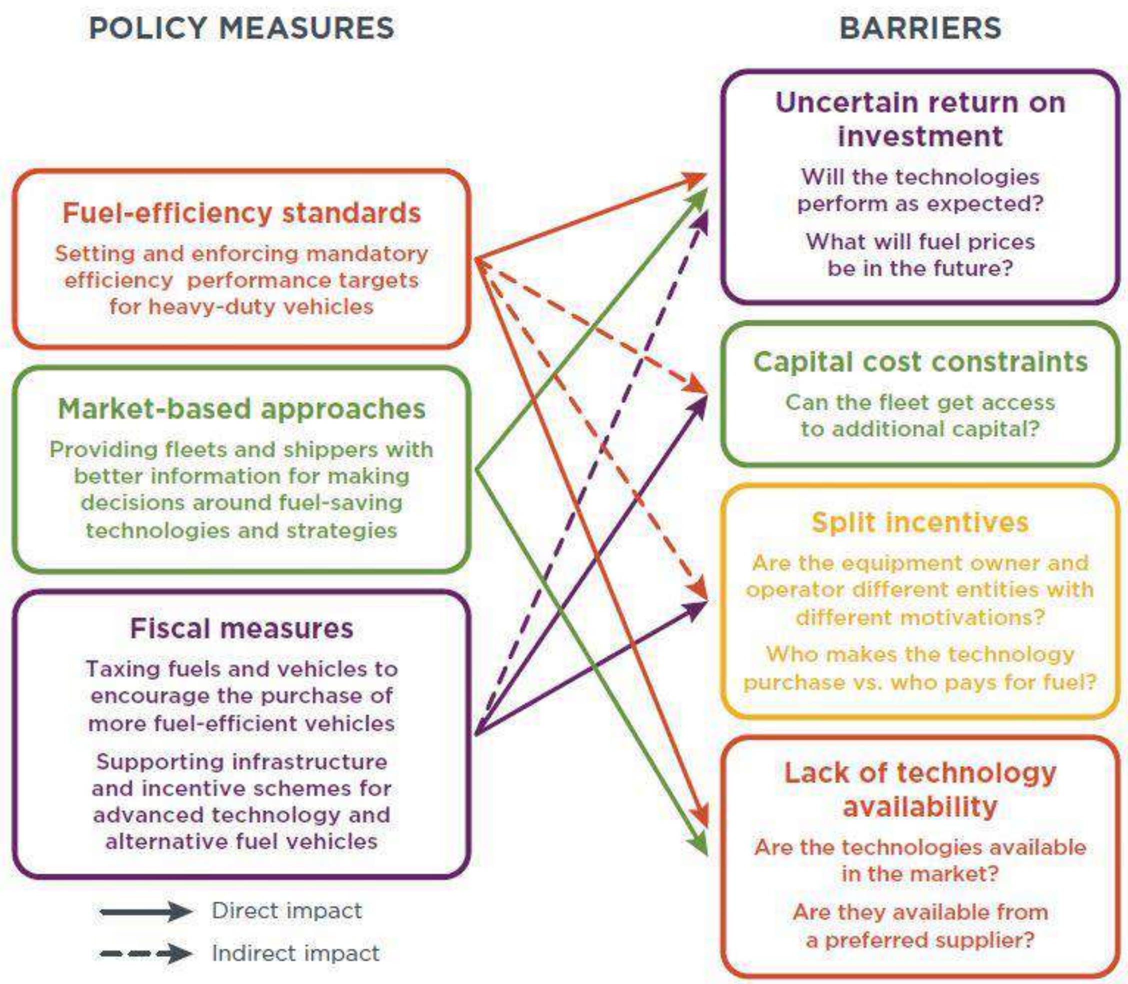


Source: Arthur D. Little research

- Original price: Greater upfront cost of eLCV vs diesel, due to the current battery cost and lack of economies of scale for electric vehicles
- One-off subsidies: Government incentives to purchase electric vehicles
- Fuel costs: Electricity a cheaper fuel per km than diesel, but magnitude of this difference depends on the location of the vehicle
- Insurance costs: Greater upfront cost and potentially more expensive part replacement, likely to be reflected in more expensive insurance premiums for eLCV
- Maintenance & repair: Anecdotally less servicing required for eLCV as fewer moving parts. However potentially more expensive part replacement, specialist servicing and over longer time periods additional cost of battery replacement must be considered
- Taxes: Low emission vehicles incentivised by scaled tax governed by vehicle emission
- Recurring subsidies: Potential exemption from yearly road tax, road tolls, low emission zone charges for eLCV
- Loss in value: Difficult to forecast as battery degradation / replacement concerns may affect the second hand market for eLCV. However, as legislation increasingly restricts the use / increases the cost of diesel LCV this is likely to affect the demand for second hand diesel LCV and increase depreciation

Overcoming barriers for low emission technologies

- Once TCO parity is reached between diesel and eLCVs, finance packages can be put together to lease the vehicles (fleets) at the same rate as the equivalent diesel LCV, likely with a service and maintenance package. This removes the barrier of a large capital expenditure from the purchaser.
- Until that cost parity is reached it will be necessary for governments to support the industry through a number of policy avenues.
- Fuel-efficiency standards, effectively increase the price of a diesel LCV, as it forces innovation and new technology to meet the standards.
- Fiscal measures such as taxes on fuel (a tax on CO2 emissions), low emission zone entry charging (a tax on NOx and PM emission), or subsidies and grants for lower emission vehicles and infrastructure installation, encourage uptake of low emission vehicles both through increasing the cost of operating a diesel vehicle and decreasing the cost of operating an electric vehicle.



Source: ICCT

Example: TCO for eLCV (Renault Kangoo)

UK Plug-in LCV Grant (20%)

Road Tax Exemption

Exempt from Congestion Zone charges

	Kangoo ML20 Energy dCi 90 (Diesel)	Kangoo Z.E. ML20 33kWh (Electric)
Vehicle cost	£16,965	£25,035
Plug-in van grant	-	£5,868
Total Price	**£16,965**	**£19,167** ↑
Fuel cost	£5,615	£2,400 ↓
Road tax	£780	- ↓
Maintainance cost	£1,168	£909 ↓
Resale value	£3,675	£4,715
TCO	**£20,853**	**£17,761** ↓
eLCV cost savings		**£3,091**
Annual milage	20,000	20,000
Ownership period (yrs)	3	3
Cost per mile	**£0.35**	**£0.30** ↓
If used in the London Congestion Zone (5 days/ week - £15.00 per day)		
TCO	£32,553	£17,761
Saving in ownership period		£14,791
Annual eLCV cost saving		**£4,930** ↓

Data source: The Telegraph via cap hpi

- TCO analysis for the diesel and electric versions of the Renault Kangoo, based on a three-year, 60,000-mile term. Vehicle operated in the UK.
- The plug in grant and road tax exemption mean that, despite a higher upfront cost for the vehicle, that over the first 3-years the TCO of the electric LCV is £3000 lower than the diesel.
- Electricity is a far cheaper fuel per km than diesel.
- eLCVs are projected to have lower maintenance cost, as a result of fewer moving parts and decreased brake wear because of regenerative braking.
- The second hand market for diesel LCVs is likely to be impacted by increasing restrictions on vehicle exhaust emissions in city centres.
- In London, exclusion for eLCVs from the £15.00 per day congestion fee could save £3K per year, and where the eLCV replaces a pre Euro 6 diesel LCV or pre Euro 4 petrol LCV, the operator will save a further £12.50 a day.
- Congestion charging / low emission zones are expected to be employed more widely across the world and are likely to make a compelling financial argument for replacing ICE LCVs with electric versions.

Example: TCO for eLCV (Nissan e-NV200)

UK Plug-in LCV Grant (20%)

Road Tax Exemption

Exempt from Congestion Zone charges

	Nissan NV200 1.5dCI Acenta 110hp (Diesel)	Nissan e-NV200 Acenta (Electric)
Vehicle cost	£16,960	£27,219
Plug-in van grant	-	£5,444
Total Price	**£16,960**	**£21,775**
Fuel cost	£7,686	£2,869
Road tax	£1,250	-
Maintainance cost	£2,730	£1,913
Resale value	£3,078	£4,697
TCO	**£25,548**	**£21,860**
eLCV cost savings		**£3,688**
Annual milage	15,000	15,000
Ownership period (yrs)	5	5
Cost per mile	**£0.34**	**£0.29**
If used in the London Congestion Zone (5 days/ week - £15 per day)		
TCO	£45,048	£21,860
Saving in ownership period		£23,188
Annual eLCV cost saving		**£4,638**

Data source: Low Carbon Vehicle Partnership

- TCO analysis by the Low Carbon Vehicle Partnership comparing diesel and electric versions of the Nissan NV200, based on a five-year, 75,000-mile term. Vehicle operated in the UK.
- Similar to the TCO analysis for the Renault Kangoo, the electric version of the Nissan e-NV200 offers a significant saving over the ownership period, despite the greater initial capital investment in the vehicle.
- Both this analysis and the previous analysis for the Kangoo exclude factors which may influence the TCO for operators, including:
- Charging infrastructure installation.
- Vehicle insurance costs. Because eLCV are more expensive to buy, and parts may be more expensive, insurance premiums for eLCV are likely to be higher.
- Payload considerations. The potential for reduced load may make it necessary to purchase more vehicles to make the same number of deliveries. However, both the eNV200 and Kangoo offer similar loads to their respective diesel versions.
- In this case the additional insurance and charging costs will be more than covered by the TCO saving.

IDTechEx

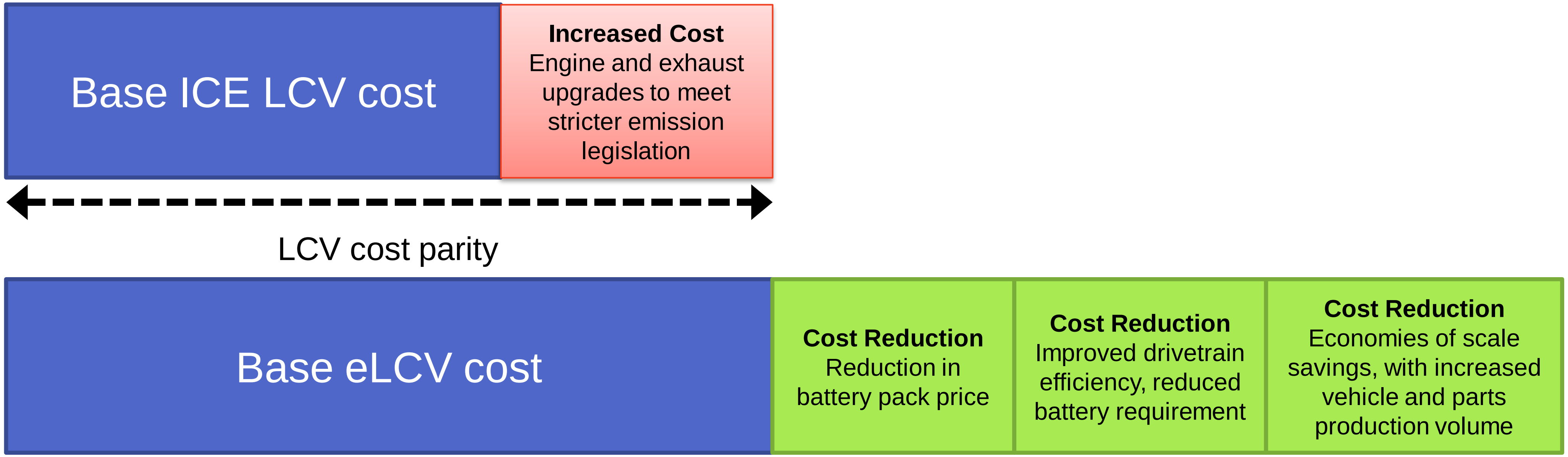
Timeline for TCO parity between diesel and eLCV

- A CE Delft analysis for The European Federation of Transport and Environment (T&E) investigated the total costs of ownership (TCO) for electric LCVs and compared it to diesel equivalents.
- The analysis split the LCV segment into three classes:
- Small LCVs (empty vehicle weight <1500 kg – car based LCVs)
- Medium LCVs (empty vehicle weight of between 1500 kg and 2000 kg)
- Large LCVs (empty vehicle weight >2000 kg)
- TCO assumptions include: an annual mileage of 25,000 km, ownership of 6-years, a 40 kWh battery and battery pack price dropping from $305/kWh in 2016 to $165/kWh in 2030.
- They suggest small LCVs are cost competitive already, with the main barrier to their uptake being lack of supply.
- TCO parity for medium and large LCVs is expected around the mid 2020s.
- Cost parity is highly dependent on the particular circumstances in each country. This analysis was conducted in Europe and reflects the market there, however in most regions, with initial support from Government, LCVs become an attractive option for electrification.

Source: CE Delft, transportenvironment.org

Electric and diesel LCV cost parity

- There is reasonable expectation that the vehicle cost for an eLCV will reach the same level as an equivalent ICE vehicle.
- Base eLCV cost will decrease as battery pack prices decrease (forecast to halve by 2030). Alongside this is the potential for decreased battery requirement through battery, power electronics, and electric motor efficiency improvements. The cost of eLCVs will also decrease as the volume of eLCV production increases, with economies of scale savings on the manufacture of the vehicle and parts.
- At the same time the price of ICE LCVs will likely increase as new technology is required to meet stricter emission standards.
- At base cost parity, the TCO calculation is so far in favour of eLCV that diesel LCV only becomes viable for the small proportion of duty cycles where the required mileage is too large to make an eLCV feasible, with diesel LCV becoming an expensive niche option.



IDTechEx Battery-Electric Van TCO Analysis

The TCO comparison for a pure battery-electric (BEV) van deployment is governed by the specific circumstances of that deployment. For example, the price of the vehicle, diesel and electric will all vary by location, with different rates of tax applied to each depending on country. This analysis provides a simplified TCO appraisal to highlight the impact of important factors.

IDTechEx's BEV Van Analysis:

- The average vehicle price is from UK manufacturer price lists, for a base model version of the vehicles, without VAT or a purchase grant.
- The cost of electricity and diesel are approximately the UK retail price (as of October 2020).
- The TCO calculations use reported on-road fuel consumption figures, rather than test cycle reported figures given by manufacturers, that do not reflect real-world fuel consumption. Considerable research has demonstrated the discrepancy between test cycle certified CO_2 emissions / fuel consumption and real world driving.
- The test cycle measured electric range has likewise been adjusted to reflect the likely on-road range. Worldwide Harmonized Light duty vehicle Test Protocol (WLTP) electric range figures have been reduced by 20% and New European Driving Cycle (NEDC) figures by 35%. This is intended to better reflect real-world capability of the electric vehicles.
- The average battery capacity has been adjusted to reflect usable battery capacity. This analysis uses a figure of 85% of the specified battery as 'usable' based on figures from Mercedes-Benz, who list the installed battery capacity on the eVito van at 41 kWh and the usable capacity at 35 kWh. Battery management prevents some capacity from being used, to protect the battery from degradation.
- From the adjusted electric range and usable battery figure an average kWh/km consumption is used to estimate the cost of electricity.
- Estimates for servicing, maintenance and repair costs were calculated using data from the CommercialFleet Van Running Cost tool.
- The analysis does not incorporate insurance costs or potential recurring subsidies for eVans (toll, tax, low-emission / congestion zone exemptions). The residual value of the vehicle is assumed to be zero and no provision is made for the potential cost of battery replacement during the operational life of the vehicle.

TCO: Small Vans

Reference Vehicles

- Citroën Berlingo Electric
- Nissan e-NV200
- Peugeot Partner Electric
- Renault Kangoo Z.E.

Small vans
empty vehicle weight ≈
< 1500 kg

Source: Renault

Source: Nissan

Source: Citroen

Source: Peugeot

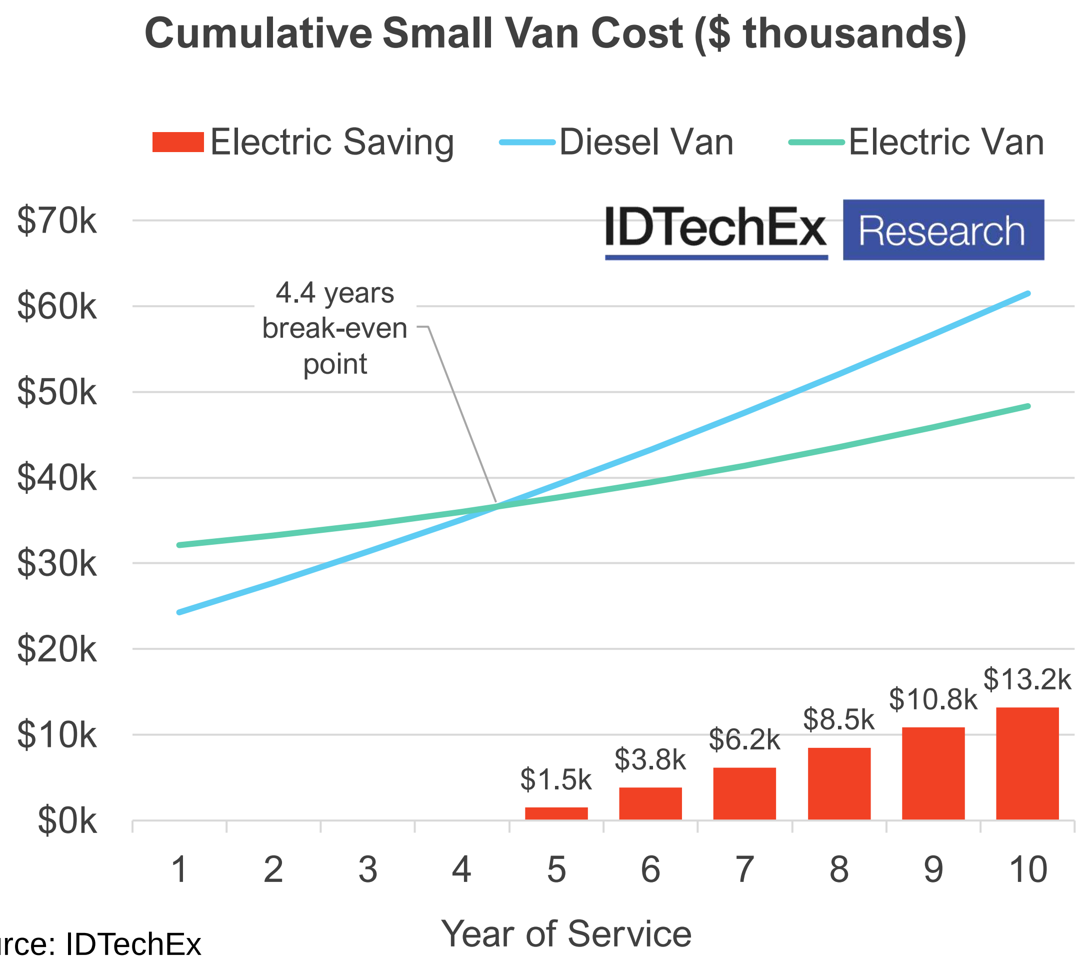
TCO Analysis Assumptions: Small Van

- IDTechEx's analysis suggests that there is currently around a **$8.9k premium** to be paid on small electric vans when compared to small diesel vans.
- Many countries are offering purchase incentives to reduce this upfront cost difference. The 'plug-in grant' from the UK government for example pays 20% of the purchase price up to a maximum of £8,000 (≈$10.3k). The base analysis presented in the table does not include a grant provision.
- A charger installation cost of $1,290 (£1k) is incorporated in to the TCO. In reality this will vary considerably depending on the type of charger being installed and the number of chargers. There are also government schemes set up to cover some of this cost.
- The base TCO model assumes that the van covers a daily range of 100km (62 miles) on 320 days a year. 100 km is within the real-world range of electric small vans on one charge.
- IDTechEx's calculations suggest that, with this yearly mileage, on average the fuel saving of a small eVan over a diesel would amount to **$1,987 per year**.
- With lower service, maintenance and repair costs, IDTechEx calculate the break-even point for small eVans at 4 to 5 years.

	Small Diesel Van	Small Electric Van
CAPEX Cost		
Upfront LCV price (excluding VAT and without subsidy)	$20,959	$29,861
Charger Installation		$1,290
LCV Annual Milage		
Daily duty cycle (km)	100	100
Operational days per year (days)	320	320
Annual Milage (km/yr)	32,000	32,000
Operational Fuel Cost		
Diesel fuel cost ($/L)	1.55	
Average real-world mpg	48.8	
Electricity cost ($/kW)		0.15
eLCV real-world range (km)		141
eLCV battery (kWh)		25
eLCV efficiency (kWh/km)		0.18
Annual Fuel Cost ($)	$2,869	$882
Servicing, Maintenance, Repair		
Average S,M,R ($/km)	0.037	0.026
Average Annual S,M,R ($)	$1,187	$837
Payback Period		
Upfront cost difference (£)	$10,192	
Fuel saving per year (£)	-$1,987	
Average S,M,R saving per year (£)	-$350	
Payback period (years)	**4.4**	

Source: IDTechEx

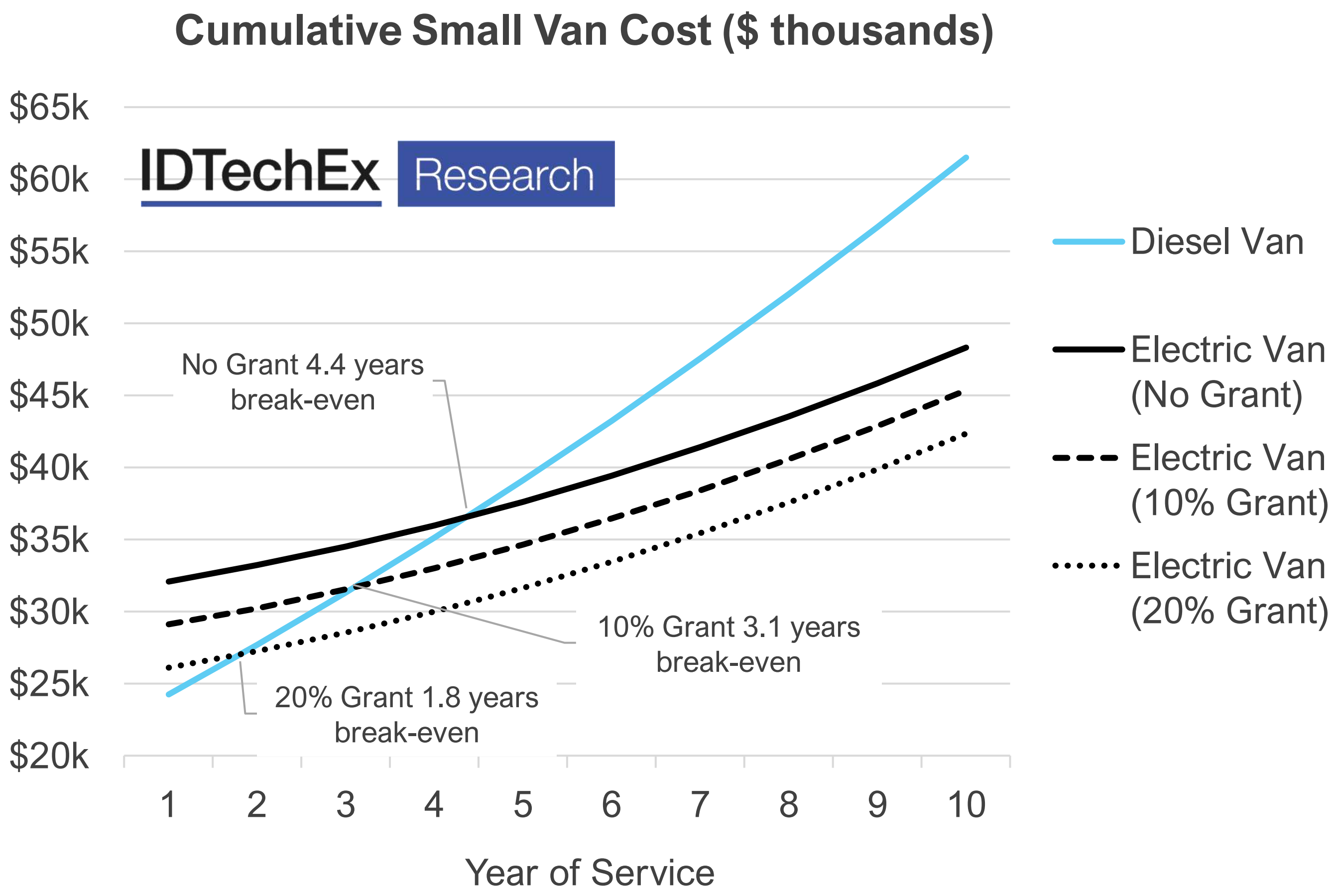
Small eVan Break-Even Point



Source: IDTechEx

- For a small van with a daily duty range of 100 km (62 miles), equating to an annual mileage of around 32,000 km (20,000 miles), IDTechEx suggest that the extra upfront cost of purchasing a small electric van would be paid off after ≈ 4.4 years.
- The current premium for buying an small electric van over a small diesel van (around $10k), is covered through reduced fuel cost (around $2k/year) and reduced servicing and maintenance ($350/year saving).
- Over the lifetime of the vehicle IDTechEx's analysis suggest it works out to be considerably cheaper to run a small eVan than a diesel van. After 10-year of operation the eVan could potentially save the operator $13.2k.
- It should be noted that after 10 years, the vehicle would have covered 320,000 km. Many battery warranties currently offered by OEMs only extend to 160,000 km, it is therefore possible in this scenario that the battery may need to be replaced inside the 10-years. However given the scale of TCO advantage of the eVan, even including the additional cost of a battery replacement, the TCO would still be in favour of the eVan.

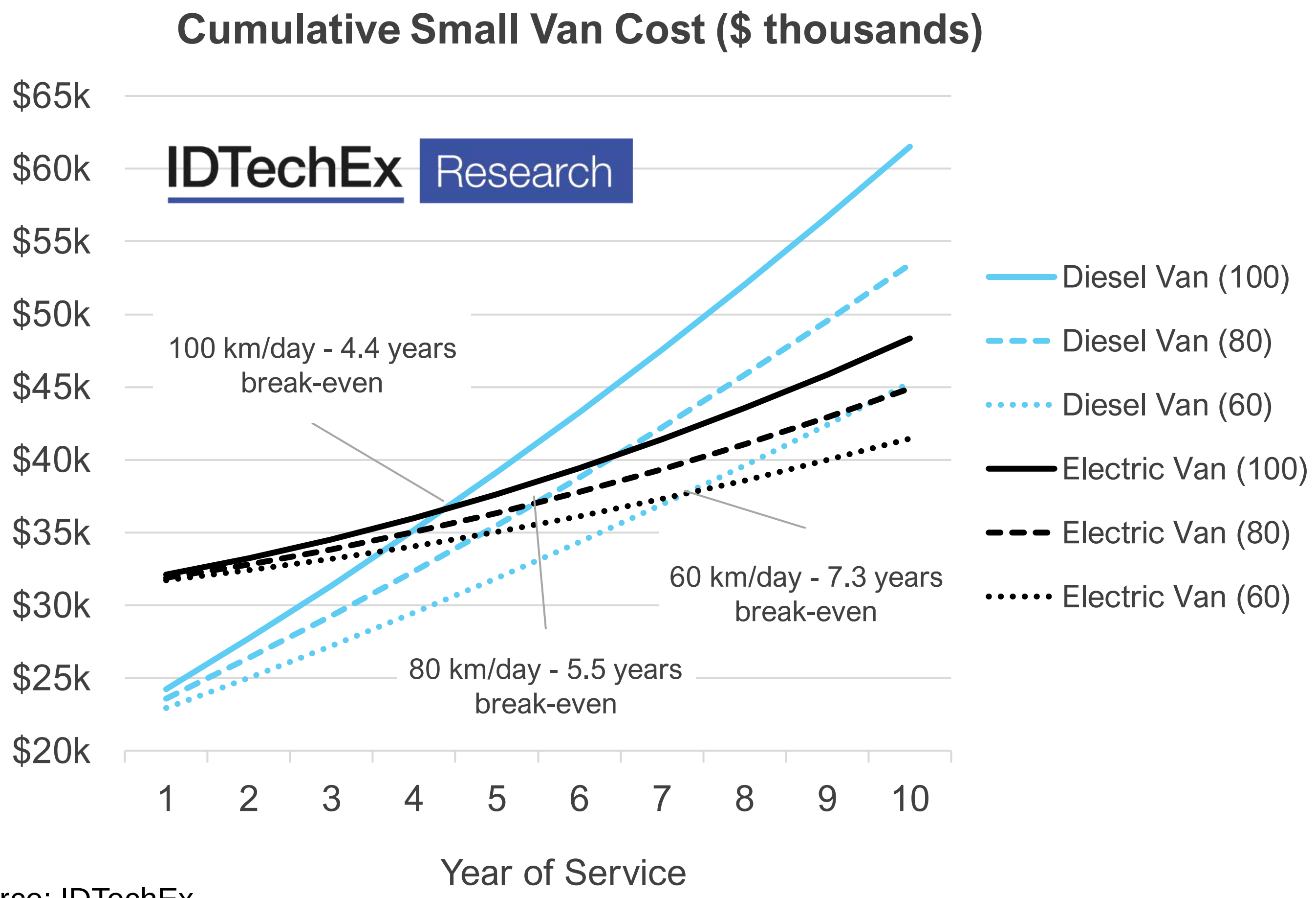
Small eVan Break-Even: Purchase Grant



Source: IDTechEx

- IDTechEx forecast that without government purchase grants the break-even point for small electric eVans is 4.4 years.
- Grant schemes promoting electric vehicle take-up are making the TCO even more attractive for small eVans.
- A 10% grant (whereby the government pay 10% of the purchase price), equating to approximately $3,000, moves the break-even point forward to 3.1 years, whilst a 20% grant (as offered by the UK government) sees a TCO advantage for small eLCV after as little as 1.8 years.
- This analysis is for a daily duty range of 100km. Lower mileage duty cycles, with a lower annual mileage, reduce the fuel saving and push back the break even point.

Small eVan Break-Even: Daily Duty Cycle Range



Source: IDTechEx

- IDTechEx forecast that for a LCV with a 100 km daily duty range and 32,000 km annual range, the break-even point for small electric eVans over a diesel equivalent is 4.4 years, without a government purchase grant.
- If the daily duty range of the van is instead 80 km per day (≈ 50 miles), with an annual mileage of 25,600 km per year, then the break-even point for electrification is pushed back to 5.5 year.
- And if the daily duty range is only 60 km per day (≈ 37 miles), 19,200 km per year, then the break-even point for electrification is pushed back even further to 7.3 year.
- This analysis highlights the need for the vehicle to be well utilised. Vans with low annual mileages will take considerably longer for electrification to reach cost parity with conventional diesel vans.

TCO: Medium Vans

Reference Vehicles

- Citroën ë-Dispatch
- Mercedes eVito
- Peugeot e-Expert
- Vauxhall Vivaro-e
- VW eTransporter

Medium vans
empty vehicle weight ≈
1500 - 2000 kg

Source: Peugeot

Source: Vauxhall

Source: VW

Source: Citroen

Source: Mercedes-Benz

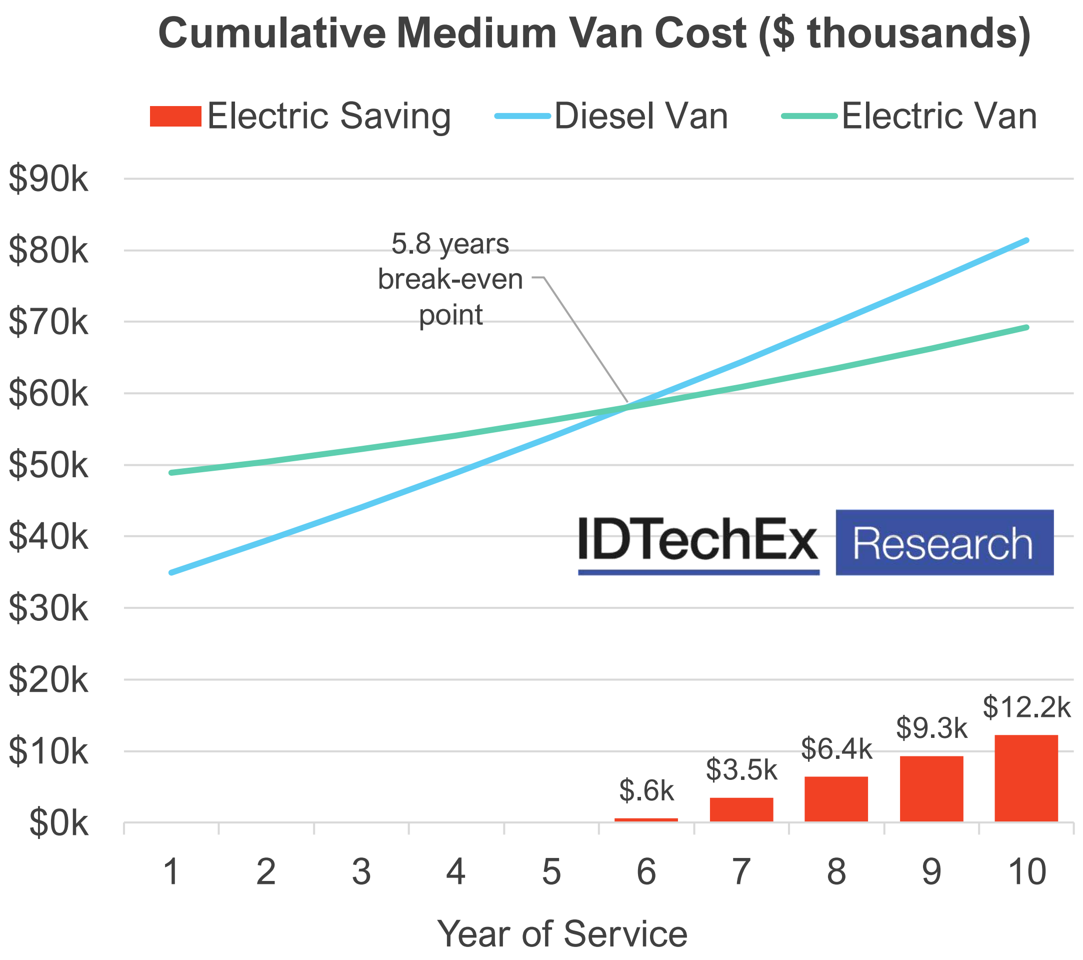
TCO Analysis Assumptions: Medium Van

- IDTechEx's analysis suggests that there is around a **$15.6k premium** to be paid on medium electric vans over like-for-like diesel vans.
- Including a charger installation cost of $1,290 (£1k) the extra cost of purchasing a medium electric van, is $16.9k, without an incentive purchase grant.
- IDTechEx calculate the average medium electric van price at $46,176 or £35.8k. In the UK, this category of van benefits from being below the £40k cut-off, qualifying for the full 20% 'plug-in grant' grant toward the purchase price.
- The base TCO model assumes that the van covers a daily range of 100km (62 miles) on 320 days a year. 100 km is within the real-world range of electric medium vans on one charge. IDTechEx's analysis calculates the average real-world range of medium electric vans at 155km (96.5 miles)
- IDTechEx's calculations suggest that with a 32,000 km annual mileage the fuel saving of an average medium eVan over a diesel would amount to **$2,653 per year**.
- IDTechEx calculate the break-even point for medium electric vans, without VAT and a purchase grant, at between 5 and 6 years as a result of fuel savings and lower vehicle maintenance.

	Medium Diesel Van	Medium Electric Van
CAPEX Cost		
Upfront LCV price (excluding VAT and without subsidy)	$30,601	$46,176
Charger Installation		$1,290
LCV Annual Milage		
Daily duty cycle (km)	100	100
Operational days per year (days)	320	320
Annual Milage (km/yr)	32,000	32,000
Operational Fuel Cost		
Diesel fuel cost ($/L)	1.55	
Average real-world mpg	35.9	
Electricity cost ($/kW)		0.15
eLCV real-world range (km)		155
eLCV battery (kWh)		39
eLCV efficiency (kWh/km)		0.25
Annual Fuel Cost ($)	$3,896	$1,243
Servicing, Maintenance, Repair		
Average S,M,R ($/km)	0.037	0.029
Average Annual S,M,R ($)	$1,187	$933
Payback Period		
Upfront cost difference (£)	$16,865	
Fuel saving per year (£)	-$2,653	
Average S,M,R saving per year (£)	-$254	
Payback period (years)	**5.8**	

Source: IDTechEx

Medium eVan Break-Even Without Purchase Grant

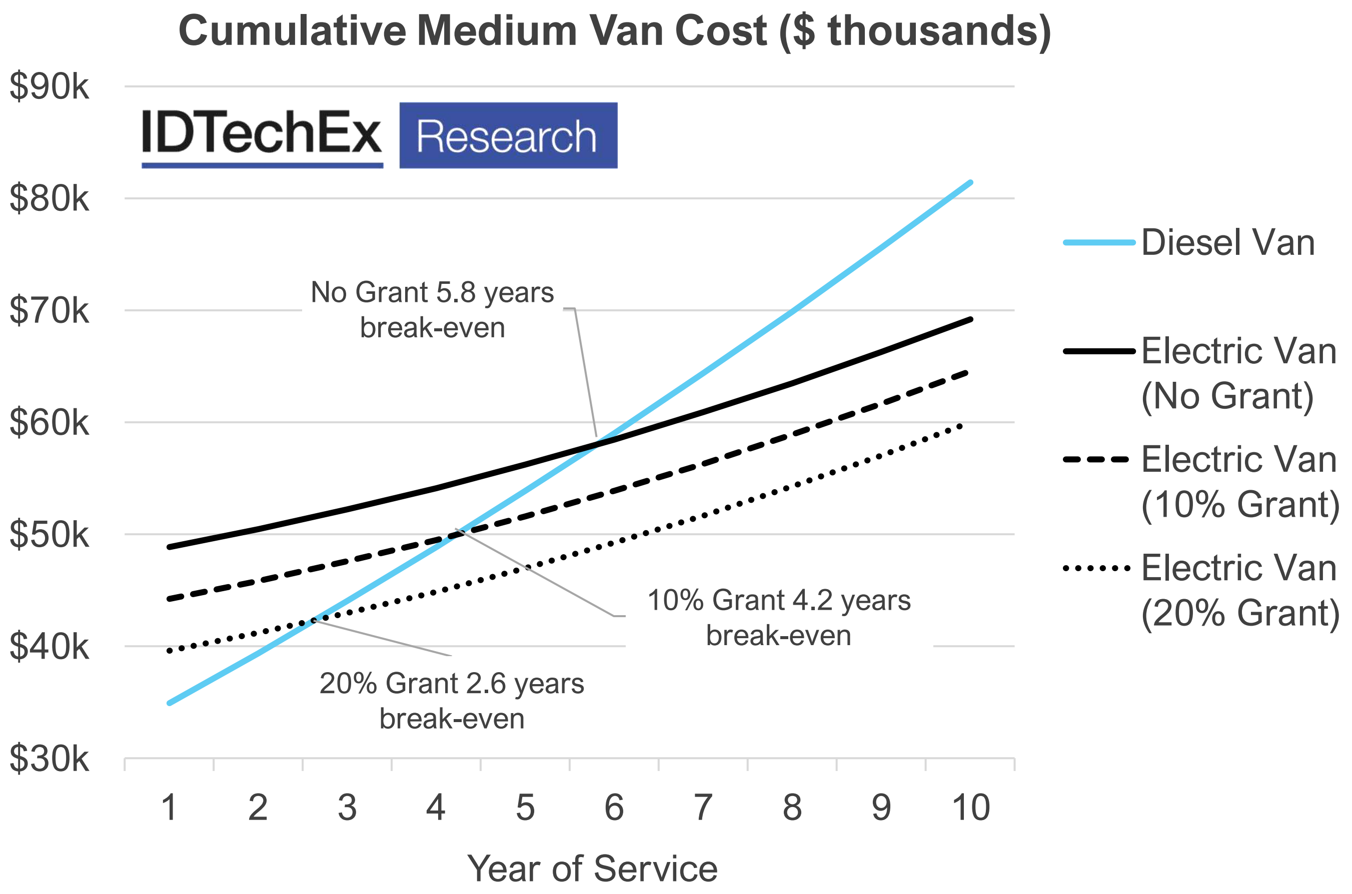


- Daily duty range: 100 km (62 miles)
- Annual mileage: 32,000 km (20,000 miles)
- Break-even ≈ 5.8 years without purchase grant.

- Medium electric van with a charger installation, premium $16,865 over a like-for-like diesel van.
- Fuel saving around $2.6k/year
- Reduced maintenance approximately $250/year

- Similar to the small van category, over the lifetime of the vehicle IDTechEx's analysis suggest it works out to be considerably cheaper to run an electric model of medium van an than diesel model of the same van, even without government financial support. After 10-year of operation a medium eVan could potentially save the operator $12.2k, which would likely be enough to pay for a battery replacement should they degrade before the operational lifetime of the vehicle, whilst still having a TCO advantage over diesel.

Medium eVan Break-Even: Purchase Grant

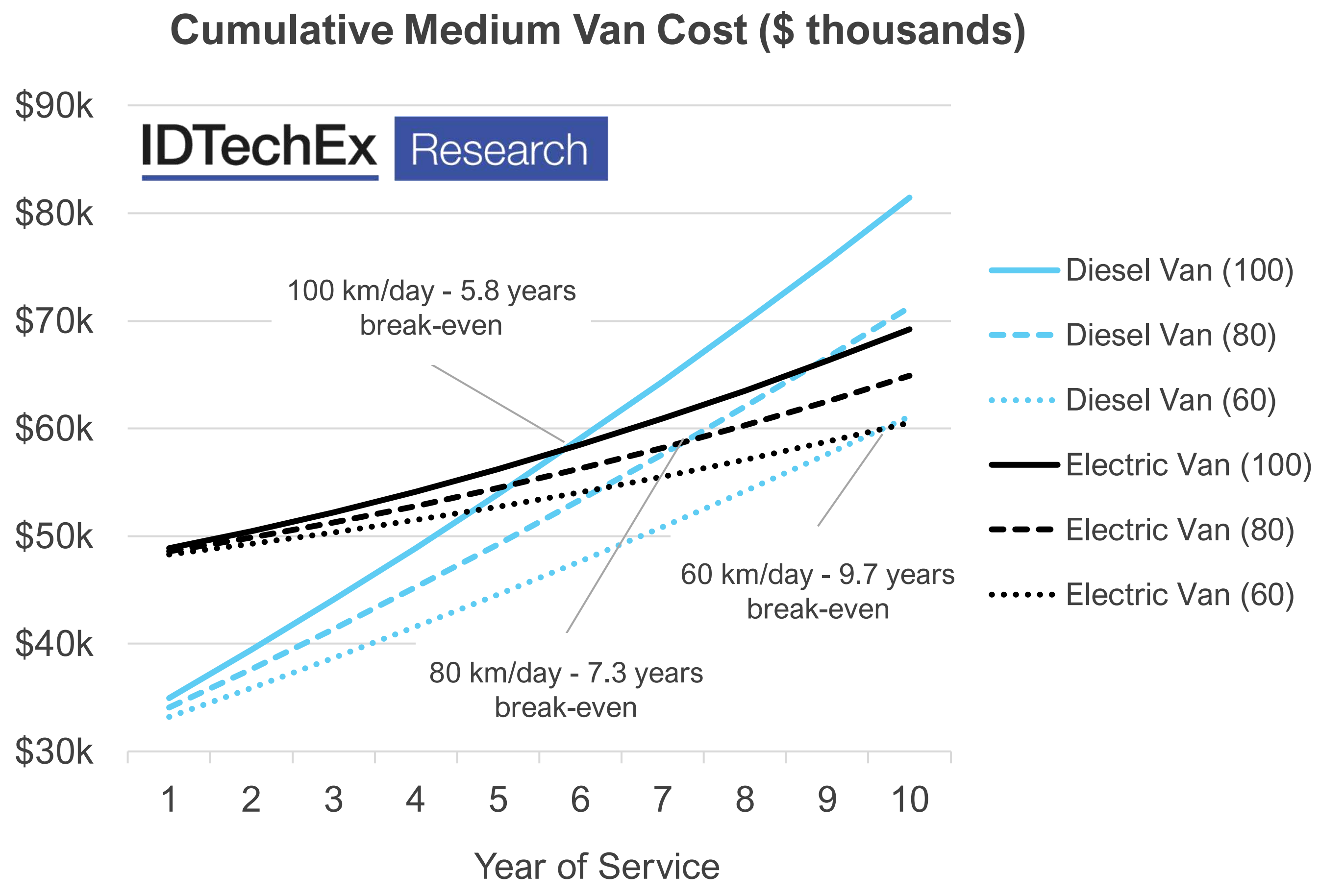


- Without government purchase grants IDTechEx calculate the break-even point for medium electric vans at 5.8 years.

- Government schemes incentivise electric vehicle purchase through contributing a percentage of the upfront purchase price.
- With a 10% purchase grant (≈ $4,600) the break-even point would move forward to 4.2 years.
- A 20% grant (≈ $9,200) would see the TCO advantage for medium eLCV at 2.6 years.

- As for the small van analysis, this TCO is calculated for an annual mileage of 32,000km. Shorter mileage duty cycles, with a lower annual mileage, reduce the fuel saving and push back the break even point.

Medium eVan Break-Even: Daily Duty Cycle Range



IDTechEx forecast for medium electric vans at different daily duty cycle ranges, without purchase grant:

- 100 km daily duty range (32,000 km annual range)
- 5.8 years till cost parity for a medium eVan

- 80 km daily duty range (25,600 km annual range)
- 7.3 years till cost parity for a medium eVan

- 60 km daily duty range (19,200 km annual range)
- 9.7 years till cost parity for a medium eVan

- As was the case for small eVans, the analysis highlights that the medium sized electric vans will only offer a decent TCO advantage if they have a duty cycle that requires good range to be covered each day. Applications in local food and parcel delivery are likely to be a good fit.

TCO: Large Vans

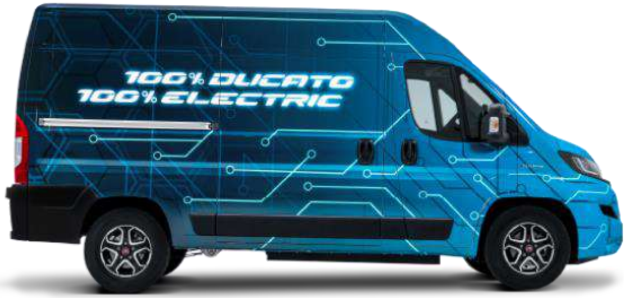
Reference Vehicles

- Fiat E-Ducato
- MAN eTGE
- Mercedes eSprinter
- Renault Master Z.E.
- VW e-Crafter

Large vans
empty vehicle weight ≈
> 2000 kg

Source: VW

Source: Renault



Source: Fiat

Source: MAN

Source: Mercedes-Benz

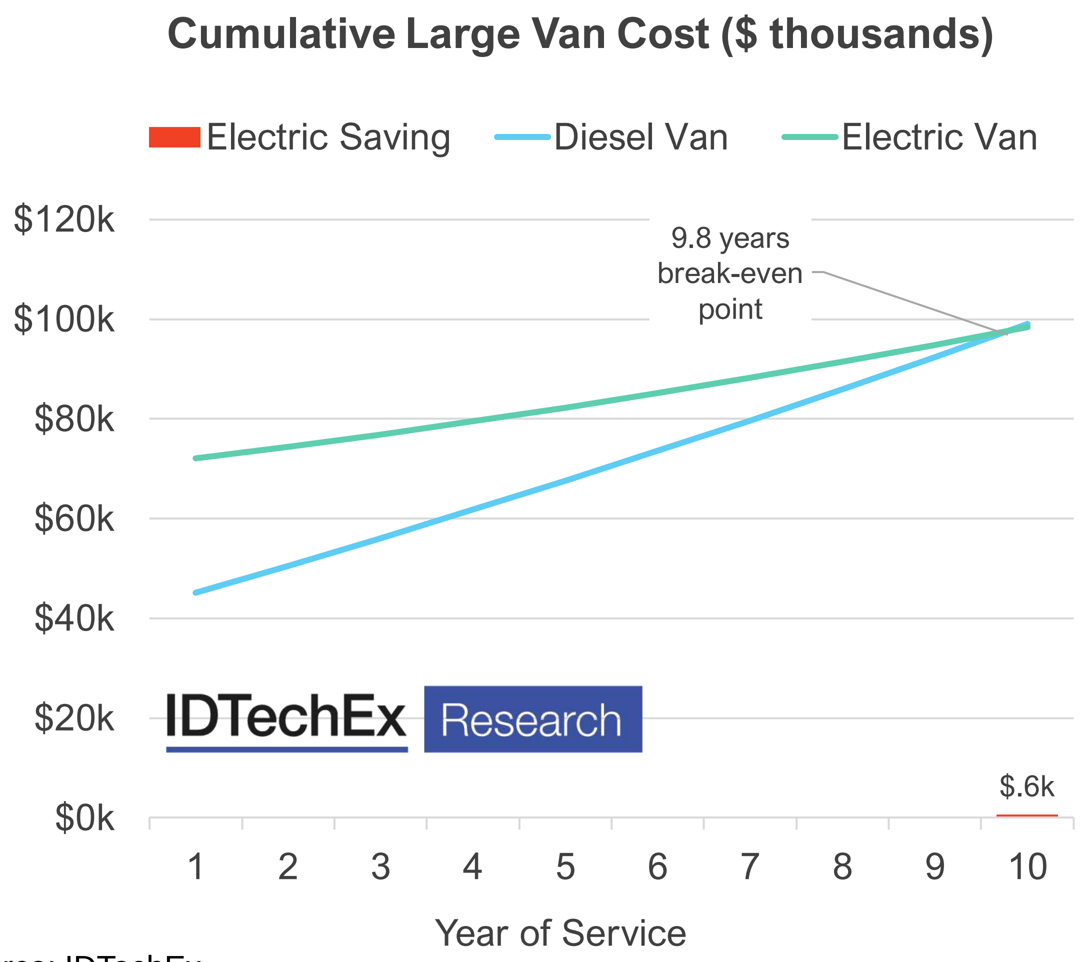
TCO Analysis Assumptions: Large Van

- IDTechEx's analysis suggests that there is a **$28.7k premium** on large electric vans over the same large diesel models.
- In the larger diesel van market there is a wide range of list prices depending on specification. As there are fewer specification options for electric large vans, the comparison between base model electric and base model diesel large vans may not be entirely fair. Base model electric versions potentially come with a considerably higher specification than the base diesel model. However, for this analysis the most basic model list prices, without VAT or purchase grant, were used to calculate average prices.
- IDTechEx's research suggests the average large electric van costs $68,565 (£53.2k). In the case of the UK government plug-in grant, all large electric vans had a list price without VAT greater than £40k. Therefore the large vans qualify of a grant of £8,000 rather than 20%.
- Surprisingly the average battery capacity in this category was found to be smaller that in the medium van category. The real-world range of the vehicles in this category is likely to be very close to the 100 km range demand assumption.
- The increased vehicle weight and drag (as a result of larger frontal area) lead to a greater average kWh/km consumption. IDTechEx calculate that the fuel saving from electrification is only marginally larger than the medium van category at **$2,856 per year**.
- The large upfront premium results in a longer break-even point for large electric vans, when compared to the small and medium van categories, of between 9 and 10 years.

	Large Diesel Van	Large Electric Van
CAPEX Cost		
Upfront LCV price (excluding VAT and without subsidy)	$39,892	$68,565
Charger Installation		$1,290
LCV Annual Milage		
Daily duty cycle (km)	100	100
Operational days per year (days)	320	320
Annual Milage (km/yr)	32,000	32,000
Operational Fuel Cost		
Diesel fuel cost ($/L)	1.55	
Average real-world mpg	30.5	
Electricity cost ($/kW)		0.15
eLCV real-world range (km)		101
eLCV battery (kWh)		35
eLCV efficiency (kWh/km)		0.35
Annual Fuel Cost ($)	$4,592	$1,736
Servicing, Maintenance, Repair		
Average S,M,R ($/km)	0.041	0.035
Average Annual S,M,R ($)	$1,318	$1,115
Payback Period		
Upfront cost difference (£)	$29,963	
Fuel saving per year (£)	-$2,856	
Average S,M,R saving per year (£)	-$204	
Payback period (years)	**9.8**	

Source: IDTechEx

Large eVan Break-Even Without Purchase Grant



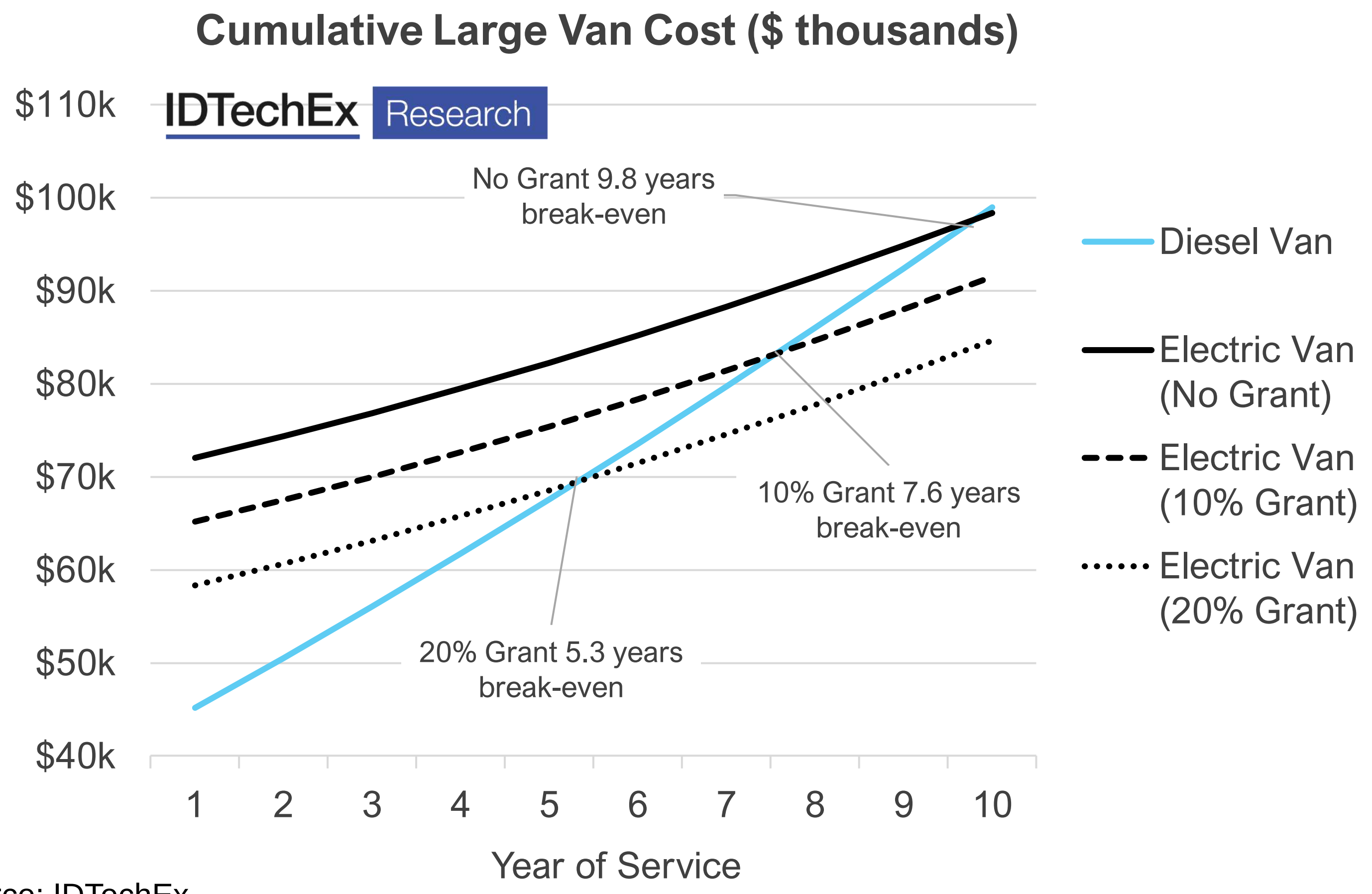
Source: IDTechEx

- Daily duty range: 100 km (62 miles)
- Annual mileage: 32,000 km (20,000 miles)
- Break-even ≈ 9.8 years without purchase grant.

- Medium electric van with a charger installation, premium $29,963 over a like-for-like diesel van.
- Fuel saving around $2.9k/year
- Reduced maintenance approximately $200/year

- Unlike the small and medium van categories, over a 10-year period of operation of a large van, IDTechEx's analysis suggest that, without government financial support, it is only marginally cheaper to run an electric model of large van than diesel model. The $600 saving would not be enough to pay for a battery replacement should they degrade during the operational lifetime of the vehicle but outside warranty. The TCO advantage is likely to be for diesel.

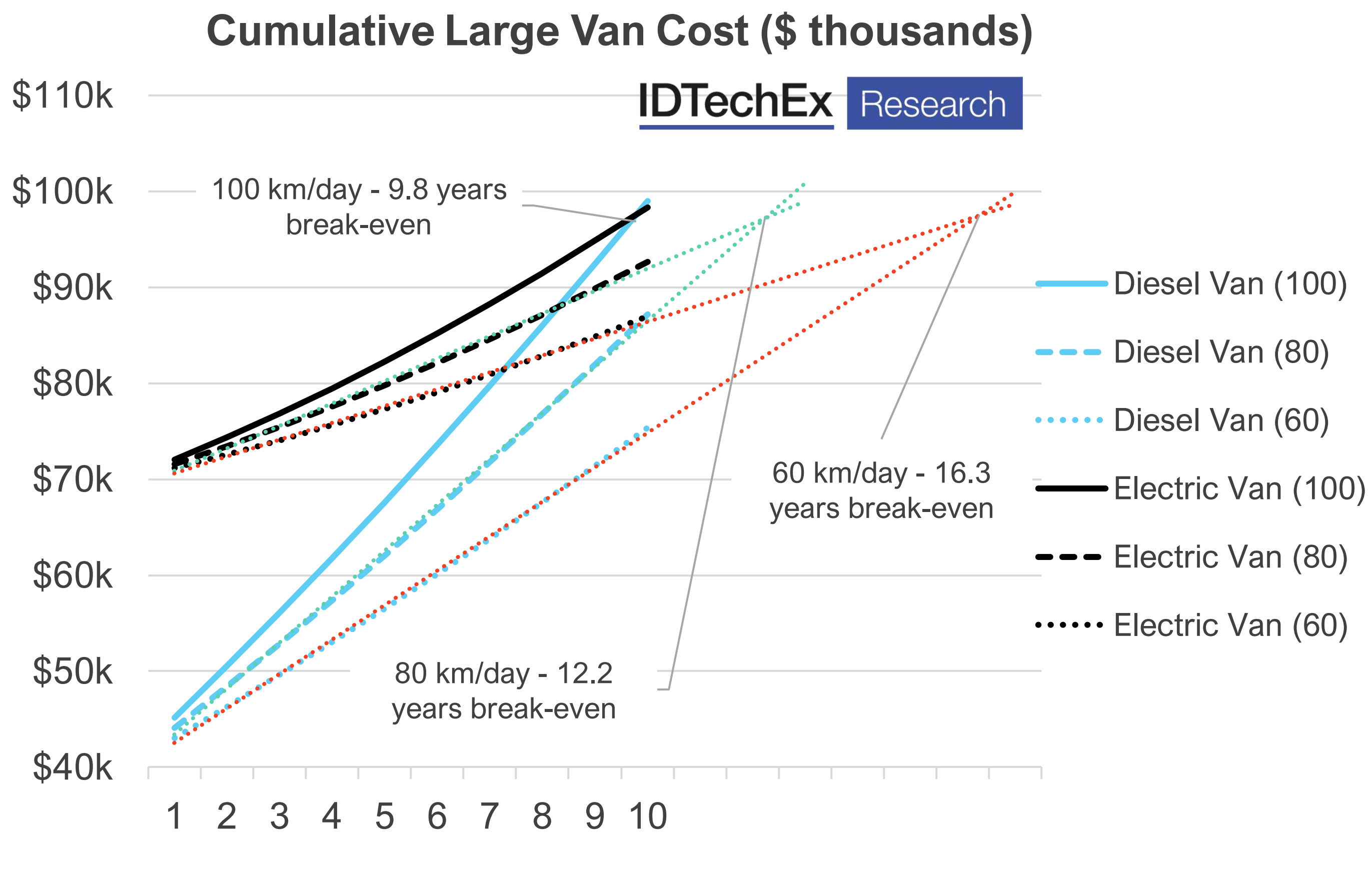
Large eVan Break-Even: Purchase Grant



Source: IDTechEx

- Without government purchase grants IDTechEx calculate the break-even point for large electric vans at 9.8 years.
- Government schemes incentivise electric vehicle purchase through contributing a percentage of the upfront purchase price.
- With a 10% purchase grant of ≈ $6,850 (£5,300) the break-even point would move forward to 7.6 years.
- A 20% grant of ≈ $13,700 (£10,600) would see the TCO advantage for medium eLCV at 5.3 years. In the UK the maximum van grant is capped at £8,000.
- At current large eVan prices, in order for the TCO to provide a compelling reason for companies to purchase large electric vans, significant government support will need to be need to incentivise the uptake. This is contrary to small and medium electric vans, which offer a TCO advantage over diesel without or with much smaller grants than are currently offered.

Large eVan Break-Even: Daily Duty Cycle Range



Source: IDTechEx

IDTechEx forecast for large electric vans at different daily duty cycle ranges, without purchase grant:

- 100 km daily duty range (32,000 km annual range)
- 9.8 years till cost parity for a large eVan

- 80 km daily duty range (25,600 km annual range)
- 12.2 years till cost parity for a large eVan

- 60 km daily duty range (19,200 km annual range)
- 16.3 years till cost parity for a large eVan

- In the case of large electric vans, relatively long daily ranges are vital in making a TCO argument for electrification. The complicating factor in this requirement is that IDTechEx's analysis suggest the real-world maximum range of large electric is likely to only be around 100 km. It may not be possible to run a 100 km route, whilst leaving sufficient charge to ensure the vehicle makes it back to the depot.

TCO Summary: Small, Medium and Large Electric Vans

Small Electric Vans

- Average small electric van premium $8,900 over diesel
- Fuel saving $1987 per year (with an annual mileage of 32,000 km)
- TCO break-even at 4.4 years without subsidy, 1.8 years with 20% purchase grant
- **A significant TCO advantage over diesel**

Medium Electric Vans

- Average medium electric van premium $15,575 over diesel
- Fuel saving $2653 per year (with an annual mileage of 32,000 km)
- TCO break-even at 5.8 years without subsidy, 2.6 years with 20% purchase grant
- **A significant TCO advantage over diesel**

Large Electric Vans

- Average large electric van premium $28,673 over diesel
- Fuel saving $2856 per year (with an annual mileage of 32,000 km)
- TCO break-even at 9.8 years without subsidy, 5.3 years with 20% purchase grant
- **Large premium on electric large vans, requires significant government financial support to improve TCO.**

Image Sources: Renault, Vauxhall, Mercedes-Benz

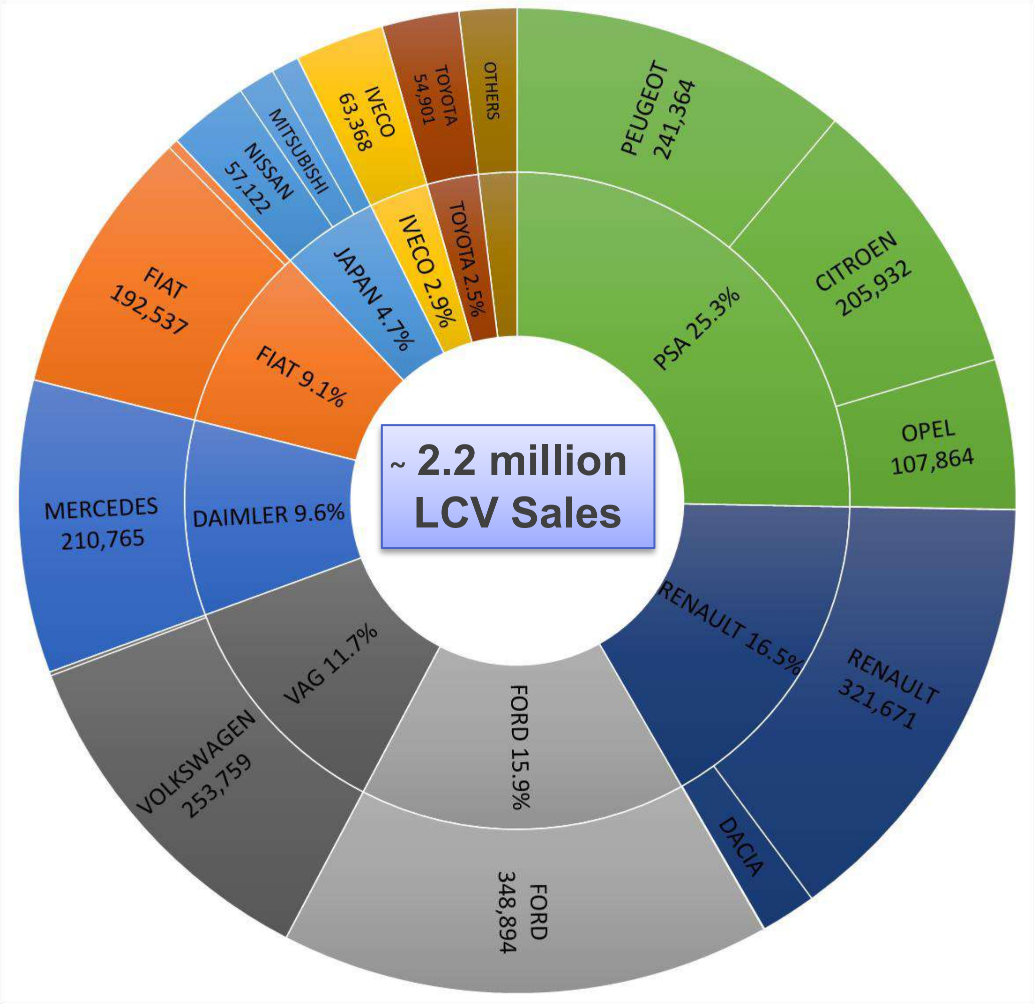
Strengthening TCO advantage for eVans

- Alongside government schemes that incentivise the purchase of electric vans though paying a percentage of the purchase price for these vehicles, mechanisms such as exemptions from yearly road tax, road toll, emission zone charges and congestion zone charges can also be used to improve the TCO calculation in favour of electric vans.
- Around the world cities are beginning to take action to tackle dangerous air quality and emission from road transport. With many European cities for example proposing bans on the entry of diesel and petrol vehicles to urban centres.
- Falling battery prices, maturing of the supply chain and greater volume of production will see the purchase price of electric vans fall over the next decade, whilst requirements to reduce exhaust emission from ICE vans will see their cost increase as new technology is deployed to clean the exhaust gases and improve engine efficiency.
- With start-up electric van manufacturers like the UK based Arrival designing new electric vans with the explicit goal of delivering them at the same or at a lower price than an equivalent fossil fuel powered van, the premium currently being paid for electric vans should fall substantially.

Source: Arrival

4. Europe

Europe: LCV sales 2019



Data Source: Association Auxiliaire de l'Automobile

Fleet in the EU + EFTA:

Total 2019 LCV Registrations: ~ **2.2 Million**
In-use EU LCV Fleet (2018): ~ **33.17 Million**

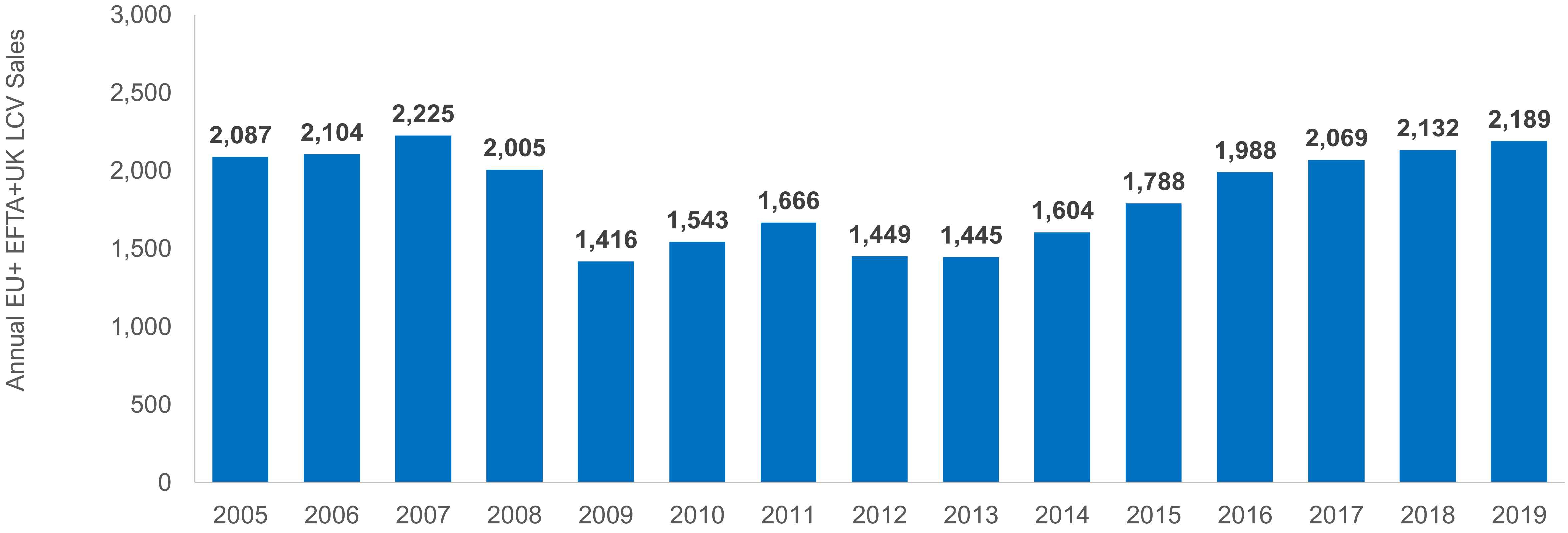
Top-Selling LCV Models in EU-28 (2018)

- Ford Transit – **284,635** (13.9%)
- Mercedes Sprinter – 97,942 (4.8%)
- Citroën Berlingo – 91,397 (4.5%)
- Renault Kangoo – 89,886 (4.4%)
- Peugeot Partner – 88,179 (4.3%)
- VW Transporter – 87,190 (4.3%)
- Renault Master – 85,713 (4.2%)
- Fiat Ducato – 80,083 (3.9%)
- Renault Traffic – 72,331 (3.5%)
- VW Caddy – 67,304 (3.3%)

Data Source: ICCT

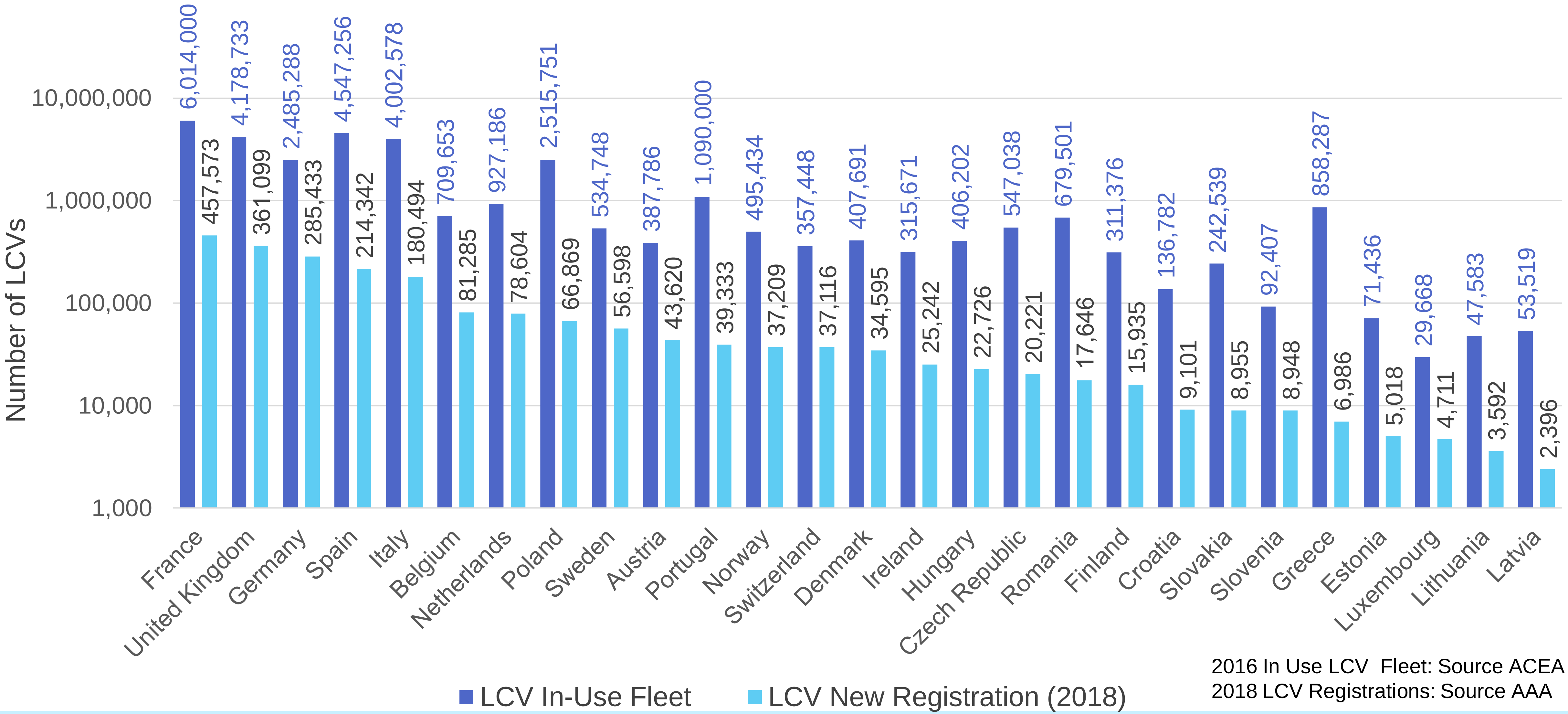
European market for LCVs

The sales of commercial vehicles are strongly influenced by economic conditions. The dramatic decrease in sales in 2009 was due to the global recession. Since then sales have turned back towards the pre 2009 levels.



Data Source: acea.be

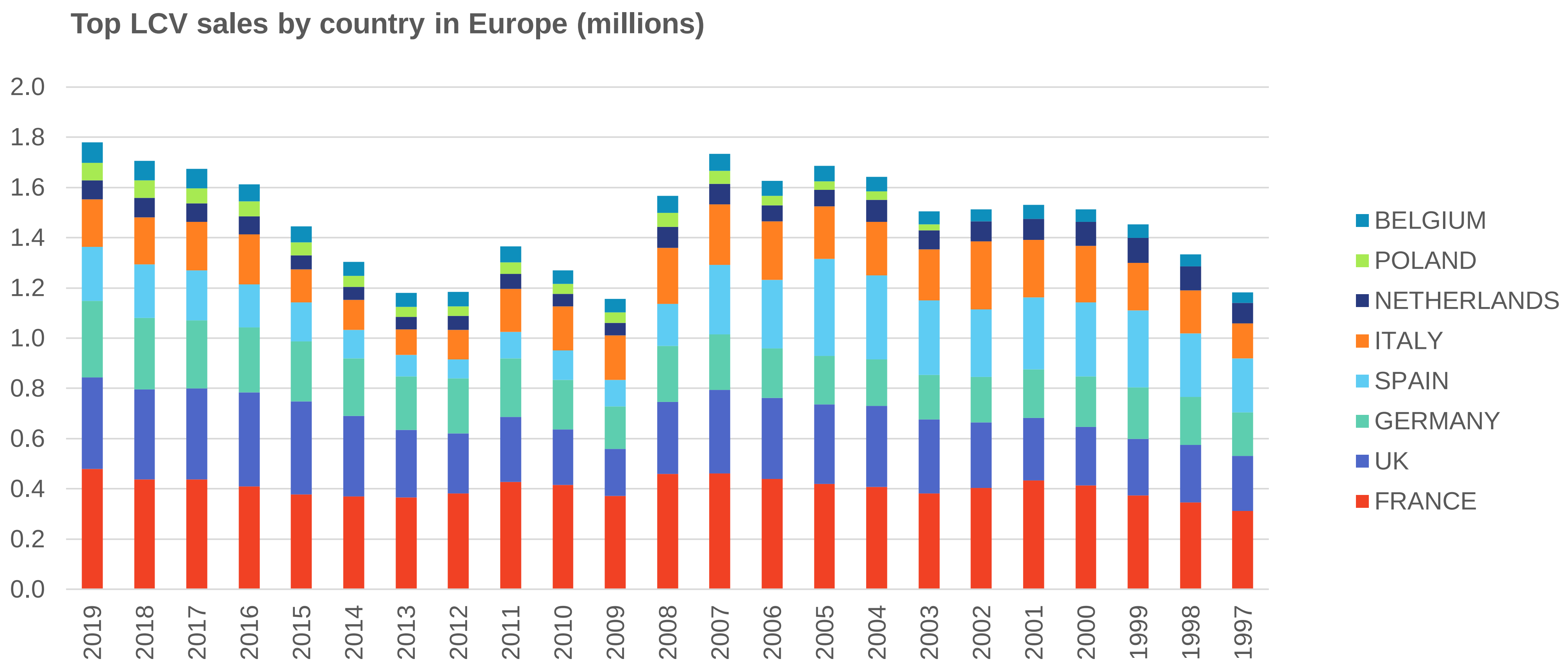
European in-use LCV fleet and new registrations



2016 In Use LCV Fleet: Source ACEA
2018 LCV Registrations: Source AAA

New registrations in Europe’s 8 largest LCV fleets

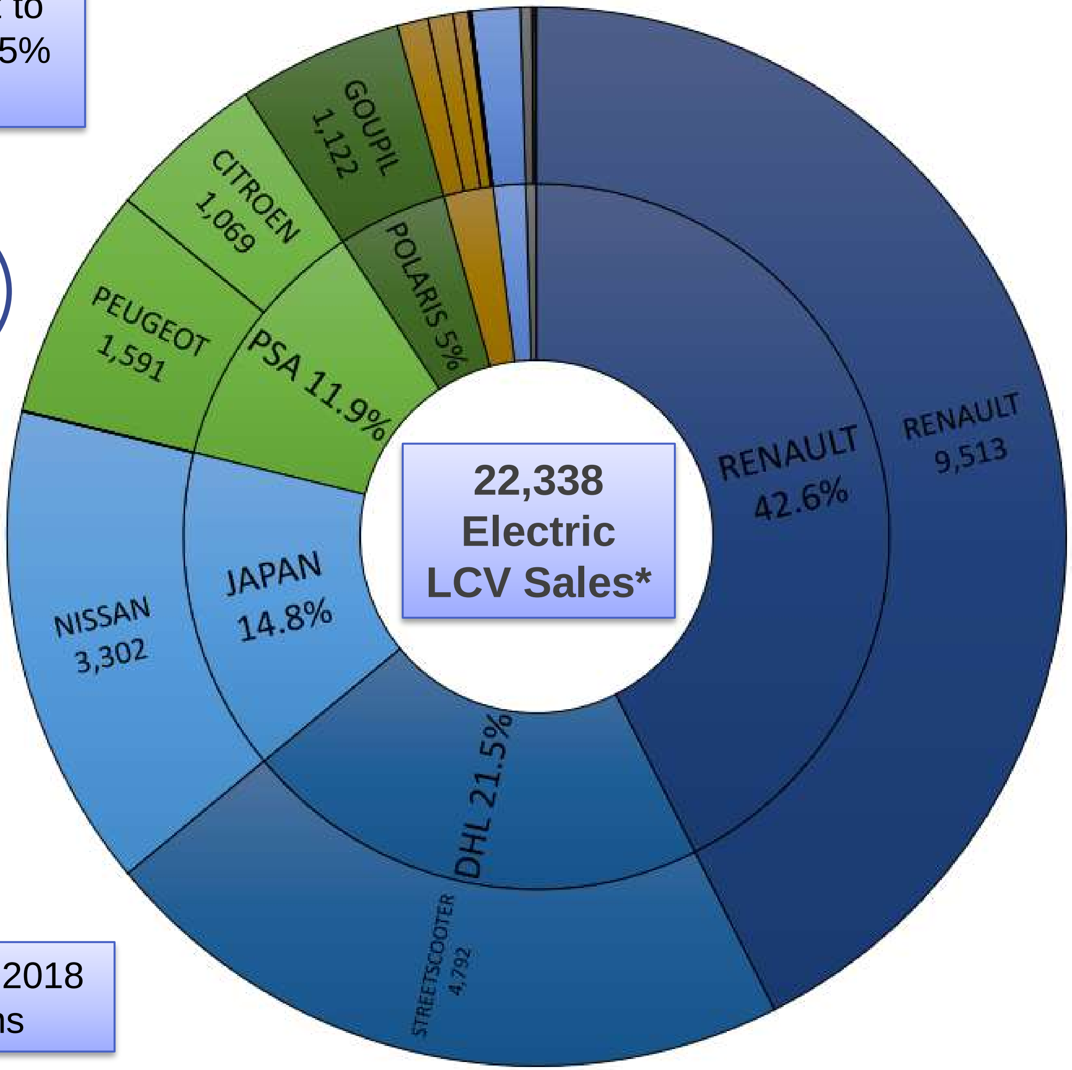
France, UK, Italy, Spain and Germany sell the most LCVs.



2018 European eLCV Sales

Some big players yet to enter the market: 34.5% of EU LCV Sales

- DAIMLER 0%
- FIAT 0%
- FORD 0%
- IVECO 0%
- JAPAN 14.8%
- PSA 11.9%
- RENAULT 42.6%
- TOYOTA 0%
- VAG 0.5%
- OTHERS 2.3%
- DHL 21.5%
- POLARIS 5%
- SAIC 1.5%



e-LCV 1.1% of total 2018 LCV Registrations

	OEM	MODEL	2018 SALES
DHL	StreetScooter	Work	4,792
IVECO	IVECO	Daily Electric	3
JAPAN	Isuzu	NLR85 E	2
	Mitsubishi	Miev Van	5
	Nissan	e-NV200	3,268
	Nissan	Leaf Van	34
POLARIS	Goupil	G5	122
	Goupil	G4	779
	Goupil	G3	221
PSA	Citroen	Berlingo L1 & L2 Electric	1,066
	Citroen	C-Zero Van	3
	Peugeot	Partner L1 & L2 Electric	1,591
RENAULT	Renault	Zoe Van	994
	Renault	Kangoo Z.E	8,342
	Renault	Master Z.E.	177
SAIC	LDV	EV80	330
VAG	Audi	e-Tron Van	1
	MAN	eTGE	21
	VW	e-Crafter	70
	VW	e-Up! Van	5
	VW	e-Golf Van	5
OTHERS	Alke	ATX	9
	Esagono	Esagono EV	2
	Colibus	Colibus	10
	Ligier	Pulse 4 L3	170
	Piaggio	Porter	104
	Others		212
TOTAL			22,338

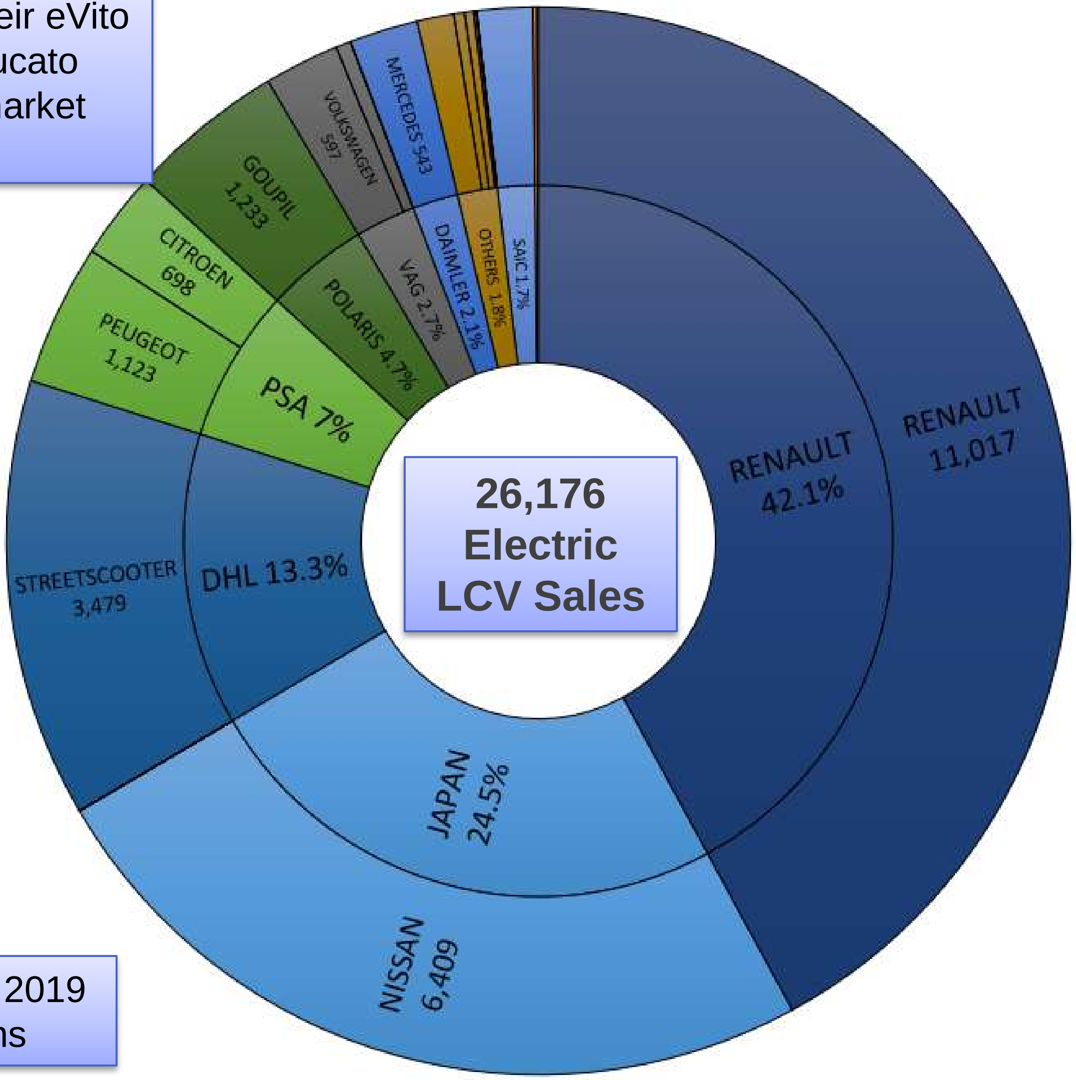
*EAFO Figure. ACEA figure 23,314 eLCV units

Source: EAFO

2019 European eLCV Sales

Daimler Launched their eVito eLCV and Fiat the Ducato eLCV. Expect Ford market share in 2020

- DAIMLER 2.1%
- FIAT 0.1%
- FORD 0%
- IVECO 0%
- JAPAN 24.5%
- PSA 7%
- RENAULT 42.1%
- TOYOTA 0%
- VAG 2.7%
- OTHERS 1.8%
- DHL 13.3%
- POLARIS 4.7%
- SAIC 1.7%



e-LCV 1.3% of total 2019 LCV Registrations

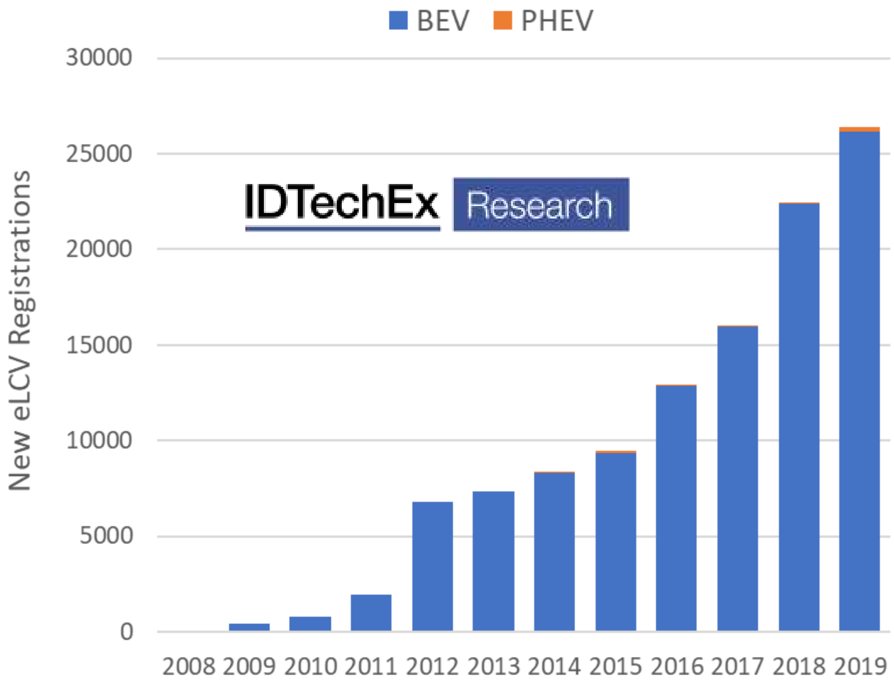
	OEM	MODEL	2019 SALES
DAIMLER	Mercedes	eVito	543
DHL	StreetScooter	Work	3,479
FIAT	FIAT	Fiat Ducato Electric	34
IVECO	IVECO	Daily Electric	7
JAPAN	Nissan	e-NV200	6,306
	Nissan	Leaf Van	103
POLARIS	Goupil	G5	54
	Goupil	G4	511
	Goupil	G3	668
PSA	Citroen	Berlingo L1 & L2 Electric	698
	Peugeot	Partner L1 & L2 Electric	1,123
RENAULT	Renault	Zoe Van	1,296
	Renault	Kangoo Z.E	9,337
	Renault	Master Z.E.	384
SAIC	LDV	EV80	442
VAG	MAN	eTGE	120
	VW	e-Crafter	597
OTHERS	Alke	ATX	2
	Esagono	Esagono EV	22
	Ligier	Pulse 4 L3	69
	Piaggio	Porter	87
	Others		294
TOTAL			**26,176**

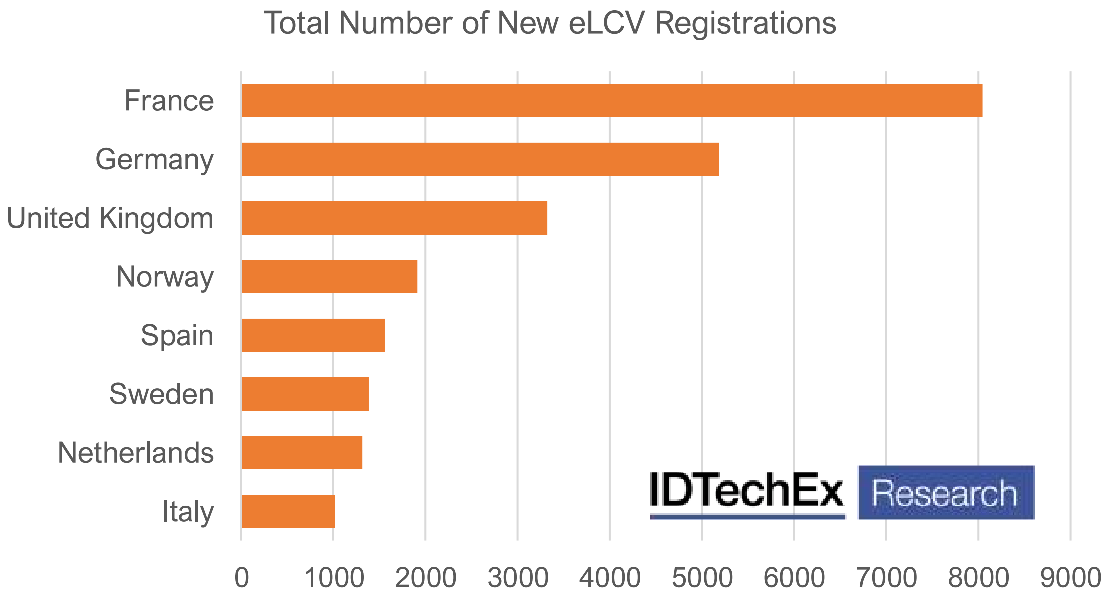
*EAFO Figure. ACEA figure 28,704 eLCV units

Source: EAFO

Increasing eLCV sales in Europe

- In 2019 there were 26,176 battery eLCV (BEV) registrations in Europe. This figure is an increase from 22,338 in 2018 (**+16.6%**)
- There were only 227 plug-in hybrid eLCV (PHEV) sales. These are all Mitsubishi Outlander PHEV Reflex, with 205 in the UK.
- For the 10th consecutive year France led the European market in eLCV sales with 8,044 registrations.
- The top three model registrations in France were the Renault Kangoo Z.E. (3,807), the Renault Zoe LCV (1,142) and the Nissan e-NV200 (925).





Source: European Alternative Fuels Observatory

Market outlook: national and local policy

Countries across Europe are making strong commitments to a transition away from fossil fuel combustion. However, the rate of progress will not be uniform across Europe, with some nations in a position to lead, whilst others will follow more slowly. Over 59% of 2019 LCV sales in Europe were in countries that have suggested they will ban the sale of petrol and diesel cars in the next 20 years, with a further 34.7% in countries which have not made explicit promises but are likely to follow a similar path to those that have.

COUNTRY	Introduction of ban on the sale of new ICE Cars / LCVs	2019 LCV SALES
Norway	2025	37,736
Ireland	2030	25,350
Netherlands	2030	76,395
Slovenia	2030	13,407
Sweden	2030	53,816
Iceland	2030	1,383
UK	2035	365,778
France	2040	478,375
Portugal	2040	38,454
Spain	2040	215,164
	Total	1,305,858
		59.6%

COUNTRY	Potential target for ban on the sale of new ICE Cars / LCV (Assumed*)	2019 LCV SALES
Austria	2040*	43,425
Belgium	2040*	81,219
Denmark	2040*	33,108
Germany	2040*	304,965
Luxemborg	2040*	5,089
Switzerland	2040*	34,555
Italy	2045*	187,725
Poland	2050*	69,872
	Total	759,958
		34.7%

COUNTRY	Potential Target for ban on the sale of new ICE Cars / LCV (Assumed*)	2019 LCV SALES
Bulgaria	No Target	5,985
Croatia	No Target	8,982
Cyprus	No Target	2,274
Czech Republic	No Target	20,436
Estonia	No Target	4,403
Finland	250,000 EV by 2030	14,702
Greece	No Target	7,972
Hungary	No Target	26,203
Latvia	No Target	2,703
Lithuania	No Target	4,355
Romania	No Target	16,985
Slovakia	31% of 2030 sales EV	8,508
	Total	123,508
		5.6%

Assumption: LCV EV uptake similar to car targets (where “Car” specified rather than “Vehicle” in national policy)

IDTechEx

European eLCV market leaders

RENAULT
Passion for life*

The **Renault Kangoo Z.E.** continued to lead the eLCV market in Europe, with 9,337 registrations in 2019, up from 8,342 in 2018 (**+11.9%**)

Kangoo Z.E registrations represent 35.4% of the eLCV market in Europe

Led by France (3,807), the UK (966), Spain (787) and Sweden (731)

Built at Renault's plant in Maubeuge (MCA), France. 450 million euros is due be spent over the next 5-years to increase production capacity.

NISSAN

- The **Nissan e-NV200** moved up to second place eLCV new registrations, with 6,306 registered in 2019 up from 3,268 in 2018 (**+93.0%**)
- New e-NV200 registrations were 23.9% of the European eLCV market
- Led by the UK (1633), Norway (978), France (925) and Sweden (511)
- According to the ACEA, Nissan's market share in Europe has fallen from 3.9% to 2.5%. Turning things around will in a large part be dependent on the potential of the e-NV200.

STREETSCOOTER

- Deutsche Post DHL's **StreetScooter Work** dropped from 4,792 registrations in 2018 to 3,479 registrations in 2019 (**-27.4%**)
- 91.3% of these registrations were primarily in Germany (3,177)
- In February 2020, Deutsche Post DHL StreetScooter, announced that production of the vehicle will come to an end in 2020

Sources: Renault, Nissan, StreetScooter, Wattev2buy.com, EAFO

IDTechEx

Popular e-LCVs in Europe

The best selling electric LCV models in Europe are currently smaller LCVs used for urban logistics.

Nissan e-NV200

Rated Power (kW)	80
Battery (kWh)	40
Payload (kg)	705
Range (km)	194
Cost ($)	> $33.6k

Source: nissan.co.uk

6,306 Sales in 2019

Renault Kangoo Z.E.

Rated Power (kW)	45
Battery (kWh)	31
Payload (kg)	650
Range (km)	230
Cost ($)	> $30k

9,337 Sales in 2019

Source: renault.co.uk

Renault Master Z.E.

Rated Power (kW)	57
Battery (kWh)	33
Payload (kg)	1128
Range (km)	120
Cost ($)	> $77k

Source: renault.co.uk

384 Sales in 2019

StreetScooter Timeline

Deutsche Post DHL Group (DPDHL) operates the largest electric fleet in Germany (**10,000+ vehicles**).

Deutsche Post DHL StreetScooter WORK & WORK L

Rated Power (kW)	48
Battery (kWh)	20 / 40
Payload (kg)	720 / 905
Range (km)	80

Source: DHL

3,479 Sales in 2019

GOAL: To replace 70% of their mail and parcel delivery fleet with electric vehicles by 2025 and to reduce their logistics related emissions to zero by 2050.

MILESTONES:
- 100 million km driven with 36,000 tonnes of CO_2 savings.
- electrified 700 depots and installed 13,500 charging points
- 10,000th StreetScooter delivered in August 2019

TIMELINE:

- **In 2012**, the first StreetScooter prototype was tested. Designed to meet the needs of DPDHL in terms of equipment, load capacity and safety standards.
- **In 2014** DPDHL fully acquired StreetScooter.
- **Apr 2016** – announces intention to begin series production of the WORK model, scaling up to a production capacity of 10,000 units per annum, in 2017.
- **May 2018** - StreetScooter opens a new manufacturing plant Düren, Germany, raising production capacity to 20,000 vehicles per year, in combination with its main factory in Aachen.
- **Oct 2018** - Ford began series production of the larger StreetScooter WORK XL (based on a Ford Transit chassis) at its plant in Cologne – with an annual production capacity of 3,500 units.
- **Sep 2019** - MOU StreetScooter & Chery Holding Group – to begin local production, sourcing and development of last-mile eLCVs (eLCV) for the Chinese market.
- **Feb 2020** - Deutsche Post / DHL announce end of StreetScooter electric LCV production. Ordered vehicles to be manufactured in 2020. But joint venture with Chery will not go ahead.

StreetScooter: End of the Road

- In February 2020 Deutsche Post DHL announced they will be ending production of the StreetScooter in 2020.
- However, rather than reflecting a declining eLCV market in Europe IDTechEx believe this move is an indication of its growing strength.
- DHL failed to find a suitable electric vehicle in 2012, so effectively built their own. With the increasing entry of OEMS into the into the eLCV market (Daimler; VW; Ford in 2021) it is no surprise that DHL have decided that they cannot compete.
- Last year StreetScooter made around 100 million euros in losses.
- StreetScooter is simply no longer a necessary part of Deutsche Post's fleet electrification plans (which remain unchanged). There are now eLCV options available, with more to come, that were not there in 2012 and which are considerably cheaper.
- Whilst the base price for the Streetscooter is > $50k, the Kangoo Z.E and e-NV200 both are under < $35k.
- Having failed in attempts to find a buyer for the business, Deutsch Post have decided to end production. This also ends planned joint venture cooperation with Chinese manufacture **Chery**, who had looked likely to buy the company.
- Though it would seem the end of StreetScooter, their ground-breaking work in demonstrating the strengths of electric platforms for last-mile delivery, at a fleet scale, have laid the foundations for others to follow. They simply could not manufacture the vehicle at a cost competitive price versus existing OEMs.

Source: DHL

2019 Rise of the large eLCV?

A notable trend in 2019 was the growth in registrations of larger electric LCVs. Where the market had previously been restricted to primarily smaller models, 2019 marked the start of fleet piloting of larger electric models, that offer companies greater payloads

RENAULT
Passion for life*

- **Renault Master Z.E.** – Registrations **177** (2018) → **384** (2019)
- Range 200 km (WLTP), 33kWh Battery, 57kW Motor, Cost $76k
- Real world range estimate 120km in summer, 80km in winter

LDV

- **SAIC LDV EV80** – Registrations **330** (2018) → **442** (2019)
- Range 193km; 52kWh Battery; 92kW Motor; Cost $70k
- LDV to be rebranded as MAXUS by Chinese owner SAIC

Commercial Vehicles

- **VW e-Crafter** – Registrations **70** (2018) → **597** (2019)
- Range 173km (NEDC); 35.8kWh Battery; 100kW Motor; Cost $68.5k
- e-Golf battery and motor (repurposed) – Same as the MAN eTGE
- VW suggest typical crafter covers 65-95 km per day, 50-100 stops

MAN

- **MAN eTGE** – Registrations **21** (2018) → **120** (2019)
- Range 115km (WLTP); 35.8kWh Battery; 100kW Motor; Cost $75k
- MAN suggest eTGE TCO equivalent to diesel TGE in 4-years

Sources: MAN, LDV, Renault, VW, autocar.co.uk, EAFO

Movers 2019: Daimler enter the fray

PEUGEOT

CITROËN

- Mercedes e-Vito first deliveries in 2019 - **543** registrations
- Range 150km (WLTP); 41.4kWh Battery; 85kW Motor; Cost $52k

- The e-Vito is Daimler's first electric LCV model.
- 41% of registrations were in Germany; 15.5% Norway; 10.5% Spain.
- To be followed by Mercedes-Benz eSprinter in 2020.
- Daimler has committed to making its passenger car fleet carbon neutral by 2039, and the entire company by 2050.

Peugeot Partner 1,123 registrations (**-29.4%**)
Citroën Berlingo 698 registrations (**-34.5%**)

Aside from the badge these are basically the same vehicle. Whilst the diesel equivalents have had a update a new version of the electric models is not due until 2021.

Toyota are collaborating with PSA to release an electric version of their PROACE on the same platform in 2021.

Increasing competition in the eVan market will see outdated models quickly lose market share

Sources: Mercedes, Peugeot, Citroën, Toyota, EAFO

Vastly increasing eVan model choice

ABT VW e-Transporter (2020)

SAIC LDV e-Deliver [EV30] (2020)

Mercedes eSprinter (2020)

Fiat Ducato Electric (2020)

Vauxhall Vivaro-e / Peugeot e-Expert / Citroen e-Dispatch (2020)
Same electric-drive specification.

Peugeot Electric Boxer / Citroen Relay Electric (2020)

Dongfeng Sokon (DFSK) EC35 (2020)

Ford Transit All-Electric (2021)

Source: LDV, ABT, Mercedes-Benz, Fiat, Ford, Parkers, Citroën

New e-LCV models

- Major players Ford, Daimler, Fiat (who make up around 1/3rd of the total LCV market) have now entered the eLCV market.
- The past 12-months has seen a significant expansion in model choice in the eLCV market
- Whilst all other large OEMs have gone for all-electric powertrains Ford have chosen to enter the market with a plug-in hybrid model (to be followed by an all-electric Transit in 2021).

Source: insideevs.com

Fiat Ducato Electric (Due 2020)

Power (kW)	90
Battery (kWh)	47 or 79
Payload (kg)	1900
Range (km)	220 - 360

Mercedes eSprinter

Rated Power (kW)	85
Battery (kWh)	41 - 55
Payload (kg)	1040 - 900
Range (km)	115 - 150

Source: electrek.co

Source: ford.co.uk

Ford Transit Custom PHEV

Rated Power (kW)	92
Battery (kWh)	14
Payload (kg)	1000
Electric Range* (km)	48

* Ford EcoBoost 1.0-litre petrol engine in series configuration increases the range to 500km

Ford Transit Custom PHEV

The Transit Custom PHEV uses a series-hybrid driveline configuration, with the vehicle's wheels driven exclusively by an electric motor, rather than by a combustion engine. The arrangement allows a 1-litre petrol engine to provide the necessary charge to the battery to power the electric drive.

The vehicle has an all-electric drive mode with a range of approximately 50km, where the petrol engine is switched off, in order to allow the vehicle to travel in a zero-emission mode.

This offers an efficient solution where a significantly greater daily mileage is required, but will only be a bridging technology until ever more stringent emission legislation dictates entirely zero emission.

Ford has also announced its intention to release a fully electric version of the transit.

Source: ford.co.uk

Available PHEV LCVs

Mitsubishi Outlander PHEV Reflex Commercial Vehicle

2.4L petrol engine + 2 electric motors (60kW front axle, 70kW rear axle), engine connects to 77kW generator but can drive the wheels directly. 13.8 kWh battery; all-electric range 45km; 500kg payload; cost $46k .

SUV but with the rear seats removed and rear windows blanked out

Mitsubishi have sold the Outlander PHEV **since 2014** – 227 registrations in 2019

Most sales in the UK – Plug in LCV Grant + exempt from London congestion, ULEZ charges

- **Ford Transit Custom PHEV – First deliveries 2020**
- 92.9kW electric motor (front axle) + 1.0L petrol engine range extender. Wheels driven exclusively by the electric motor, engine charges battery. 13.6kWh Li-ion battery; 1,130kg payload; all-electric range 55km; Cost $55k .
- Greater range but around 80% more expensive than equivalent diesel transit

- **LEVC VN5 Electric LCV – Production starts November 2020**
- 120kW electric motor (GKN Driveline eAxle) + 1.5L petrol engine range extender. Battery powers the motors, range extender only charges the battery. 31kWh Li-ion battery; 800kg payload; all-electric range 102km (WLTP); Cost around >$60k .
- A subsidiary of Chinese manufacturer Geely, who also own Volvo cars.
- Suggested fuel saving £110 per week / £27,000 over 5-years.

Source: Mitsubishi, Ford, LECV, The Engineer, Insideevs

Plug-in hybrid LCVs

- As detailed in the previous slide, Ford, Mitsubishi and LEVC are offering (or will offer) plug-in hybrid light commercial vehicles. The rational behind them lies in the greater flexibility that PHEV architecture offers; as an ICE engine within the vehicle powertrain is able to act as a generator to charge the battery, increasing the vehicles range and decreasing its dependence on available charging infrastructure. They also offer a short zero-emission range, which, to a degree, future proofs them against emission / congestion charges in urban centres. However there are a number of reasons why we feel that PHEV technologies are not suited to the LCV market and hence why PHEV LCV will have limited penetration.

  - **PHEVs are not a zero-emission solution:** countries looking to impose sales bans on ICE vehicles may in the future prevent the sale of all ICE vehicles whether the powertrain is hybrid or not, creating uncertainty for those developing PHEVs. The emission reduction potential of PHEVs, 15-55% compared to conventional vehicles, is unlikely to be as attractive as BEV LCV models to fleet purchasers, where their goal is to reduce CO2 emission to meet internal company targets. As a consequence, no major LCV OEMs outside of Ford offer (or as far as IDTechEx are aware, are developing) a PHEV LCV model.
  - **Fleet operators understand their daily duty requirements**: in many LCV applications there is little need for the flexibility of extra range (unlike cars, taxis, and long-haul trucks). Research suggests that a significant percentage of the LCV market have a daily range requirement of less than 100 km per day and depart from and return to a depot. In short range applications where a PHEV LCV would almost exclusively use only the electric range, then they would be needlessly carrying the extra weight of an ICE engine, and the demand could be met by a BEV. Moreover, LCV fleet operators have the data to plan their operations and charging schedule to optimise the use of battery-only LCVs. In the case where the range cannot be met, the operator will likely continue to purchase an ICE LCV until a ban prevents this, by which time (in most countries) battery and charging technologies (and potentially in the longer term FCEV technology) will have advanced enough to deliver longer daily duty ranges.
  - **Hybrid systems are complex:** as PHEV powertrains combine both EV and ICE parts this requires maintenance and servicing of both technologies. Therefore PHEVs will not offer the same reduced maintenance benefit that BEVs offer over ICE vehicles and given the complexity could potentially be more expensive and less reliable than ICE LCV.

- The current niche for PHEV LCV appears to be for those operators who do more than 100 km a day and regularly drive through city centres with low-emission zones. We believe is a very small percentage of the LCV market which will dwindle as powertrain technology improves range in the coming years. The proof will be in the sales performance of the Ford PHEV. We are not aware of any other major OEMs currently developing PHEV LCVs, all others have transition from ICE straight to BEVs.

2020 Large Orders for eLCV

Jan 2020 — UPS → Arrival: **10,000** Arrival electric LCVs

Feb 2020 — dpd → Nissan: **300** Nissan e-NV200

Feb 2020 — dpd → MAN: **100** MAN eTGE

July 2020 — British Gas → Vauxhall: **1000** Vauxhall Vivaro-

Aug 2020 — openreach → Vauxhall: **270** Vauxhall Vivaro-e

Aug 2020 — amazon → Mercedes-Benz: **1200** eSprinter, **600** eVito

A New Arrival

Arrival is an electric commercial vehicle start-up headquartered in London but whose main R&D facilities are in Oxfordshire. They have a team of around 1,000 employees in five countries (UK, US, Germany, Russia and Israel), and have grown rapidly over the past year. In January 2020, an investment of 100 million euros ($112 million) by Hyundai and Kia valued the company at over $3 billion making it one of the UK's largest 'unicorn' start-ups. In the same month, a 400 million euro ($450 million) order by UPS, for 10,000 of its 4-tonne electric LCVs, confirmed them as a company to watch.

The Hyundai-Kia investment is a strategic partnership. Hyundai and Kia will have access to Arrival's electric platform, technologies, and software to accelerate the development of a range of electric vehicles. Arrival will benefit from Hyundai Motor Groups' global presence and economies of scale.

Arrival manufactures the core components of its vehicle; the chassis, powertrain, body and electronic components.

The global logistics giant UPS has also invested in the company and placed an order for 10,000 LCVs to be deployed in Europe and US. Delivery is expected between 2020 and 2024, with UPS holding an option for a further 10,000 vehicles.

Arguably the most difficult step still remains for Arrival, which is to demonstrate that it can manufacture its vehicle at volume and competitive cost. However, The investment and collaboration with major partners, is recognition that there is significant potential for ground-up innovation in the eLCV market. Arrival's skateboard platform may offer substantial advantages over competitors who are simply utilising electric powertrains on traditional LCV chassis.

Sources: Arrival, UPS, Hyundai

Arrival’s Business Model

Arrival's focus is on the commercial vehicle market with the aim of delivering an electric vehicle at the same (or lower) price than an equivalent fossil fuel vehicle: approximately £35,000 ($43,500). They call this a Generation 2 electric vehicle, designed to outperform comparable fossil-fuelled LCVs, being both cheaper and offering the driver a much-improved experience.

Arrival have designed the vehicle from the ground up, with a strategy for it to be manufactured robotically in individual cells. The LCV will be built in micro-factories of around 10,000 sqft, producing about 10,000 LCVs a year. Rather than having a centralised production facility that ships globally, Arrival intend to build these in micro-factories at locations close to demand. The facility size means that production at a location can be up and running in three to six months. Arrival suggest the advantage of this micro-factory model is that it can achieve profitability at relatively low production volumes.

In May 2020 it was announced that Arrival had acquired an additional 30,000 sqft facility in Bicester, Oxfordshire for composites production. This expands the 120,000 sqft manufacturing facility leased in February 2020 at the same location. Arrival are expecting the facility to be operational in 2021, producing 10,000 vehicles a year. They have other facilities in Banbury and Reading in the UK and one in New Jersey in the US.

They have trialled their vehicles with Royal Mail, UPS, BT, DHL and John Lewis.

This partnership echoes that of Ford with US electric vehicle start-up Rivian. With a large OEM investing significant capital into an innovative start-up developing a skateboard platform. This is likely recognition that ground-up design for electric commercial vehicles can offer substantial advantages over squeezing electric powertrains onto existing LCV model chassis.

Source: engadget, guardian, Forbes, arrival.com

Specifications of eLCVs available in Europe

OEMs in Europe will soon be offering the full spectrum of light, medium and large LCVs in electric versions. All will be fighting for their market share. Driver for LCV transition to electric is emission regulation in the short-term, and TCO in the medium-term.

Key specs	Nissan E-NV200	Peugeot Partner Electric	Citroen Berlingo Electric	StreetScooter Work	Renault Kangoo Z.E.	StreetScooter Work L	Iveco Daily Electric	VW E-Crafter	Renault Master Z.E.	Mercedes eVito	SAIC MAXUS EV80
Battery type	Li-Ion 40 kWh	Li-Ion 22.5 kWh	Li-Ion 22.5 kWh	Li-Ion 40 kWh	Li-Ion 33 kWh	Li-Ion 40 kWh	Li-Ion 60 kWh	Li-Ion 36 kWh	Li-Ion 33 kWh	Li-Ion 41 kWh	Li-Ion 56 kWh
Range	~280 km	~170 km	~170 km	~232 km	~270 km	~187 km	~280 km	~175 km	~200 km	~189 km	~200 km
Payload	700 kg	591 kg	695 kg	585 kg	625 kg	905 kg	700 kg	970 kg	1128 kg	1015 kg	950 kg
Load volume	4.2 m^3	3.7 m^3	3.3 m^3	4.3 m^3	3.5 m^3	8 m^3	7.3 m^3	11 m^3	8 m^3	6 m^3	10.2 m^3
Vehicle weight	2.25 t	2.225 t	2.225 t	2.18 t	2.13 t	2.6 t	3.28 t	3.5t	3.1t	3.2t	3.5 t
Base price[1]	€34,105	€25,335	€24,978	€48,730	€33,180	€54,085	~€70,000	€82,747	€59,900	€47,588	Only rent options

Source: Arthur D. Little research, OEM websites

e-LCVs in Europe: compact utility vehicles

Small electric utility vehicles, are also seeing some uptake around Europe, primarily in municipal fleets.

Goupil G4

Source: goupil-ev.com

Piaggio Porter

Source: piaggiocommercialuk.com

Ligier Pulse 4 L3

Source: ligier-professional.fr

Goupil G5

Source: goupil-ev.com

Alkè ATX

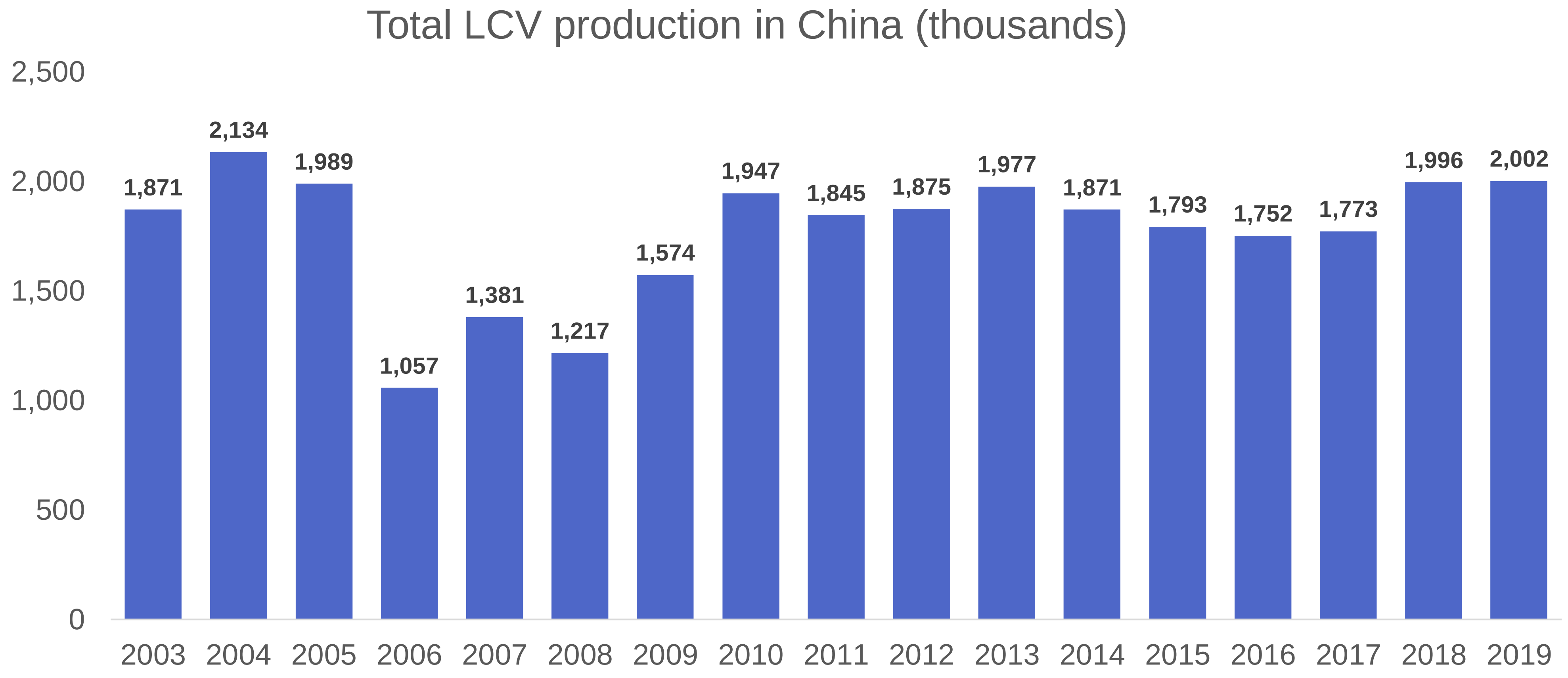
Source: alke.com

UK Electric Fleets Coalition

- In June 2020 the ‘UK Electric Fleets Coalition’ was formed as an alliance of 21 companies, led by BT Group. The Coalition comprises some of the UK’s biggest LCV fleets, collectively operating over 400,000 LCVs and cars in the UK.
- The Coalition has recommended a package of measures to boost the uptake of electric vehicles. This includes moving forward the UK target for 100% electric new car and LCV sales to 2030; stimulating eLCV supply with a zero-emission production mandate for vehicle manufacturers; driving eLCV demand and encouraging investment in infrastructure.
- Whilst part of the driver behind these actions is green credentials, it also is evidence that eLCVs are increasingly able to offer companies a competitive cost advantage generating significant demand from large businesses.

5. eLCVs in China

Chinese Market for LCVs

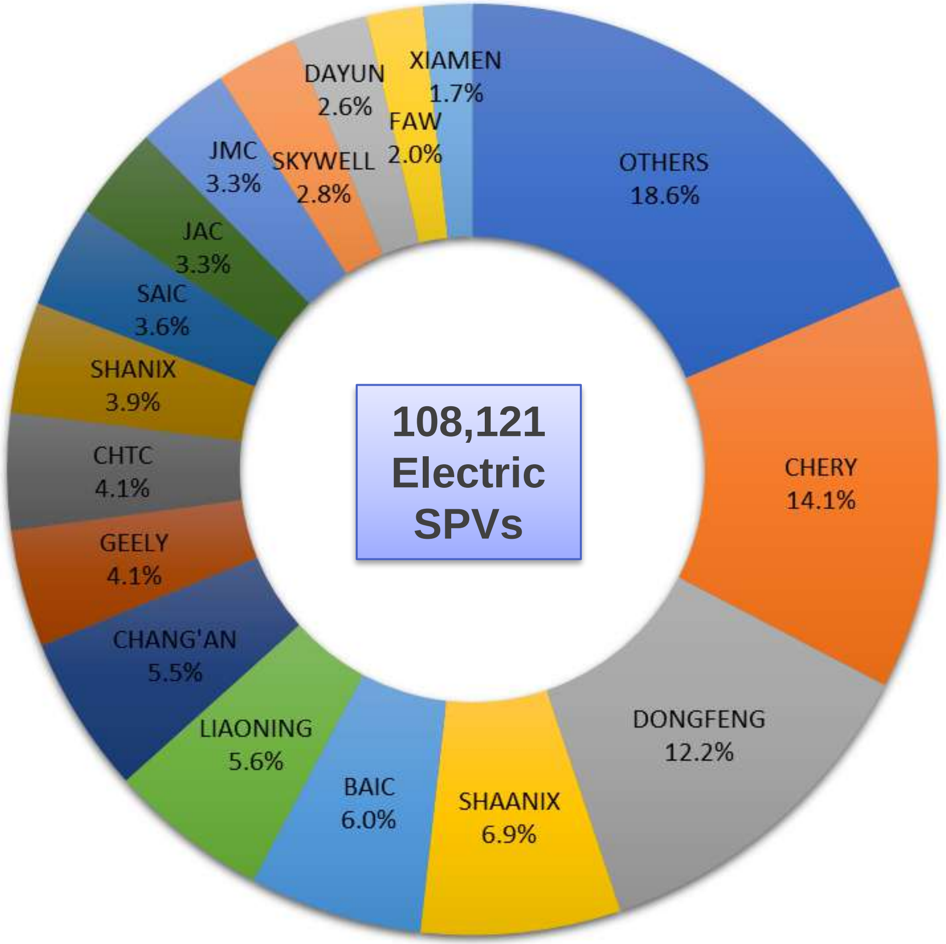


*Data excludes micro-LCV segment

Data Source: OICA / CAAM

China: Electric Special-Purpose Vehicle Sales 2018

2018 China Electric SPV Sales



Data Source: evpartner

Special Purpose Vehicle (SPV) incorporates LCVs, trucks, articulated vehicles and other vehicles, excluding passenger cars and buses.

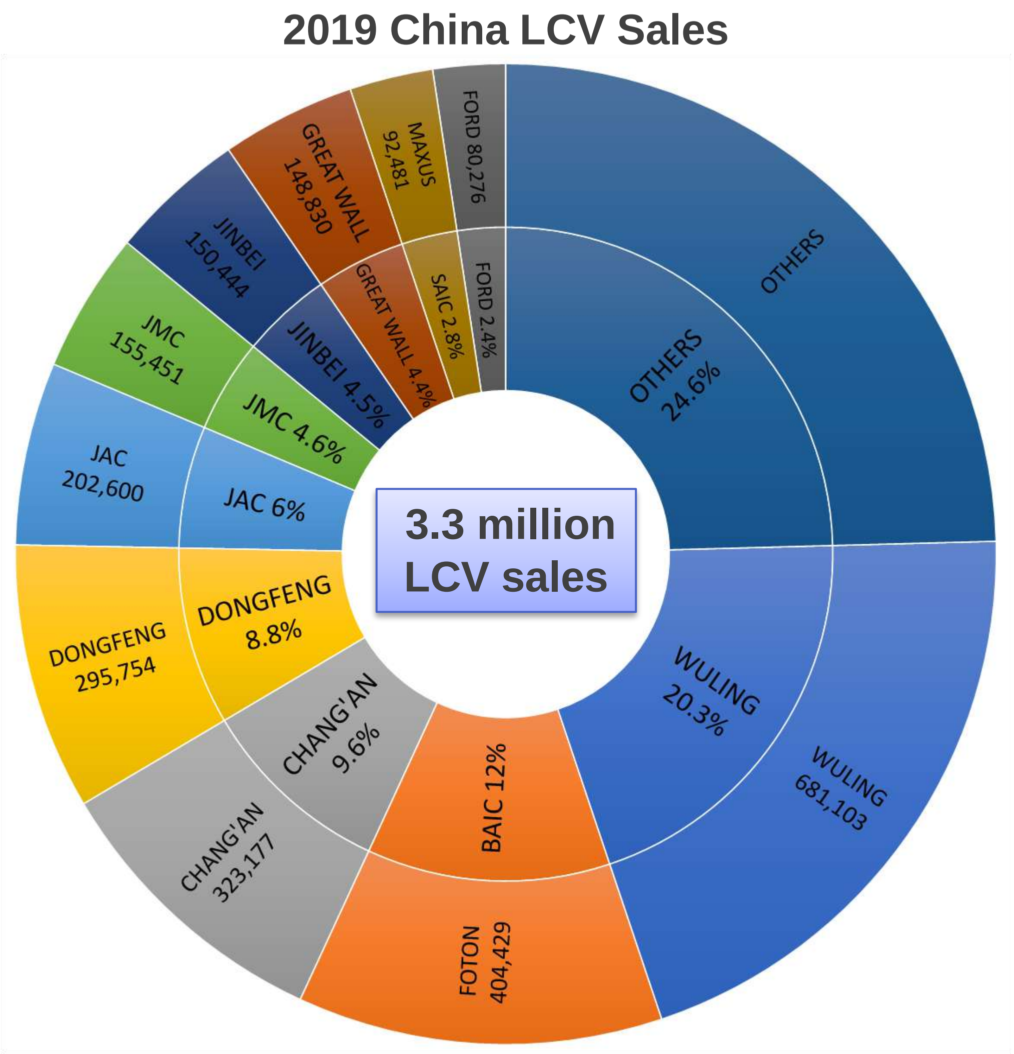
2018 Electric SPV Sales by Segment

Micro-LCV: 49% - 53,000 units
Light truck: 29% - 32,000 units
Full-size LCV: 11% - >11,000 units
Mini-truck: 10% - <11,000 units
Heavy-duty truck: 200 units
Other electric SPV: 1000 units

Data Source: evpartner.com (孙玉瑞)

- Total 2018 Electric SPV Sales: **108,121**
- Total 2018 LCV Sales: **3,360,718**

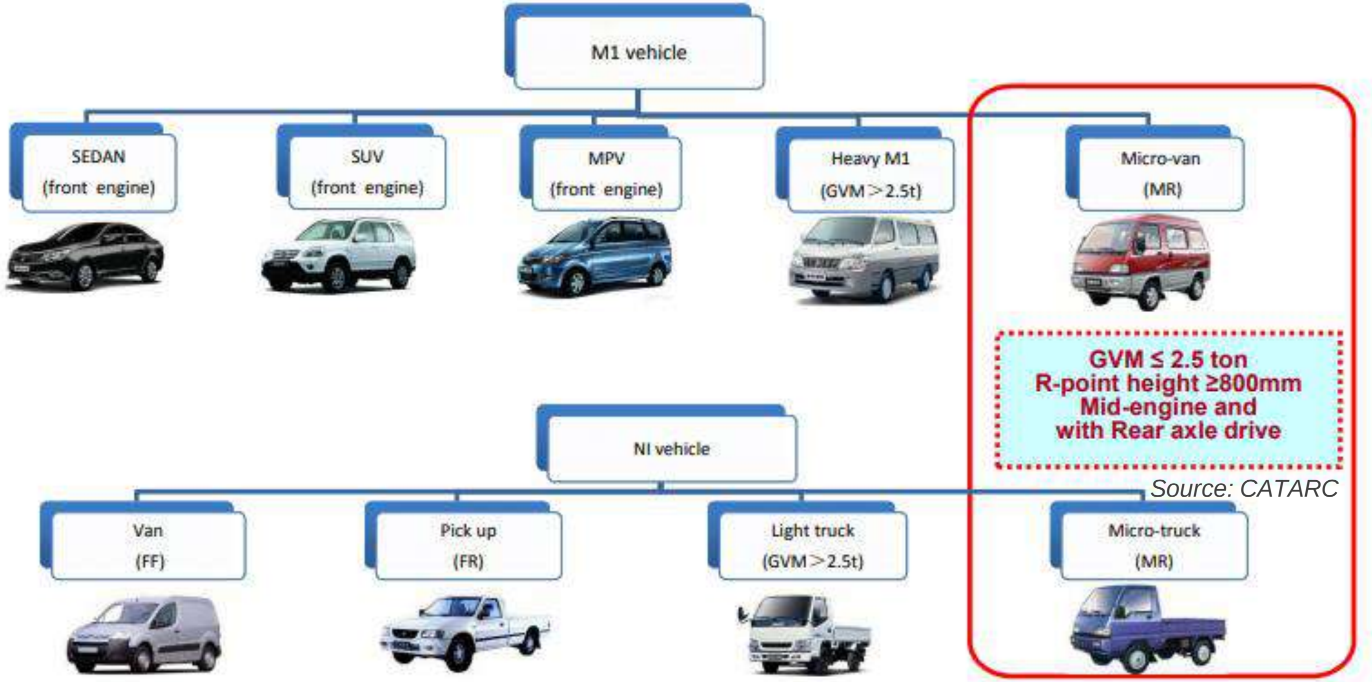
China: Commercial Vehicle Sales 2019



Data Source: LMC AUTOMOTIVE / CAAM

With more than 460 vehicle makers, China's commercial vehicle market is more highly fragmented than the consolidated large Western markets.

The LCV sector figures are difficult to disaggregate. Micro-LCVs (<2.5 tonnes) which are used for a variety of construction, logistics and agricultural purposes are usually incorporated into the passenger vehicle category statistics.



Source: CATARC

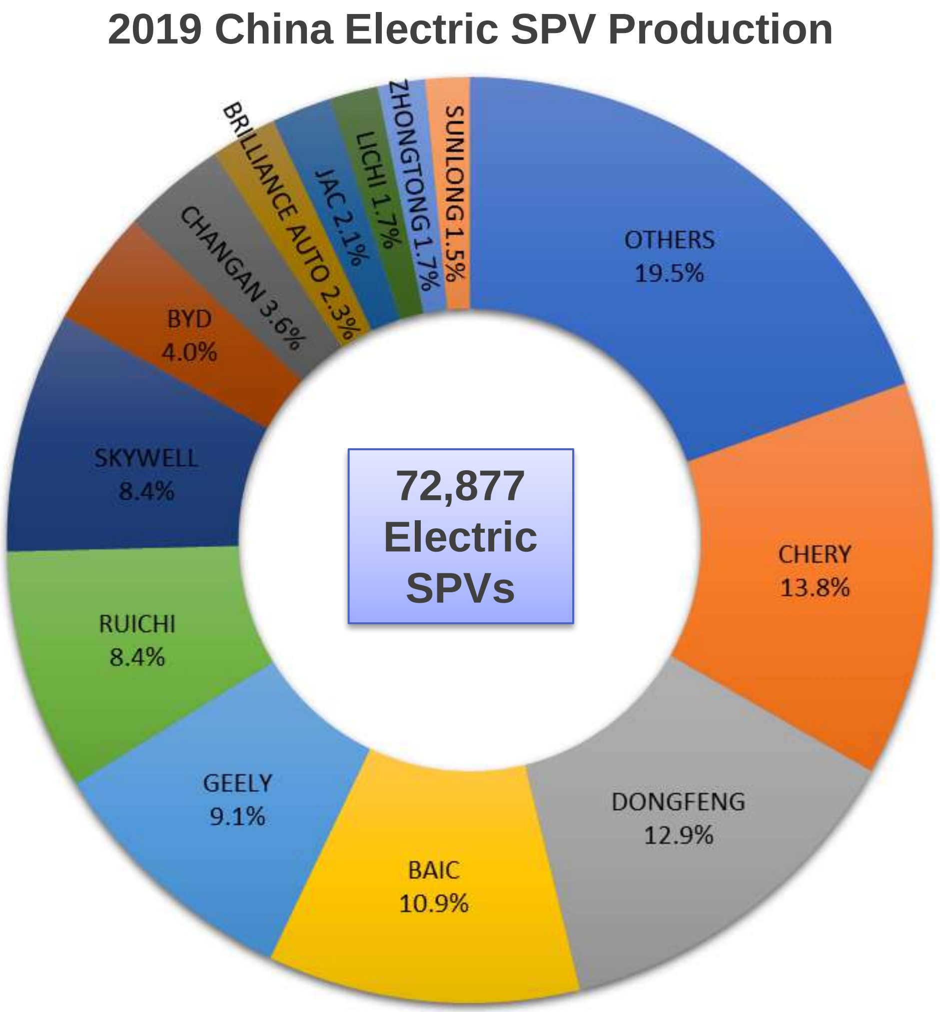
China: SPV Production 2018 Top 15 Manufacturers

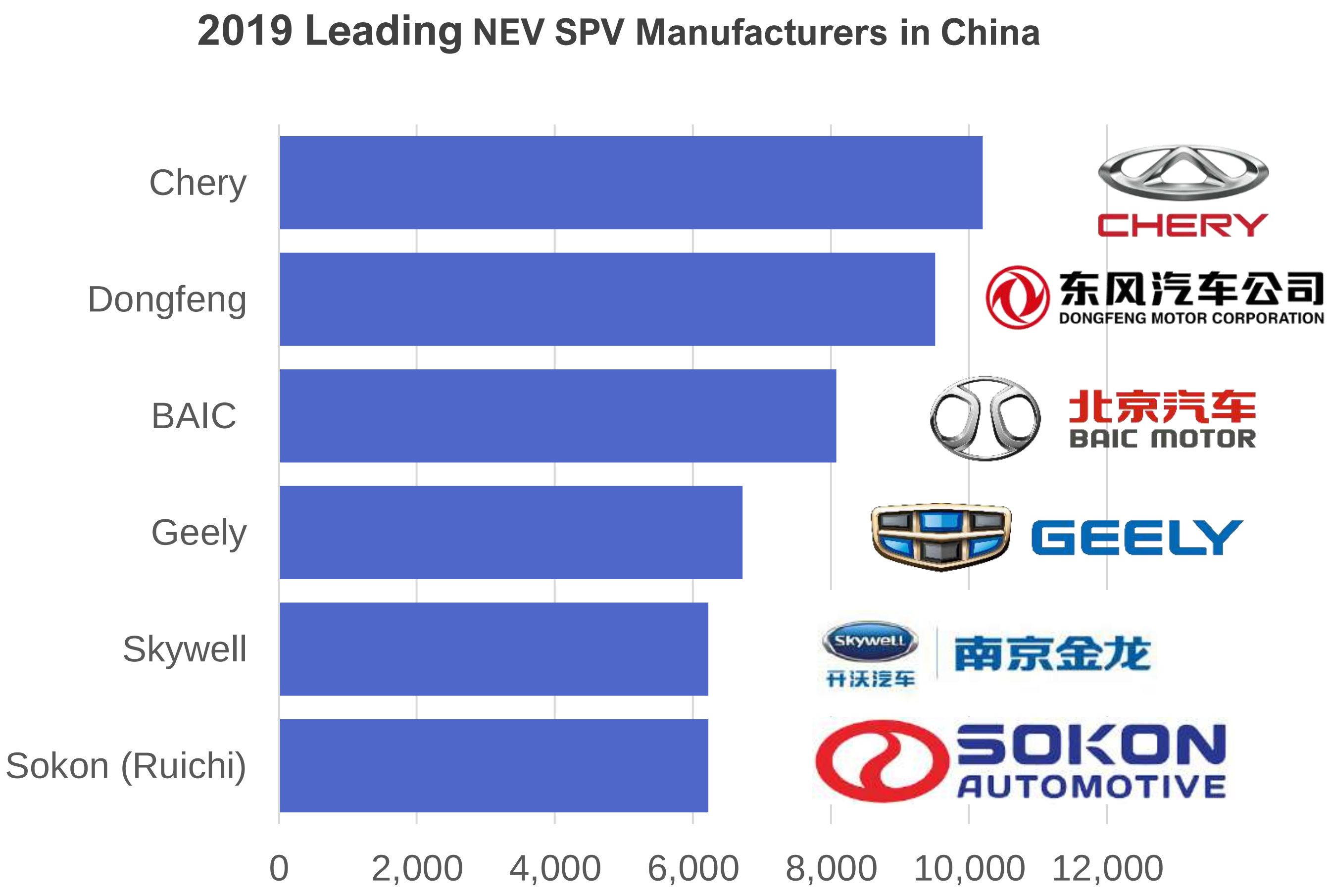
A mixture of private companies and subsidiaries of large state-owned commercial vehicle brands. Like other vehicle sectors in China there is a significant drive towards the electrification of commercial vehicles.

130 Chinese companies manufactured and sold electric SPVs in 2018

Data Source: evpartner.com

China: Electric SPV Production 2019





Data Source: evpartner.com

IDTechEx Research

China NEV eLCV production / sales fall in 2019

In 2019, the production of New Energy (NEV) Special Purpose Vehicles (SPVs) decreased by 35.3% to 72,877 units.

SPVs include vehicles employed in freight transport, construction, logistics, emergency services and sanitation. This incorporates, micro-LCVs, full-sized LCVs, mini-trucks, light-trucks, heavy-duty trucks along with more niche SPVs.

Approximately 92% of the produced NEV SPVs were logistics vehicles (67,900 units), 6% sanitation vehicles and 2% other. A majority of NEV SPV are LCVs and light trucks.

Decline in the market is due to: reduced subsidies applied in July 2019 for EVs in China, which for N1 trucks (<3,500kg) decreased from 750 yuan ($105) to 350 yuan ($50) per kWh battery capacity.

The eLCV market in China is now largely reflecting real eLCV demand rather than subsidy driven demand

Electric SPV Production (Units)

2017		2018		2019
156,273	↓ 27.9%	112,607	↓ 35.3%	72,877

Electric SPV Sales (Units)

2017		2018		2019
151,887	↓ 28.8%	108,121	↓ 42.8%	61,858

eLCV Sales (Units)

2017		2018		2019
82,019	↓ 13.0%	71,360	↓ 33.0%	47,835

Source: Tram resources, Evpartner, Interact

Best selling new energy LCVs in China

There are several hundred companies which produce NEV SPV, however only 20 of these produced more than 1,000 vehicles in 2019

Karry (Chery) Youyou
40kWh LFP battery (Gouxuan);
30kW motor (PMSM)
2.6t GVW, 990kg payload; 254km range

Price 110k yuan ($16.5k)
before incentives

≈ 7,000 sales in 2019

Ruichi (Sokon) EC35II
41.4kWh LFP battery (CATL); 2.51t GVW;
30kW motor; 960kg payload; 233km range.
Ruichi is a subsidiary of Chongquing Sokon Industrial Group whose joint venture with Dongfeng, “DFSK”, is looking to sell the EC35 in the UK.
Price 120k yuan ($18k) before incentives

≈ 6,000 sales in 2019

Changhe (BAIC Group) - EV5
32.3-43 kWh LFP battery (Guoxuan);
30kW motor; 2.68t GVW,
1050 kg payload; 210 - 270km range

Price 104k–114k yuan ($15k-$17k)
before incentives

≈ 3,750 sales in 2019

Source: Evpartner, NDANEV

Best selling new energy LCVs in China

Dongfeng – Yufeng EM19
32 (Dongfeng Haibo) - 42 (CATL) kWh battery (LFP) ; 30kW motor; 2.55t GVW, 970 kg payload; 185-260km range

Price: 137k–146k yuan ($20k-$22k) before incentives

≈ 3,500 sales in 2019

Changhe (BAIC Group) – EV2 / EV100
8-10 kWh LFP battery; 6kW PMSM motor (Foton); 1.5t GVW, 715 kg payload; 103km range

Price: 35.8k–41k yuan ($5.5k-$6k) before incentives

≈ 1,800 sales in 2019

Nanjing Golden Dragon (Skywell) – Kaiwo D10
49.2 kWh Ternary Li (Youlion) – 52.5 kWh LFP battery (CATL); 47kW-55kW motor; 3.36t GVW, 1360 kg payload; 225km range
Price: 149k–159k yuan ($22k-$23.5k) before incentives

≈ 3,100 sales in 2019

Karry (Chery) - Dolphin EV
44.5kWh LFP battery (Guoxuan); 30kW motor; 1070kg payload; 251km range

Price: 145k–149k yuan ($21k-$22k) before incentives

≈ 1,600 sales in 2019

Source: Evpartner, NDANEV,

Popular Larger Electric LCVs in China

Source: evpartner.com

SKYWELL Nanjing Golden Dragon Kaiwo D11

Rated Power (kW)	70
Battery (kWh)	80.8 LFP (Youlion)
Range (km)	305
Mass GVW (kg)	4490
Payload (kg)	1595
Price ($)	37k - 38.5k

Source: chinatrucks.com

JAC Shuailing i6 Electric LCV

Rated Power (kW)	60 (Hefei Daoyai)
Battery (kWh)	92.16 LFP (Guoxuan)
Range (km)	430
Mass GVW (kg)	4495
Payload (kg)	1250
Price ($)	33.5k - 37k

Source: njgdbus.com

SAIC MAXUS EV80 Electric LCV

Rated Power (kW)	60
Battery (kWh)	53 - 71 LMO
Range (km)	180 - 230
Mass GVW (kg)	3760 - 4100
Payload (kg)	1400 - 1530
Price ($)	35k - 42k

Sources: evpartner.com, wattev2buy.com

China: Main Battery Suppliers to Chinese eLCVs

The Chinese Government has provided strong support to its automobile industry to promote the development of its electric automotive sector, with the aim of making it the global lead for electric vehicles. This support has seen the rise of significant companies across the supply chain.

Company logos from Wikipedia

Battery suppliers to the Chinese NEV SPV Market

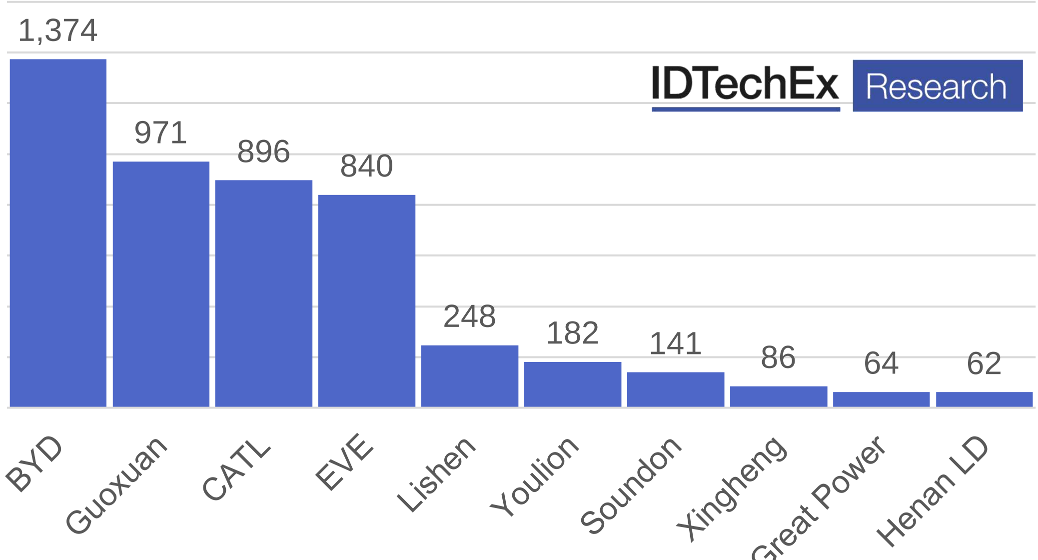
NEV special purpose vehicle installed battery capacity was 5.41 GWh in 2019 across all SPV segments.

118 companies provide batteries for this market, but 89% of supply comes from the top ten companies shown below.

SPV Segment	2019 Installed Battery Capacity (MWh)	Year-on-Year Change
Logistics	4,320	-32.2%
Sanitation	1,003	+650.0%
Other	89	+287.2%
SPV Total	5,411	-17.1%

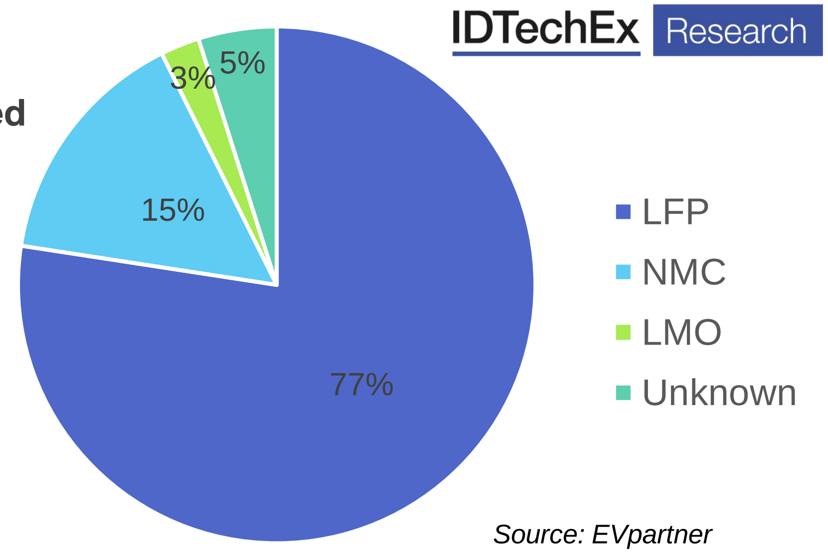
Source: China Power Battery Association

2019 Top 10 – Battery Suppliers to NEV SPV Installed Capacity (MWh)



Source: Gaogong Industry Institute GGII

2019 SPV Installed Battery by Type



Source: EVpartner

China: Main Motor Suppliers to Chinese eLCVs

Examples of motor suppliers to the eLCV market.

Zhejiang Lutong

Drivers for the electrification of LCVs in China

The International Organisation of Motor Vehicle Manufacturers (OICA) gives a figure of ~27 million commercial vehicles in-use in China (2017) across light, medium and heavy-duty sectors. The ratio of new sales to in-use fleet is ~ 7, which indicates significant influx of new vehicles into the market.

Like Europe, the move toward low emission vehicles is being driven by concerns over air quality in major urban centres. eLCV uptake will be in part driven by the introduction of increasingly stringent national and local environmental protection policies. China's Clean diesel action plan 2018-2020, was launched in January 2019, with the goal to substantially clean up diesel powered fleets.

Targets for China's Clean Diesel Action Plan 2018-2020

- > 90% of diesel vehicles should be compliant with current emission standards
- Implementation of China VI emission standards by July 1st 2019 in 12 key regions and by 2021 nationally
- Eliminate 1 million pre-China IV diesel trucks by 2020
- Promote the uptake of electric vehicles, through subsidies and road-access privileges
- 80% of new urban vehicles should be EVs by 2020 in key regions – including buses, postal, light delivery trucks.

City Targets

- Beijing (pop. 21.5 Million) has announced its aim to have 90% of new purchases of <4.5 tonne trucks as electric vehicles by Q4 2020. (Aug-19)
- Shanghai, Tianjin and 8 other cities, along with the provinces of Anhui, Henan, Shandong, Guangdong and Zhejiang remove traffic limits on electric micro- and light trucks, with the provinces subsidising the replacement of diesel trucks with electric. (July-19)
- Guangzhou (pop. 15 Million) has mandated that >70% of new light trucks purchased by courier and logistic companies must be electric vehicles and are working with police to create delivery zones that can only be accessed by EVs. (Aug-19)

Market Outlook: China eLCVs

Key Regions for the Clean Diesel Action Plan

Source: ICCT

- Increasing emission standard restrictions
- Purchase incentives for eLCV at both regional and central government levels
- Development of both eLCV industry and supply side
- China's Clean Diesel Action Plan 2018-2020 stipulates a target that **by 2020, 80% of new urban vehicles should be EVs in key regions** (source theicct.org)

Potential in the relatively short term to see a boom in e-LCV sales in China akin to the uptake of electric buses.

China to support e-SPV sales in 2nd and 3rd Tier Cities

The pattern of increasing share of NEV SPV sales in Tier 2 and Tier 3 cities in China looks likely to continue, as the Chinese Government supports efforts in these places to see 50% of new or replacement logistics vehicles as NEV or National VI emission standard compliant by the end of 2020.

China NEV SVP Percentage of Sales by City Tier

City Tier	2017	2018	2019	Jan 2020
1st	43.7%	35.5%	36.8%	26.0%
2nd	25.4%	28.4%	31.8%	31.9%
3rd	13.3%	15.5%	13.3%	16.6%
4th	11.8%	15.6%	14.4%	13.1%
5th	5.8%	5.1%	3.7%	12.5%

Source: China Passenger Car Association (CPCA)

IDTechEx

BAIC EV5 with UV disinfection to counter covid-19

In response to the coronavirus pandemic BAIC have released a version of their EV5 electric LCV equipped with a UV disinfection function.

UV sterilization lamps have been installed in the cargo box. The 30W lamps, with an irradiation intensity of 70μW per cm² for objects within a meter, emit short-wave UV which “destroys the molecular bonds that hold the DNA of viruses and bacteria”. BAIC suggest it takes around 24 minutes to sterilize the cargo area.

By mid-February, 24 BAIC EV5 UV disinfection vehicles have been deployed in Wuhan, Xiaogan, Huanggang, Zhengzhou, Nanyang, Xinyang, Beijing, Hangzhou, Ningbo, Wenzhou, Taizhou, Changsha, Yueyang, Chenzhou, Shaoyang, Shanwei, Chaozhou.

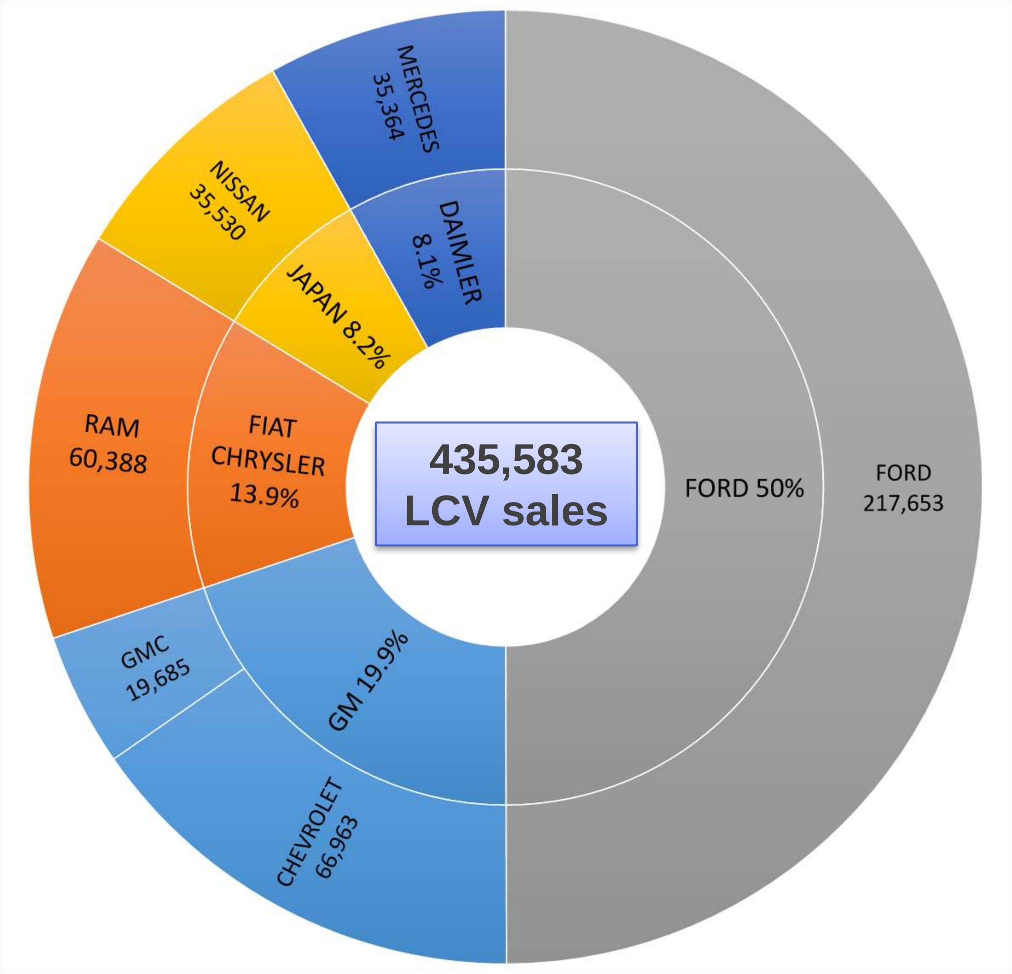
Whilst the current outbreak of the coronavirus may encourage operators to seek ways in which they can ensure that goods can be delivered uncontaminated and the UV cleaning technology has been deployed in other areas for many years, it is also a health hazard. Human exposure has been linked to skin cancer and cataracts, and humans should not be present when it is used in room cleaning applications. It would need to be determined that this technology was not detrimental to the health of the driver.

Source: Tram Resources, Insider.com

6. eLCVs in the US

US: Commercial LCV Sales 2018

2018 US LCV Sales



Source: goodcarbadcar.net

In the US, the LCV market for LCVs is smaller than Europe and China. This data focuses exclusively on LCVs. passenger pickup trucks are a very large share of the LCV market, but there is significant crossover between private and commercial use of these vehicles.

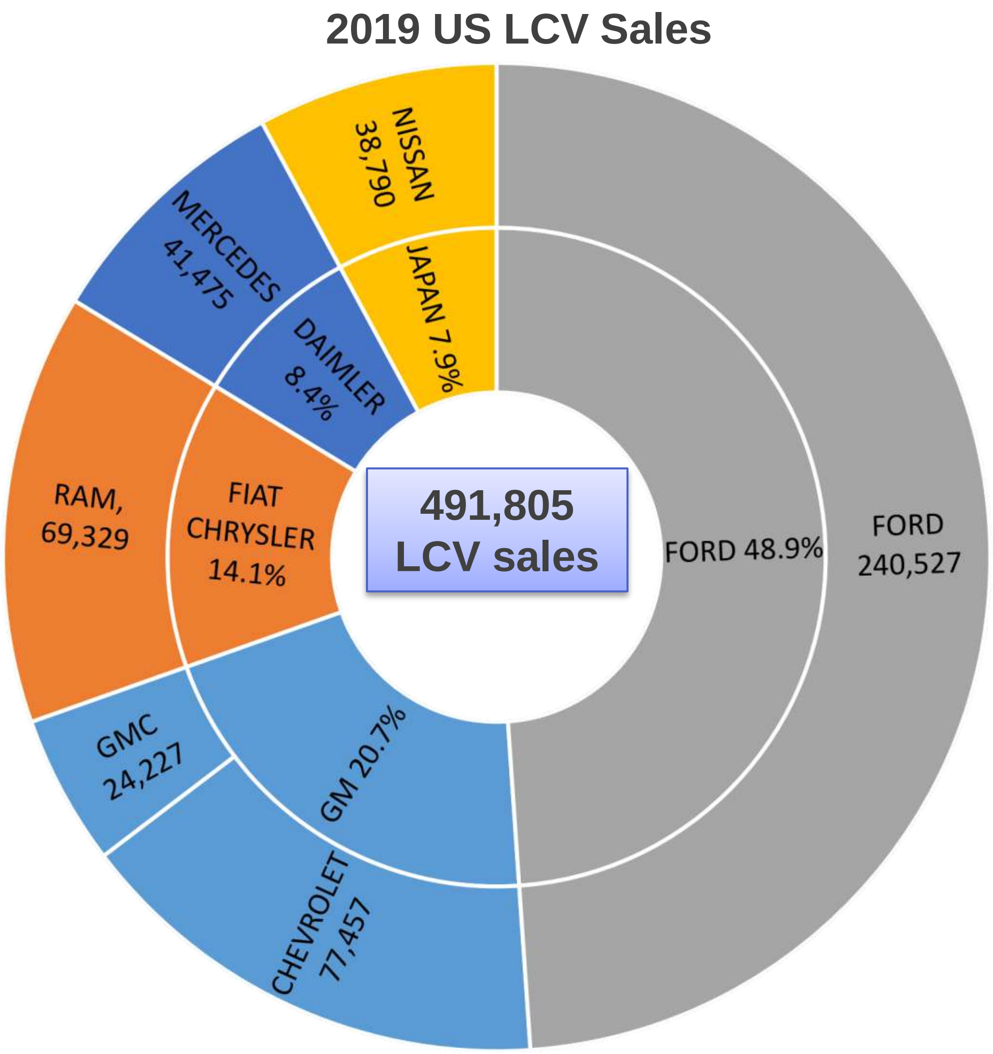
LCV Fleet in the US:

- Total 2018 LCV Registrations: 435,583
- US LCV Fleet (2017): 16,222,359 (Source: FHWA)

Top-Selling LCV Models in the US (2018)

- Ford Transit – 127,360 (31.6%)
- Chevrolet Express – 66,963 (15.4%)
- Ford E-Series – 47,936 (11.0%)
- Ram ProMaster – 46,600 (10.7%)
- Ford Transit Connect – 31,923 (7.3%)
- Mercedes-Benz Sprinter – 27,564 (6.3%)

US: Commercial LCV Sales 2019



Source: goodcarbadcar.net, FHWA

LCV Fleet in the US:

- Total 2019 LCV Registrations: 491,805
- US LCV Fleet (2018): 15,389,921 (Source: FHWA)

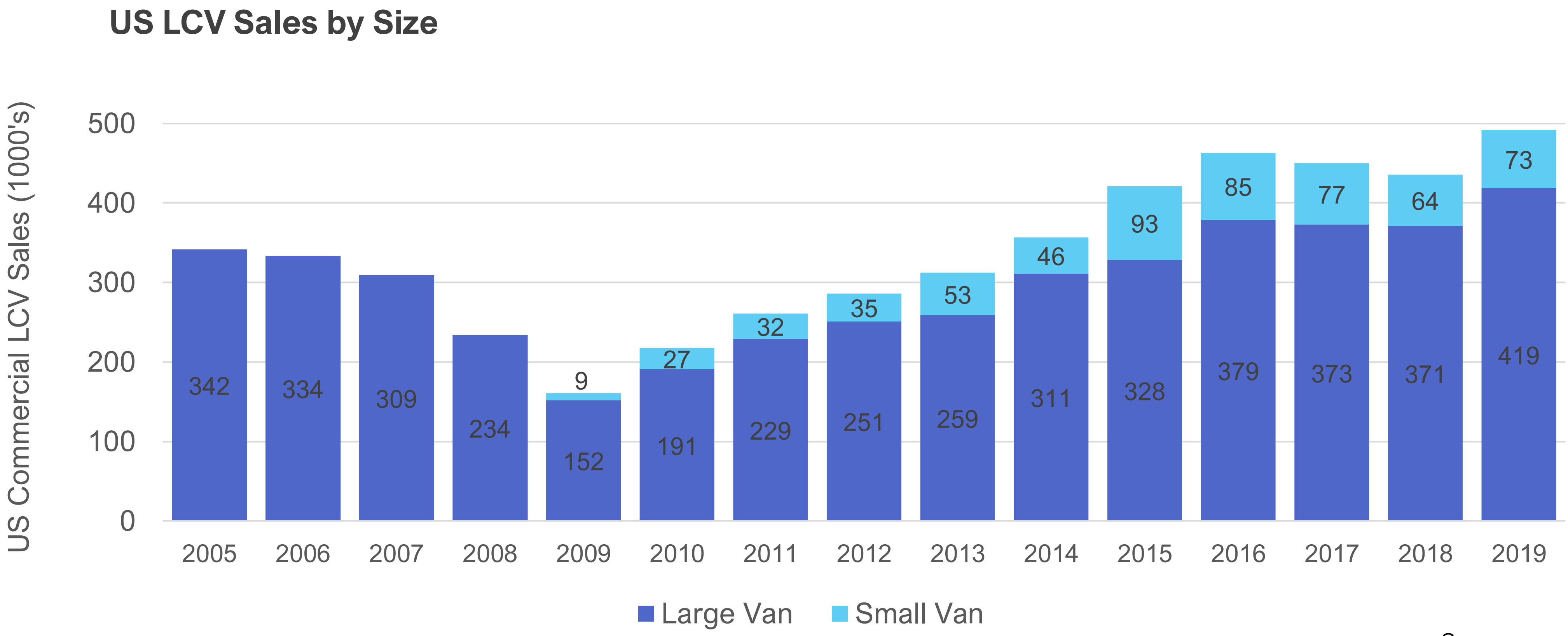
Top-Selling LCV Models in the US (2019)

- Ford Transit – 153,867 (31.3%, +20.8% YoY)
- Chevrolet Express – 77,457 (15.7%, +15.7% YoY)
- Ram ProMaster – 56,410 (11.5%, +21.1% YoY)
- Ford E-Series – 45,063 (9.2%, -6.0% YoY)
- Ford Transit Connect – 41,597 (8.5%, +30.3% YoY)
- Mercedes-Benz Sprinter – 29,757 (6.1%, (+8.0% YoY)

However, in 2019, none of the major commercial vehicle manufactures were offering an electric or hybrid electric version of their LCVs in the US

Growth in US commercial LCV sales

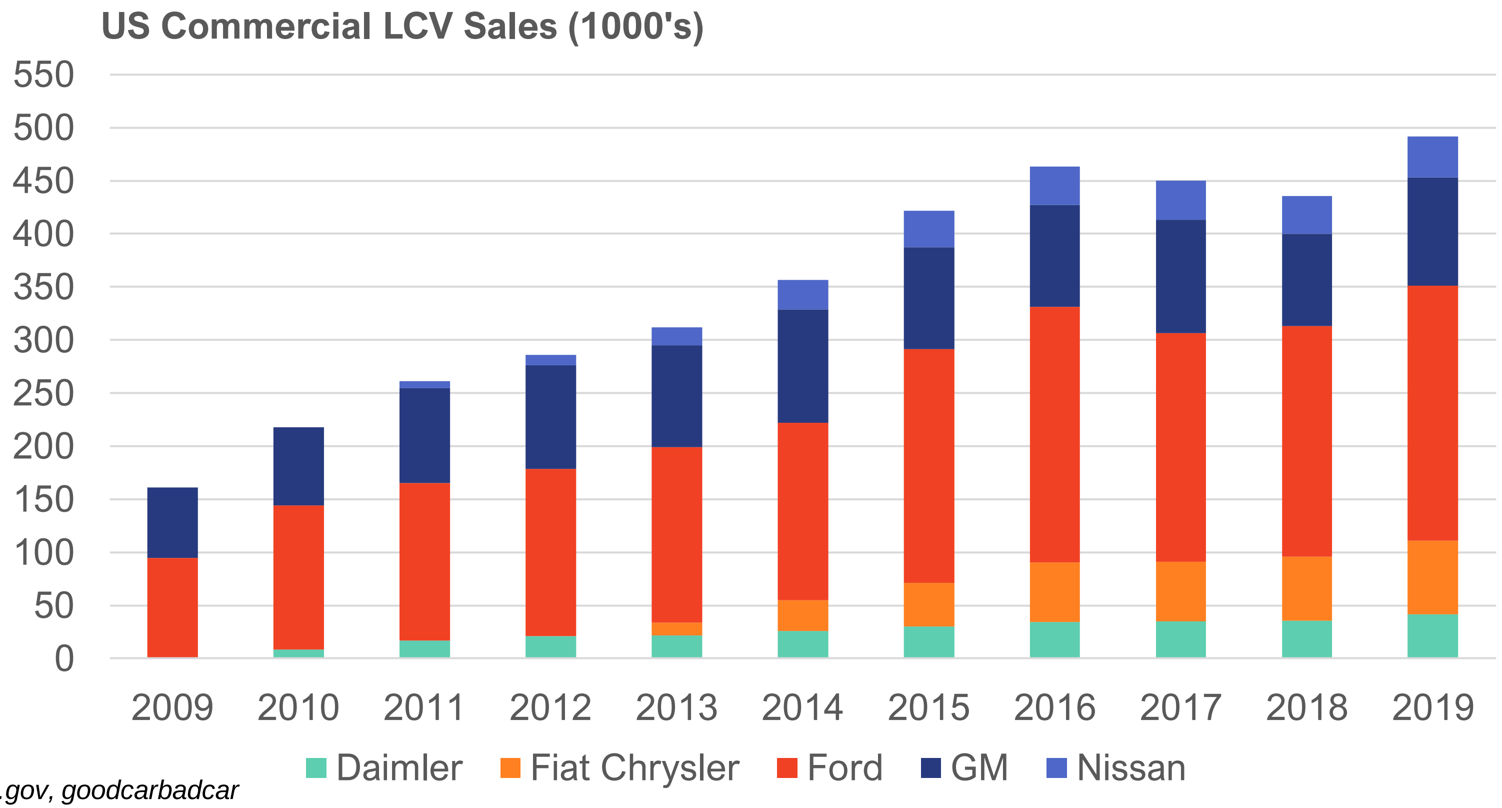
2019 was a very good year for commercial LCV sales in the US, rising from 435,500 units in 2018 to 491,800 units in 2019 (**+12.9%**)
Strong sales followed economic growth in the US, and a booming US e-commerce sector up 14.9% from 2018 to $601.7 billion.



Sources: census.gov, goodcarbadcar

US LCV Sales by OEM

The LCV market in the US is relatively small but growing, where in Europe LCV sales are only now approaching the pre 2009 economic crash levels, the US sales have increased above 2009 levels. Likely the result of increased online sales and the resultant expansion of logistics fleets. Ford hold 48.9% of the market, followed by GM on 20.7% and Fiat Chrysler at 14.1%.



Sources: census.gov, goodcarbadcar

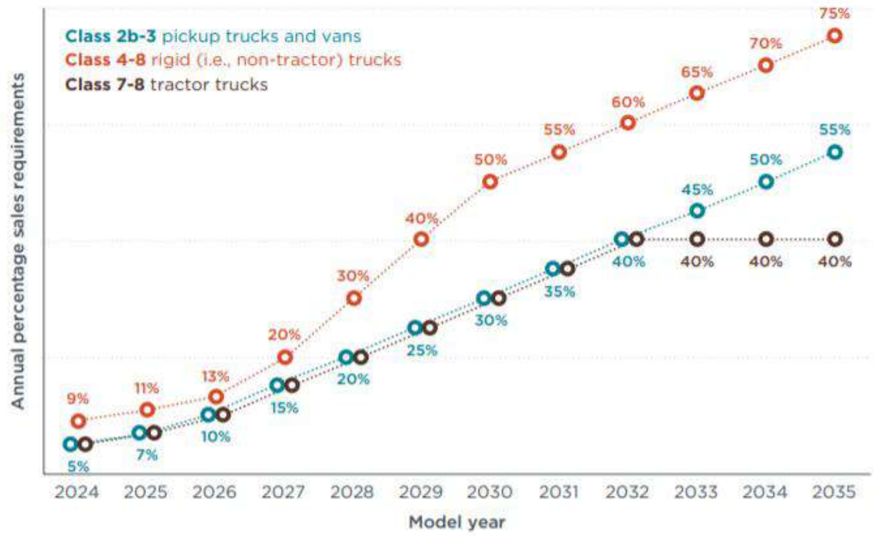
California's Advanced Clean Trucks Regulation

In June 2020, the Californian Air Resources Board (CARB) adopted new standards which will force truck and LCV manufactures (with >500 annual sales) to sell an increasing percentage of zero emission or near zero emission trucks (ZEVs / NZEVs). California's Advanced Clean Trucks (ACT) regulation stipulates the percentage share of ZEV trucks that must be sold in the state each year, starting from 2024, across three categories; Class 2b-3 passenger pickup trucks / LCVs, Class 4-8 rigid trucks and Class 7-8 tractor trucks.

A credit and deficit systems will operate, under which a deficit is accrued based on the manufacturers total sales of trucks within California, and this deficit must be offset by credits generated through the sale of ZEV and NZEV trucks under the following calculation:

Each vehicle model must be certified to CARB's zero-emission powertrain standards in order to be eligible for ZEV or NZEV credits. For Class 2b-3 credits can also be earned under CARB's Advanced Clean Cars regulation. Compliance involves meeting or exceeding the deficit each year, failure to comply will result in financial penalties for the manufacturer. Any excess credits generated can be banked, traded or sold.

California Zero-Emission Sales Percentage



By 2030 50% of Class 2b-3 sales within California will need to be zero-emission LCVs and pickup trucks. With California having approximately 10.6% (1.6 million LCVs) of the US LCV fleet, this legislation will be a significant driver for the US electric LCV market

Source: ICCT

CARB Voucher Incentive Project

In 2009 the Californian Air Resources Board (CARB), in partnership with clean transport non-profit CALSTART, launched the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). This initiative promotes clean vehicle adoption by offering vouchers to support the purchase of zero-emission trucks and buses. Since its introduction HVIP has supported projects with $433.8 million of investment.

HVIP is funded through California Climate Investments which distributes funds generated by California's cap-and-trade program. The cap-and-trade program controls the greenhouse gas (GHG) emissions of around 450 businesses (mainly large electric power plants, industrial plants and fuel distributers) who are responsible for 85% of California's GHG emissions. In November 2019, the Californian Air Resources Board had to put the incentive project on hold as voucher requests were made for its entire $142 million budget. Additional funding is expected in autumn 2020.

As of September 2020 there are only three Class 2b – Class 3 (<14,000 lbs, 6.35t) delivery or panel LCVs eligible for voucher funding and none of these are manufactured by major OEMs.

HVIP FY 19-20 Funding Table

Zero-Emission Truck Voucher Amounts

	GVWR (lbs)	Base Vehicle Incentive: Outside Disadvantaged Community	Base Vehicle Incentive: In Disadvantaged Community
Class 2b - Class 3	5,001 – 8,500	$20,000	$25,000
Class 2b - Class 3	8,501 – 10,000	$25,000	$30,000
Class 2b - Class 3	10,001 – 14,000	$50,000	$55,000
	14,001 – 19,500	$80,000	$90,000
	19,501 – 26,000	$90,000	$100,000
	26,001 – 33,000	$95,000	$110,000
	>33,000	$150,000	$165,000
	>33,000 Hydrogen Fuel Cell Truck	$300,000	$315,000

HVIP Eligible Class 2b-Class 3 LCVs

OEM	Model	Incentive	GVWR	Type
Lightning Systems	Ford Transit 350HD	$50k	<14,000 lbs	Panel LCV
Workhorse	C-1000	$50k	<14,000 lbs	Delivery
Workhorse	C-650	$50k	<14,000 lbs	Delivery

Source: Californiahvip

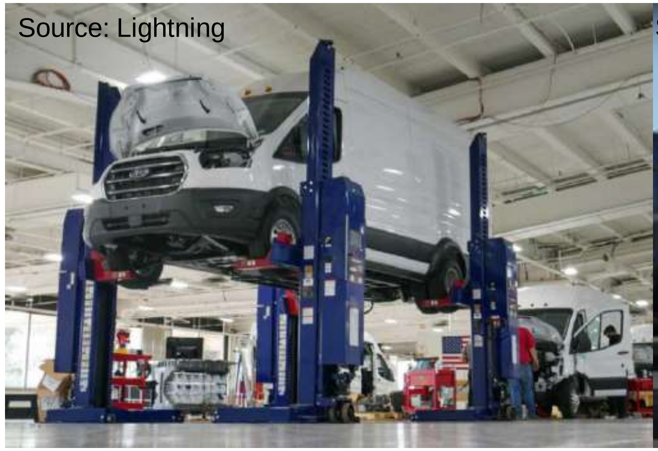
Lightning Systems - Electric Ford Transit Cargo LCV

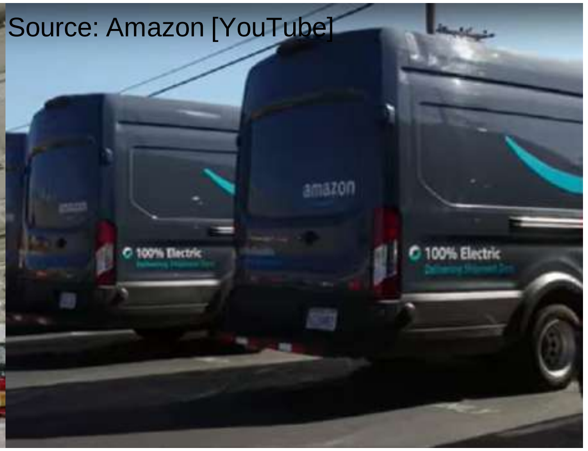
Lightning systems, headquartered in Colorado, design, manufacture and fit all-electric powertrains into LCVs and medium- and heavy-duty trucks. In December 2019, they completed a $41 million financing round to scale up production, citing $25 million in orders from major commercial fleets. They have a 142,000 sq ft manufacturing facility in Loveland, Colorado.

Lightning Systems - Electric Ford Transit 350HD Cargo LCV

Source: Lightning

Peak Power (kW)	160
Battery (kWh)	43 / 86
GVWR (kg)	4699
Payload (kg)	1680 / 1315
Charge time (hours)	5.5 to 11.25 (Level 2 6.6kW) 1 to 1.5 (Level 3 up to 50 kW)
Electric Range (km)	95 / 190


Source: Lightning



Source: Amazon [YouTube]

- In August 2019, Lighting announced that it would be lowering its 2021 prices by 10% to 50% across the range of its Class 3 to Class 8 battery and fuel cell electric vehicles, citing higher sales volumes. “With our influx of large orders, we are realizing economies of scale, moving from producing tens of vehicles per month to hundreds of vehicles per month. Our component costs are falling fast, and we are constantly introducing new automation and efficiencies in our manufacturing processes”.
- The listed starting price for the Lightning LCV is $53,000 including the HVIP voucher incentive. The vehicles are backed by the Ford electrified powertrain Qualified Vehicle Modifier (eQVM) program and warranty, with a matching Lightning powertrain warranty.
- Amazon are operating at least 14 of Lightning’s electric Ford Transit LCVs from a depot in San Diego California.

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Workhorse C-Series Electric Delivery Trucks

Workhorse, headquartered in Loveland, Ohio, have been developing electric vehicles since their founding in 2007. They have a 265,000sqft manufacturing facility in Union City, Indiana, with the capacity to produce 60,000 vehicles per year.

Since 2018 Workhorse's focus has been on the development of their C-Series delivery trucks (previously called the Workhorse N-GEN), which is available in two configurations, the 650 ft^3 cargo space C^{650}, and the 1000 ft^3 cargo space C^{1000}. The LCVs are built on a skateboard platform. In March 2020, they shelved plans for an electric pickup truck, licencing their IP to spin-off start-up Lordstown Motors (owning a 10% stake in the company), who purchased GM's 6.2 million ft^2 Lordstown manufacturing facility in Ohio.

Workhorse report orders for 1,345 vehicles, with UPS, DHL and Ryder having vehicles on order. Workhorse are aiming for production volume of 100 delivery trucks per month in Q4 2020 and 200 delivery trucks per month in 2021.

In April 2020, they received $1.4 million from the U.S. Business Administration and in June 2020 they announced a $70 million dollar investment by a single institutional investor. This latest investment gives Workhorse almost $110 million to accelerate production efforts.
Workhorse are one of three teams in the running for a US Postal Service contract worth an estimated $6.3 billion, to replace USPS's aging 165k vehicle fleet with a next generation delivery vehicle.

Peak Power (kW)	180 kW (2 x MAGALEC Axial Flux Permanent Magnet)
Battery (kWh)	70 (4-packs) or 105 (6-packs) - Usable
Charging	2 x 6.6kW (50kW optional)
GVWR (kg)	5,669
Payload (kg)	2,722
Electric Range (km)	160 - 240

Source: californiahvip.org

Rivian / Amazon electric delivery LCV

In September 2019 Amazon placed the largest ever order for electric delivery vehicles, ordering 100,000 units from start-up electric vehicle manufacturer Rivian (order worth an estimated $4 billion).

Amazon have invested heavily in Rivian (Head office: Plymouth, Michigan) as part of their 'Climate Pledge' to use 100% renewable energy by 2030, and be net zero carbon by 2040.

As no large OEMs are currently offering an eLCV or hybrid eLCV in the US market, Amazon have chosen instead to aid the development of an eLCV to meet their needs.

Production of the vehicle is scheduled to begin in 2021 (though Rivian are yet to produce a vehicle), with the aim to have 10,000 on the road by 2022 and 100,000 by 2030, saving 4 million tons of CO_2 per year (for reference Amazon's 2018 carbon dioxide emissions were 44.4 million tonnes).

Rivian Company Financials: Raised approximately $5.8 billion

- $2.5 billion investment round (July 2020) – further investment by Amazon, Soros Fund Management, Coatue.
- $1.3 billion investment round (Dec 2019) - includes further investment by Amazon and Ford
- $350 million from Cox Automotive (Sep 2019)
- $500 million from Ford (April 2019)
- $700 million round of investment (Feb 2019) – Led by Amazon
- $200 million debt round (May 2018) – Led by Standard Chartered Bank
- $250 million from Saudi Arabia based investment group Abdul Latif Jameel and Japans Sumitomo Corporation (Dec 2017).

Rivian: Three sizes of delivery LCV for Amazon

Before Amazon’s 100,000 unit order Rivian had been primarily know for the development of their R1T electric pickup.

Production at Rivian's Normal, Ill., plant is scheduled to begin in 2021 with the goal of having 10,000 on the road by 2022 and 100,000 by 2030.

The LCVs built on Rivian’s skateboard architecture, will integrate Amazon Alexa along with other logistics management, delivery and routing technology systems provided by Amazon.

Amazon announced in Feb 2020 that there will be three size variants, with multiple battery sizes in order to optimize for specific delivery routes. It is refreshing to hear a company talk about battery right-sizing. Larger than necessary battery capacity adds unnecessary weight, increasing kW/km consumption, and increases the upfront cost of the vehicle. For commercial applications with known daily routes and predicable depot charging range anxiety should not be the concern, rather optimization.

However if the battery sizes are those suggested for Rivian’s pickup truck skateboard at 105 kWh, 135 kWh and 180 kWh, providing over 300km range, this would likely vastly exceed what is necessary for most delivery duty cycles.

Source: Amazon

Amazon and Ford (amongst others) have invested heavily in Rivian. In 2019 Rivian raised a total $2.85 billion.
A further funding round in 2020 has raised $2.5 billion

Bollinger Motors Deliver-E All-Electric Concept LCV

Detroit based start-up Bollinger Motors were founded in 2015 and have been developing two all-electric vehicles, a sport utility vehicle called the B1 and a 4-door heavy-duty electric pickup the B2, built around their Class 3 e-chassis, which was unveiled in March 2020.

In August 2020, Bollinger released details about the Deliver-E, an all electric LCV concept utilising their modular skateboard platform to enable construction of class 2b, 3, 4 and 5 cargo vehicles. The platform will be available with 70, 105, 140, 175 and 210 kWh, battery packs and variable wheelbase lengths to meet the varying duty demands of their customers in terms of range and cargo payload. The platform is enabled with up to 100 kW DC fast charging.

Bollinger had previously stated they see their future as a low-volume manufacturer, focusing on craftsmanship. It is not yet clear how this potential new vehicle type fits in to that business model. Selling their electric skateboard platform may be the most lucrative avenue for Bollinger, depending on price point. In the US it is common for OEMs to supply only the chassis, with specialist 2nd stage body builders adding the desired body. In the US commercial vehicle body manufacturers will be keen to continue the business model they have established over many years, this electric platform offers them that avenue, as the country transitions to electric vehicles.

Bollinger Deliver-E Concept

Source: Bollinger

Karma Automotive E-Flex Utility LCV

Karma Automotive based in Irvine, California are best known for their luxury ($130k+) plug-in hybrid electric supercars, but they are also developing a range of skateboard type chassis platforms for a wide variety of different battery electric and extended-range electric vehicles.

In April 2020 they unveiled both a Level 4 autonomous all-electric LCV and an extended range electric vehicle (EREV) utility LCV based on their E-Flex skateboard platform. The L4 E-Flex LCV, was developed in partnership with Chinese autonomous driving technology startup WeRide. Karma's EREV E-Flex LCV hybrid platform, with an on-board generator, is a demonstration of Karma's ability to deliver an all-electric range of up to 320 km, with a combined range of over 640 km.

The E-Flex platforms integrate proven Karma technologies including drive motors in various configurations, gearbox, suspension, subframes and steering and body structure parts.

It seems these vehicles are intended as demonstration projects to promote sales of the electric skateboard to customers who will then develop their own vehicles around the Karma platform.

Source: karmaautomotive

"Our Karma EREV E-Flex LCV platform offers a variety of e-powertrain configurations and a flexible design. We provide the canvas for our partners to create mobility solutions their way, while integrating Karma technology…"
Lewis Liu - Karma Automotive VP of Business

Source: Businessinsider.com

Ford: Finally an OEM offering an eVan option in the US

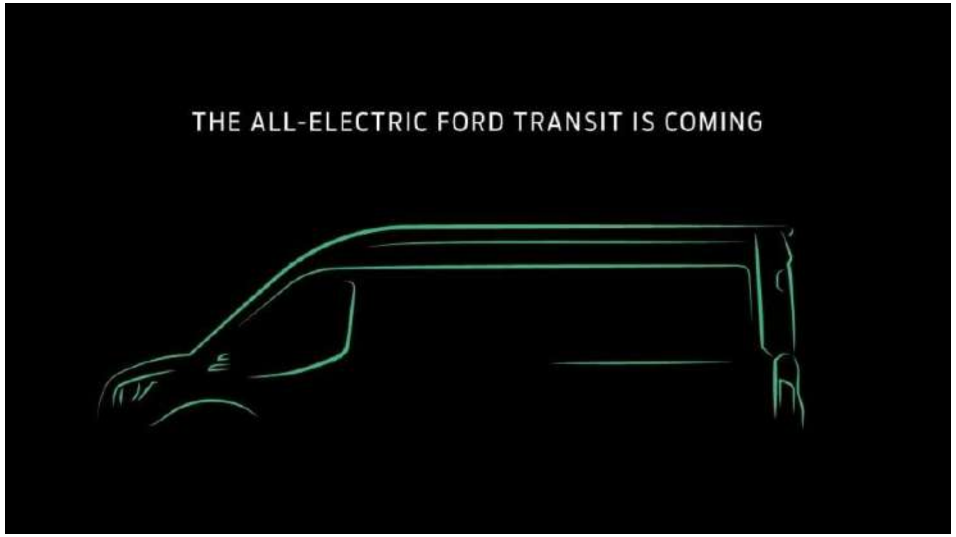
On the 3rd of March 2020, Ford announced in a press release that it would be offering an all-electric version of the Ford Transit in the U.S. and Canadian markets from the 2022 model year.

This announcement makes them the first OEM to launch an electric commercial LCV. The eVan will be built in the US as part of its $11.5 billion investment in electrification.

Having seen the huge order Amazon placed with Rivian to develop electric delivery LCVs along with increasingly vocal demand from large corporations, through mechanisms like the corporate vehicle alliance, this announcement by Ford is something we have been expecting.

The launch of the all-electric transit in US will come a year after its debut in Europe in 2021.

- IDTechEx expect other LCV manufactures in the US to make similar announcements over the course of this year, which could be:
- An electric version of the Ram ProMaster (which is a rebadged Fiat Ducato - electric version launched in Europe in 2020)
- Launch of the Mercedes-Benz eSprinter in the US
- Release of the Nissan e-NV200, perhaps with the new LEAF 62 kWh battery rather than the 40 kWh battery employed in Europe



Source: Ford

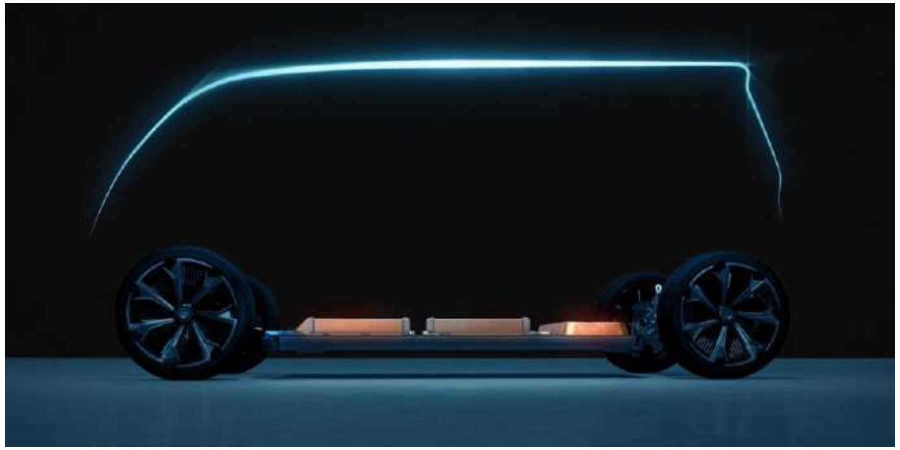
General Motors All-Electric Delivery LCV BV1

In June 2020, Reuters broke the news that GM is developing an all-electric commercial LCV, the BV1, with a target for production late in 2021. This fits with GM's relatively new goal of "aggressively going after every aspect of the EV ecosystem", backed by $20 billion worth of investment.

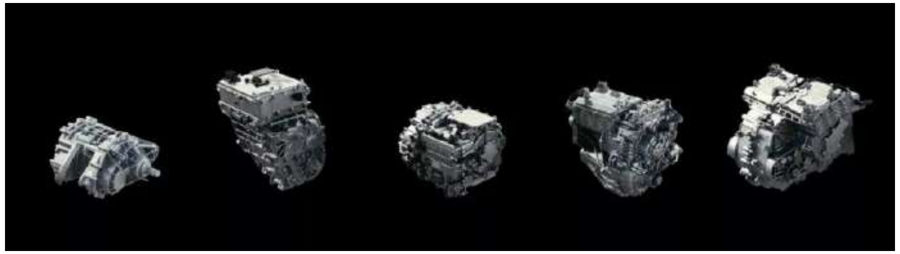
No official details about the LCV have been released by GM, but it is believed it will utilize GM's new Ultium advanced battery system and is expected to be manufactured at GM's Detroit-Hamtramck plant.

The Ultium battery platform is intended to be modular and flexible to act as the foundation for a range of vehicles types. It incorporates a wireless battery management system (wBMS), negating the need to design complex wiring systems for each new vehicle, enabling GM to get their EV offerings to market faster. GM estimate the their wBMS could reduce wiring within the battery systems by up to 90%, leading to lighter batteries improving vehicle range.

The Reuters article in which the BV1 development was announced suggests that GM move into the electric LCV markets is to beat Tesla to this lucrative market. As of September 2020, Tesla have not announced any development plans for an electric delivery LCV, though in February 2019 it was reported that Tesla and Daimler had held talks about co-operating on a battery powered LCV, following a tweet by Elon Musk in which he said it "maybe interesting to work with Daimler/ Mercedes on an electric Sprinter"



GM's Ultium Drive Units



Source: GM

Popular Electric LCVs in the US

Chanje V8100 All-Electric Panel LCV

Source: californiahvip.org

Peak Power (kW)	148 kW (Dual motor - Synchronous Permanent Magnet)
Battery (kWh)	100 (CATL LiFePO4)
Charging	13.2 kW (DC Fast Charge)
GVWR (kg)	7,500
Payload (kg)	2,722
Electric Range (km)	240

Chanje is a California-based company providing electric trucks for the commercial last mile industry.

They have partnered with Hong Kong-based electric vehicle OEM FDG Electric Vehicles Limited, who operated a 3.8 million sq ft manufacturing facility in Hangzhou, China, to produce an all electric medium-duty panel LCV the Chanje V8100.

The vehicle has a 150 mile range. Chanje suggest that the average route for a medium duty commercial truck is 65 miles.

In November 2018 it was reported that FedEx working with Ryder Systems have ordered 1,000 Chanje electric delivery LCVs that will be deployed in California. These are due to be delivered in the first half of 2021. It is reported there was a pause in delivery whilst Change waited for an upgrade of battery supplier CATL's battery energy density to enable greater range.

Ryder System Inc., a commercial fleet management, dedicated transportation and supply chain solutions company, started taking Chanje vehicles in November 2017, ordering 125 units.

N.B. This is a medium-duty truck (> 6.35 tonnes) rather than a LCV, but frequently is included in discussions about LCV delivery LCVs.

eLCV Demand: Corporate Electric Vehicle Alliance

Led by Ceres, a sustainable nonprofit organization headquartered in Boston, MA, The Corporate Electric Vehicle Alliance was launched in January 2020.

The goal of this alliance is to help member companies achieve bold commitments for fleet electrification by **leveraging their buying power** to send a strong message to both automotive manufactures and policy makers.

This alliance looks to support:

- The development of new EV models
- EV market growth with increasing economies of scale
- The adoption of policies to support EV and remove policy barriers
- Shared learning between partners to develop best practices

The press release which accompanied the announcement highlighted “significant benefits” of electrification for companies, including “reduced greenhouse gas emissions, cost savings on fuel and maintenance, freedom from reliance on volatile oil and gas prices, improved passenger safety, and enhanced company reputation”

Huge businesses in the US are very keen to pilot low on-road emission commercial vehicles in order to meet their own internal climate change targets. Recent activity, such as the corporate electric vehicle alliance may be the motivation OEMs required to launch electric LCV models into the US market.

Members

amazon, American Airlines, AT&T, CLIF BAR, Consumers Energy, DHL, Direct Energy, IKEA, JLL, LeasePlan, Lime, SIEMENS

*Genentech is also a member of the Corporate Electric Vehicle Alliance.

Source: Ceres

Business to drive electrification of LCV fleet in US?

Whilst no large OEMs are currently offering an eLCV or hybrid eLCV in the US market, demand appears to be increasing for zero emission delivery LCVs, as multinational organisations around the world make their own internal commitments to reduce emission from their activities. The last 12 months have seen significant momentum developing in this market.

Examples of companies ordering electric delivery vehicles in the US:

- Amazon – Rivian / Lightning Systems / Chanje
- FedEx - Chanje
- DHL – StreetScooter
- UPS – Workhorse / Arrival

A large number of paid pre-orders have also been placed for the electric Tesla Semi Truck, by a large American companies, including Anheuser-Busch, DHL, FedEx, PepsiCo, Sysco, UPS, and Walmart.

Whilst the initial orders, are primarily for at scale pilot projects to test the technology. The growing demand, for clean transport solutions is likely to see manufacturers begin to offer eLCV option in the US market in the near future.

"Waiting for electric vehicles is like seeing the sign at the bar that says, 'Free beer tomorrow'" Scott Phillippi, Senior director of maintenance and engineering at UPS

Source: ttnews.com

7. eLCVs in the RoW

Toyota PROACE

- In July 2019, Toyota announced plans to produce all-electric version of its PROACE LCV.
- Toyota are collaborating with PSA on the vehicle, meaning the electric PROACE is likely to be almost identical to the electric Citroën Berlingo / Peugeot Partner.

- *"Growing concerns about climate change and air quality are leading to new, low emission regulations in many European cities. These factors are changing LCV customers' requirements and priorities, especially in urban areas. In collaboration with Groupe PSA, Toyota will add BEV (Battery Electric Vehicle) versions of PROACE and PROACE CITY. They will be introduced in 2020 and 2021 respectively, allowing Toyota to meet new LCV customer needs."*

- Initial plans suggest that the electric version is only being released in the European market.
- In the domestic Japanese market, it is likely given Toyota's focus on fuel cell technologies (Mirai) that future LCV developments will be FCEV, but no announcements has yet been made.

Source: Toyota.eu

Yamato / DHL StreetScooter

- Japanese logistics company Yamato have signed a contract with StreetScooter to develop a small electric LCV to be deployed initially around Tokyo.
- StreetScooter will produces the electric LCV, whilst Yamato will provide a refrigerated transport box, which will be mounted on the vehicle by Japanese supplier Topre.
- The initial project is for 500 vehicles (StreetScooter Work without bodywork), with plans for future expansion.
- Yamato has plans to convert its entire 40,000 fleet to electric vehicles.
- As of March 2019, DHL suggest that Yamato is the only company in Japan to have put large scale investment into electric commercial deliveries despite accessible charging infrastructure (over 100,000 electric Nissan Leaf passenger cars have be sold in Japan since 2010).

Mitsubishi MiniCab MiEV LCV

- Since 2011, Mitsubishi have been manufacturing a small electric LCV, the MiniCab MiEV.
- Mitsubishi in-house research conducted a survey of LCV driver in Japan, finding 77% of daily use was less than 65 km.
- The LCV is available in two models, a 10.5kWh battery version with 100 km range and a 16.0 kWh version with 150 km range. The batteries come with an 8-year, 160,000 km warranty for an SOC capacity at least 70% of the original capacity.
- The LCV is equipped with a 30kW permanent magnet synchronous motor.
- In November 2019 Japan Post announced it would be purchasing 1200 electric vehicles for mail and parcel deliveries, by March 2021 in order to improve its environmental impact. The first 20 will be the MiEV LCV in red livery.

Source: Mitsubishi, nippon.com

Hyundai Porter EV and Kia Bongo EV

Kia Bongo III EV

Peak Power (kW)	135
Battery (kWh)	58.8
Charging	7.2kW or 100 kW Fast Charging
Curb Weight (kg)	1965
Price ()	$34.8k – $36.7k
Electric Range (km)	211

- In December 2019 Hyundai and Kia launched their electric cargo trucks in Korea. The Porter II EV and Bongo III EV
- In April 2020 the South Korean Ministry o Environment announced it would be providing subsidies for 8,200 electric cargo trucks, as part of efforts to reduce particulate and carbon emissions. Signing MoU's with Hyundai and Kia and five logistics firms to get more environmentally friendly cargo trucks on the road.
- Reports from Korea suggest that 2890 eLCVs were sold in Korea in Q1 2020, up from 3 eLCV units in Q1 2019.
- The specifications of the vehicles are identical. Both come with a Battery warranty for 120,000 km or 8-years (65% SoH)

Hyundai Porter II EV

Peak Power (kW)	135
Battery (kWh)	58.8
Charging	7.2kW or 100 kW Fast Charging
Curb Weight (kg)	1965
Price ()	$34.8k – $36.7k
Electric Range (km)	211

Source: hyundai.com

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Tata Motors Ace

- Tata Motors is India’s leading LCV manufacturer producing 251,611 units in FY18-19, capturing 40.8% of the market.
- In March 2018 it was announced that Tata Motors, was developing an electric versions of its 1 tonne Tata Ace.
- Tata stated its commitment to electric vehicles and leading the e-mobility evolution.

“Tata Motors is developing an electric variant of the small commercial vehicle Ace and is at the development stage now. It should be in the market by late 2019 or 2020. Given the way the Union government wants to encourage the use of EVs in commercial purposes, this is perfectly suitable for ferrying goods and passengers within city limits."

- Tata previously worked on an electric version of this 0.75t commercial vehicle in 2012, when it was launched in the UK market in small volume. A demonstration programme was undertaken, but sluggish uptake and a change in incentives saw the project discontinued.
- Tata is set to unveil new powertrain combinations at the 15th Auto Expo in Greater Noida, India in February 2020, that demonstrate their connected, electric, shared and safety vision of the future.

Source: Tata, indiatimes.com, livemint.com

Mahindra ^{e}Supro Cargo LCV

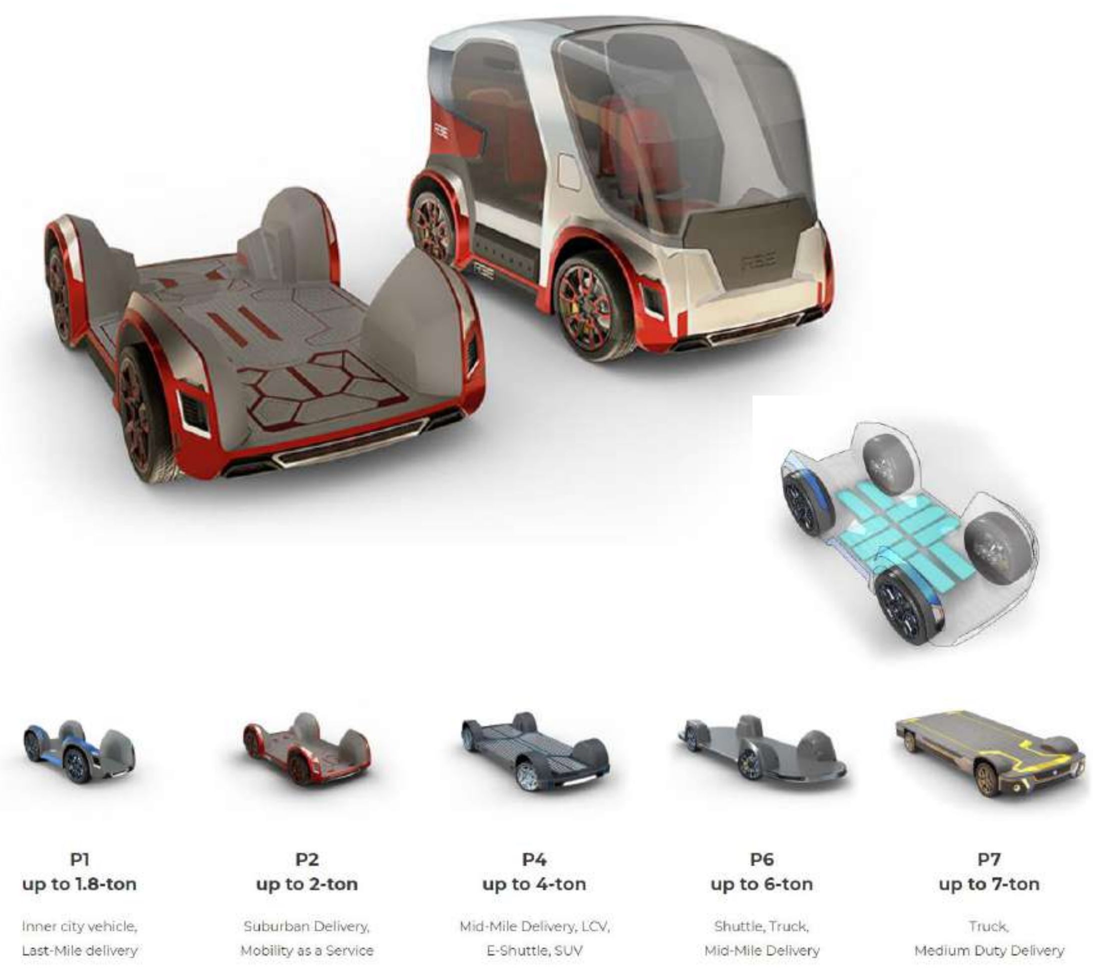
- Mahindra and Mahindra, India's second largest commercial vehicles manufacturer (38.3% market share, 236,377 units FY18-19), offers an eLCV through its subsidiary Mahindra Electric Mobility Ltd (formally the Reva Electric Car Company acquired in 2010).

- The eSupro cargo LCV is India's first closed body electric LCV.
  - Payload: 600kg
  - 14.4 kWh battery (200Ah, 72V battery pack, Lithium-Ion – likely LG Chem NMC)
  - Range: 115 km
  - Charge time 8.5 hours 0 to 100%
  - Motor: 3 phase, AC induction max power 25kW
  - Warranty 2 years 40,000 km, battery 3 years
  - GVW 1920 kg

- The eSupro cargo qualifies for India's Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles - FAME-II incentives ($1.4 billion scheme), designed to encourage the uptake of electric vehicles in India. Offering a maximum incentive of about $2,000 on electric commercial four-wheel vehicles with a factory price up to $20,000.

Source: mahindrasupro.com, indiatimes.com

Mahindra and REE eLCV Partnership



- In August 2020, Indian automaker Mahindra and Mahindra signed an MoU with Israeli start-up REE Automotive to utilise REE's electric skateboard platform with integrated in-wheel motors, suspension and steering components, to develop and manufacture electric commercial vehicles for the global market.
- REE will leverage Mahindra's expertise and scale in vehicle design, engineering, manufacturing and materials sourcing.
- REE suggest the market for electric commercial market will be in the order of 200,000 to 250,000 over the next few years, Mahindra likely bring with them a potentially large Indian market for such vehicles.
- REE's EV platform technology spans a broad range of potential applications for EV and autonomous vehicles. The smallest platform offers a 20 kWh battery capacity, 47 kW motor power, 350 kg load with 220 km range and the largest platform incorporates a 100 kWh battery, with a 4-tonne payload, 170 kW vehicle peak motor power and 250 km range.
- This collaboration has the potential to push forward the eLCV market in India, which has been slower to adopt electrification than other large automotive markets.

Source: ree.auto

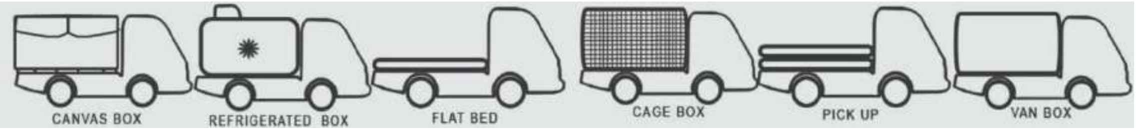
Maruti Suzuki India Eeco Charge Concept

- In 2010 Maruti Suzuki, India's third largest manufacturer of commercial vehicles, developed a zero-emission, pure electric, 'future technology' concept vehicle, the 'Eeco Charge', in the run up to the Delhi Commonwealth Games.
- The development was conducted as part of the Government initiated National Hybrid Propulsion Program (NHPP) and the Ministry of New & Renewable Energy Sources (MNRE)'s High Energy Density Battery Development Program
- The Eeco Charge was powered by a 50kW motor and a 24kWh Lithium-ion battery, with a range of round 100km.
- The vehicle did not go into production.
- There had been expectation that Maruti Suzuki would be launching an electric car, the WagonR, in 2020, however in October 2019 they announced it would not be launched, citing lack of infrastructure and government support.
- Maruti Suzuki India Chairman R C Bhargava is quoted as saying "If you want to do an EV programme in India, somebody has to manufacture batteries in India", along with other key components, in order for EVs to be sold at mass scale.

Source: cartrade.com, marutisuzuki.com

Croyance Electro 1.T and Electro 2.T

- Croyance Automotive based in Vapi, Gujarat, India, are a small start-up in the electric commercial vehicle market, who were founded in December 2015.
- They offer two models
  - Electro 1.T, a battery powered vehicle designed for e-commerce, cold storage services and transportation services. With a AC 5kW motor and kerb weight 670kg, payload 1000kg
  - Electro 2.T based on the Electro 1.T, is a soft-top with a loading capacity of 2000 kg, aimed for internal use in warehouses and large factories.
- Battery Pack Capacity is 150Ah at 72V ≈ 10.8 kW, 6 lead acid (VRLA) batteries, which Croyance say is enough for 120 mile range. Charging time 6-7 hours.
- Croyance suggest their vehicles will be considerably less expensive than competing bigger brands, with an ex-showroom price of Rs 7-7.5 lakh (approx. $10,000).
- They have a production facility in Surat, India, with an annual capacity of 6000 vehicles. In 2019, they set themselves a sales target of between 700 and 800 vehicles.
- Croyance is looking for around $56 million dollars, for the project and are in discussions with government banks for the finance, as well as looking for angel investors.



Source: elecro1t.in

SEA E4V Delivery LCV

Australian company SEA Electric assembles and electrifies 100% electric commercial vehicles. The company was founded in 2013 and launched commercial operations in 2017.

SEA's approach involves fitting its own electric driveline technology to a chassis built by Chinese firm XGD for its LCV model the SEA E4V and FAW and Mercedes Benz for their larger commercial vehicles.

They work directly with companies to supply and licence their patented technology.

They suggest the payback period for equipping their electric powertrain is 2 to 4 years.

SEA E4V specs:

- 88kWh battery pack [NMC - Lithium-Ion (LiNiMnCoO2)]
- Charge time: Approx. 5-hours to full charge
- Motor: 75kW Asynchronous (134kW peak)
- Range up to 300km
- Charging: 3 phase and 240V charging
- Warranty: 3 year or 100,000km (5-year battery)

Source: Sea-electric

8. Technologies

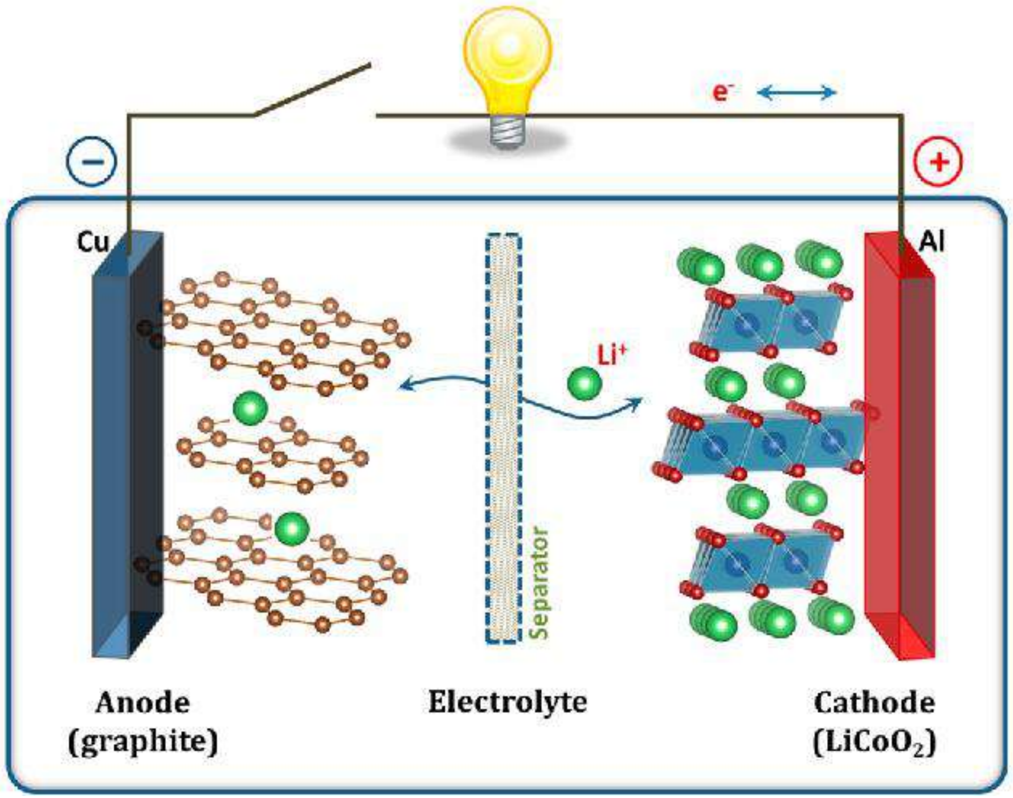
Li-ion Batteries

What is a Li-ion battery?

At their simplest, Li-ion cells consist of an anode, cathode and electrolyte.

Lithium-ion batteries function through a “rocking chair” principle. Li^+ is extracted from a positive electrode (cathode) and migrates into the structure of a negative electrode (anode). These reversible insertion processes occur at the same time as redox reactions in the electrodes, at defined potential ranges.

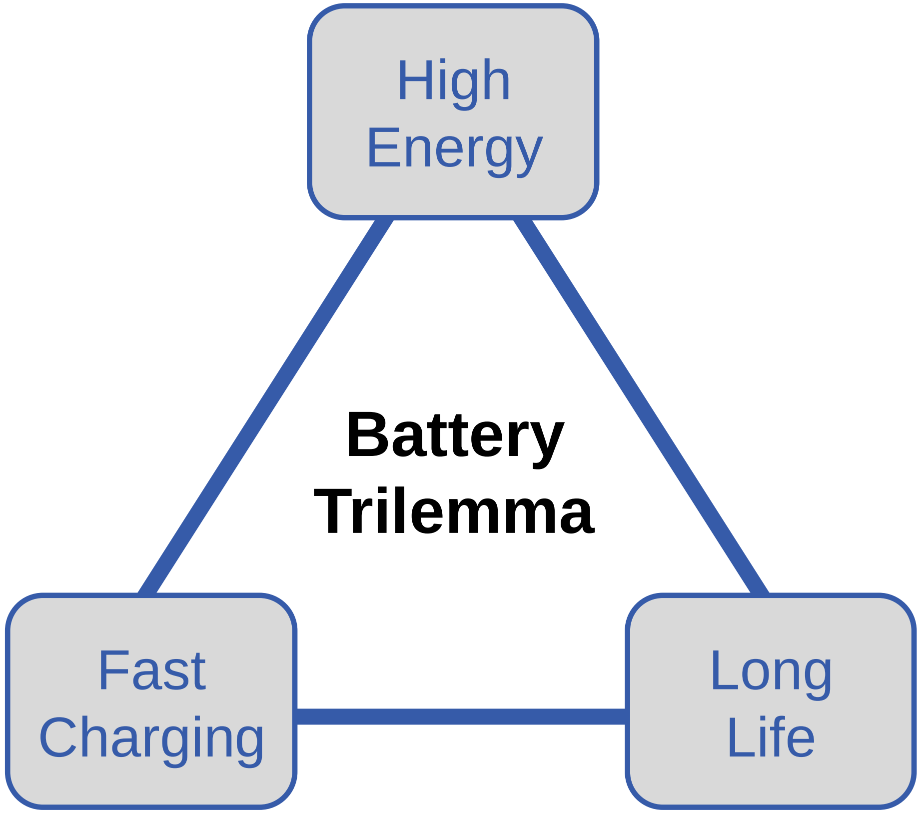
In reality, the working mechanisms in a Li-ion cell are far more complex, with many more components needed at the cell and battery level.



Source: Goodenough et al, ACS, 2013

The Battery Trilemma

- It is difficult to simultaneously improve the performance metrics shown right in Li-ion batteries.
- For example, fast charging often comes at the expense of cycle life as it deteriorates the active materials at a faster rate and also requires thinner electrodes, reducing energy density. Similarly, high energy cathodes are less stable and so capacity degradation is often more severe, reducing cell lifetime.
- As of now, simultaneous improvements in energy density, fast charging and lifetime are incremental. They typically can only be carried out by large battery manufacturers as the R&D required is very capital-intensive.



Electrochemistry Definitions

- **Gravimetric** and **volumetric energy density**: the amount of energy (expressed in watthour, Wh) that can be stored in 1 kg (or 1 L) of battery. The gravimetric energy density is often referred to as **specific energy**.

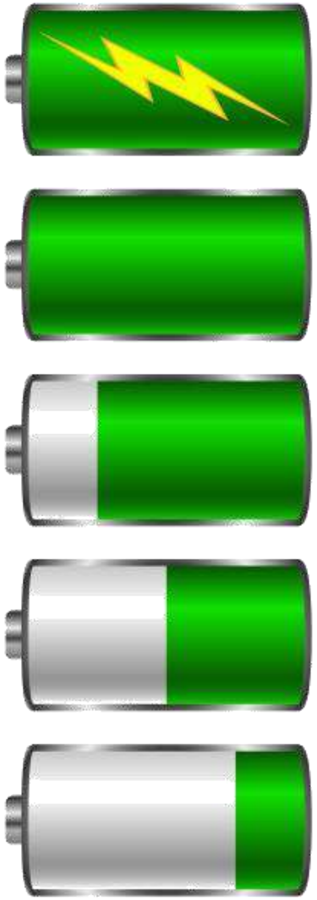
- **Gravimetric** and **volumetric power density**: the amount of power (expressed in watt, W) that can be delivered by a battery (or a supercapacitor) per 1 kg (or 1 L) of device. The gravimetric power density is often referred to as **specific power**.

- **Cycle life**: the number of times that a battery can be charged and discharged before its energy density drops to 80% of its nominal value, though a battery may still be useable beyond this point.

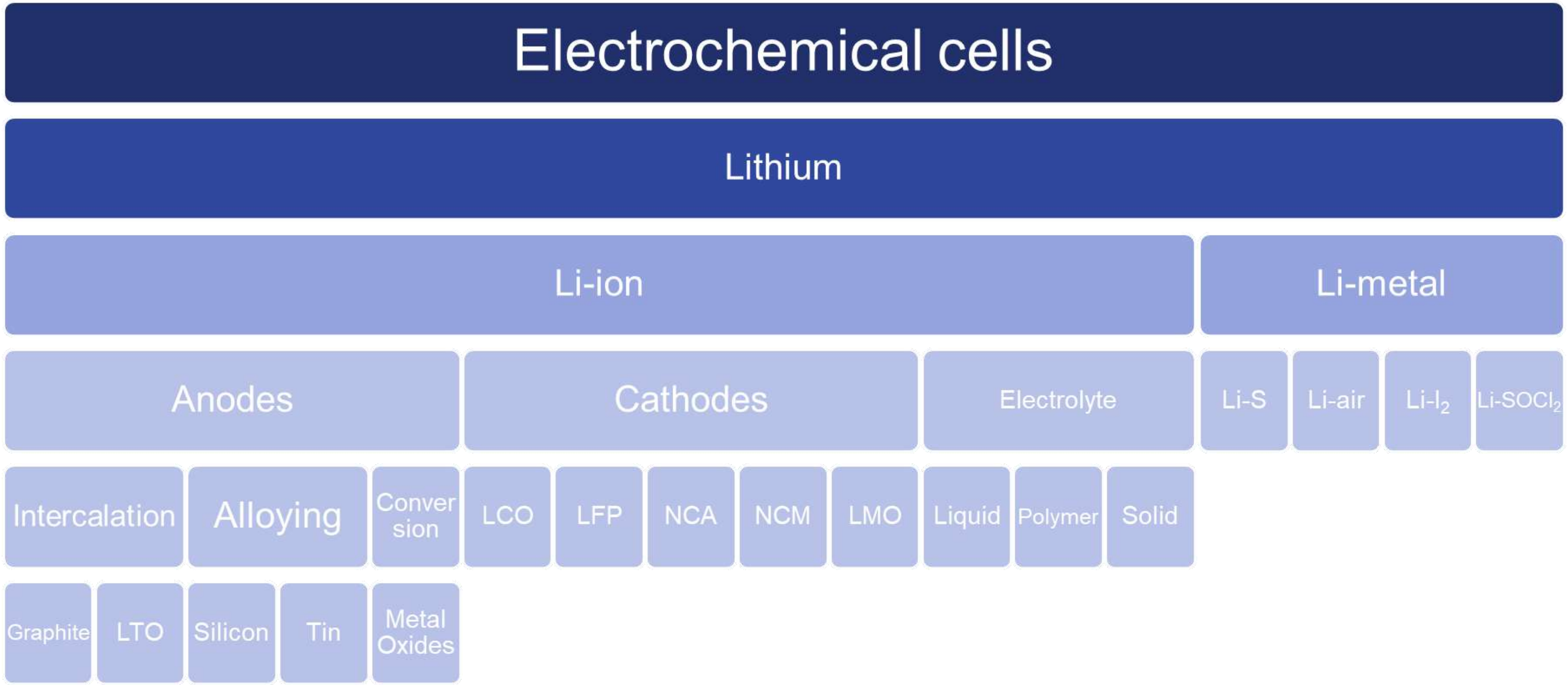
- **Capacity**: the amount of charge a cell can reversibly store - measured in ampere-hours (Ah). Specific capacity (mAh/g) is often used to compare electrode materials.

- **Dendrites**: from ancient Greek “tree-like”, these are sharp branched lithium structures that can form on the anode’s surface; they can grow all the way to the cathode and cause a short circuit.

- **Thermal runaway**: an exothermic reaction that leads to an exponential heat increase, ultimately resulting in fires, explosions and/or release of toxic chemicals.



Lithium-based Battery Family Tree

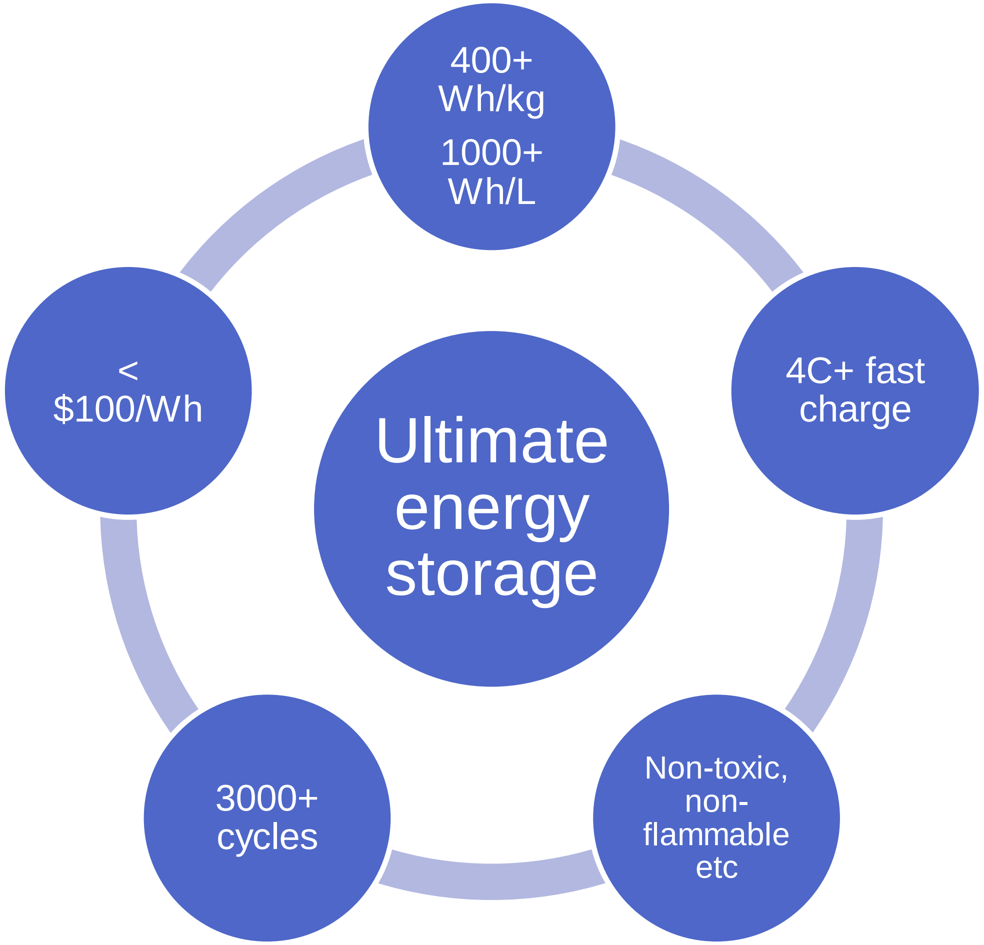


Source: IDTechEx

IDTechEx

Battery Wish List

- The ultimate energy storage device for a car would be able to meet all the performance requirements outlined to the left.
- The values are currently above the current state-of-the-art for any given Li-ion chemistry. Unfortunately, obtaining these values within a single cell chemistry is not currently possible.
- For example, a battery cell capable of reaching 1000 Wh/L will not reach a cost of $100/Wh, be able to fast charge at a 4C rate (15 minutes or less), reach a cycle life of greater than 3000 times or be immune to thermal runaway.
- Different applications will naturally have different requirements and so various chemistries will find use cases. For example, cells with a Lithium Titanite Oxide (LTO) anode replacing the conventional graphite are able to be cycled 20,000 times or more at a 10C rate, but have much lower energy densities than NMC / NCA / LFP cathode and graphite anode based cells.
- Development is often focussed on the battery-electric vehicle sector as improvements to energy density, cost and fast charging are likely necessary for mass adoption, and this will be the largest market.



Source: IDTechEx

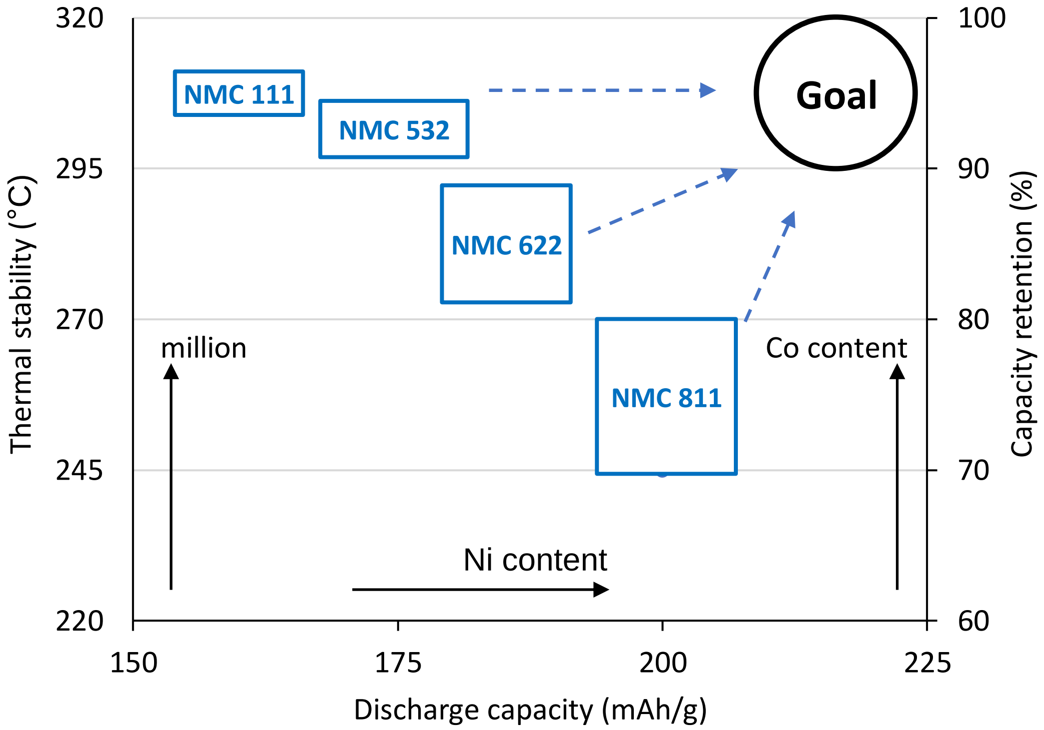
More Than One Type of Li-ion battery

Name	Cathode	Companies (selected)	Power	Energy	Safety	Cycle Life	Cost
LCO	$LiCoO_2$	Panasonic, Sony-Asahi Kasei, Hitachi, ATL	++	+++	+	+	+
NCA	$Li(Ni_{1-x-y}Co_xAl_y)O_2$	SAFT, Panasonic, Toyota	+++	+++	+	++	++
NMC111	$Li(Ni_{1/3}Mn_{1/3}Co_{1/3})O_2$	LG Chem, Panasonic, NEC, BASF, Umicore, Johnson Matthey (Axeon), ATL, Sanyo, Xalt Energy	++	++	++	++	++
NMC811	$Li(Ni_{0.8}Mn_{0.1}Co_{0.1})O_2$	SKI, CATL, LG Chem, Umicore	++	+++	+	+	+
LFP	$LiFePO_4$	Johnson Matthey, A123 Systems, Valence, China Bak, LiFeBATT, ATL	+++	+	+++	+++	+++
LMO	$LiMn_2O_4$	LG Chem, Samsung, Enerdel, NEC, ATL	+++	+	+++	+	++

Source: IDTechEx

NMC: from 111 to 811

- There is a trend from battery makers to increase nickel content in electric vehicles and reduce cobalt content. The chart to the right shows why this matters from a performance perspective – but also why it's difficult to do so.
- NMC 111 (where the numbers represent ratios, for example 111 means 1/3 Nickel, 1/3 Manganese, 1/3 Cobalt, and so on), shown in the chart on the top left hand corner, has a higher thermal stability at 300 ºC but lower discharge capacity than the theoretical LiNiO2 (NMC 900), which is represented by the bottom-right limit of the chart. However, a minimum amount of cobalt and manganese is needed because LiNiO2 does not cycle reversibly, which is why there is currently a convergence on NMC 811. A capacity retention of 75% means that the hypothetical battery would lose more than half of its capacity in just 3 cycles.
- For this reason, researchers and companies are working hard to harness as much specific capacity with the highest possible amount of nickel, without compromising the cycle life.
- The secondary reason to increase nickel content and reduce cobalt content is that 70% of the worlds cobalt supply, and 48% of the global reserves, come from the Democratic Republic of Congo (DRC) in Africa, which relies on unsafe practices such as artisanal mining. It is hypocritical for an industry which prides itself as being sustainable to rely on unsustainable mining practises.



Source: IDTechEx, adapted from Jang-Yeon Hwang et al, 2016

Cobalt: Price Volatility

Another reason to reduce reliance on Cobalt is that the prices are high and volatile, fluctuating between $10 and $40 per pound in recent years due to supply and demand dynamics. Currently we are in a period of oversupply, and prices have been falling.

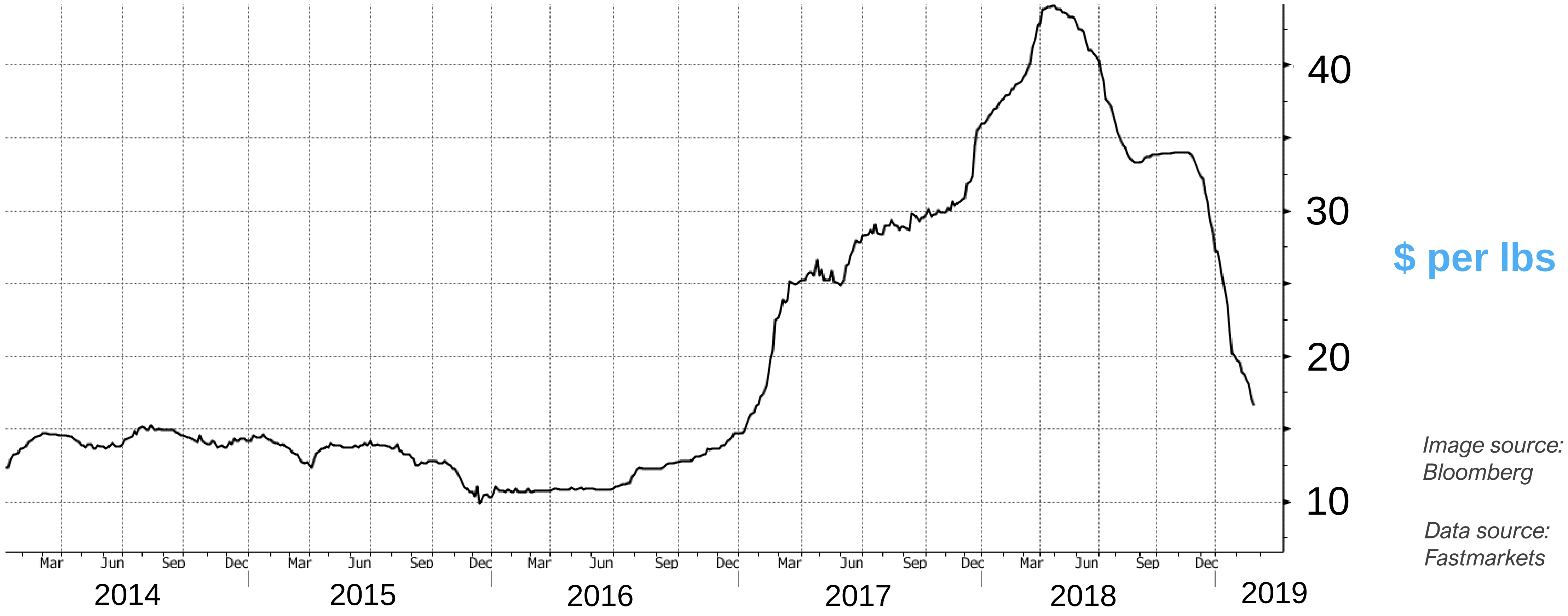


Image source: Bloomberg

Data source: Fastmarkets

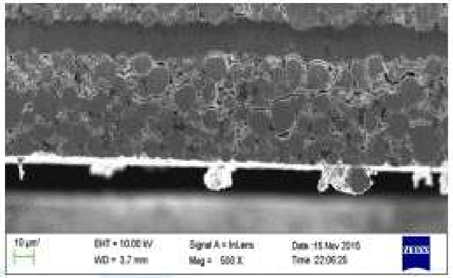
Cathode Performance Comparison

Some representative performance metrics are given below for commercial Li-ion cathode materials. However, the values of these metrics can still vary, for a given cathode material, depending on quality control as well as optimisation for power, energy or cycle life.

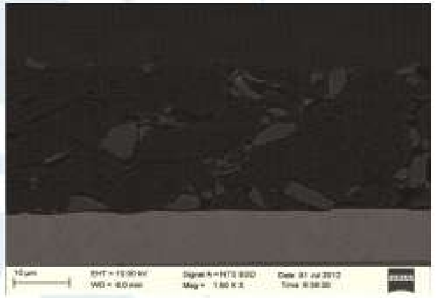
	LCO $LiCoO_2$	**LMO** $LiMn_2O_4$	**LFP** $LiFePO_4$	**NMC111** $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$	**NMC811** $LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$	**NCA** $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$
Specific capacity (mAh/g)	120	100	150	155	200	200
Voltage vs Li/Li^+	4.0	4.1	3.3	3.7	3.7	3.7
Cycle life	500-1000	500	4000-5000	2000	1500	2000
Thermal stability	Good	V. poor	V. good	Good	Reasonable	Reasonable
Comments	Simple manufacture process but high cobalt content.	While relatively safe, very poor thermal stability causes accelerated degradation.	High rate capability and low cost but low voltage limits energy densities.	Good performance metrics but being phased out due to high cobalt content.	High capacity and low cobalt content - limited by low stability	Highest energy release upon thermal runaway

811 Commercialisation Examples

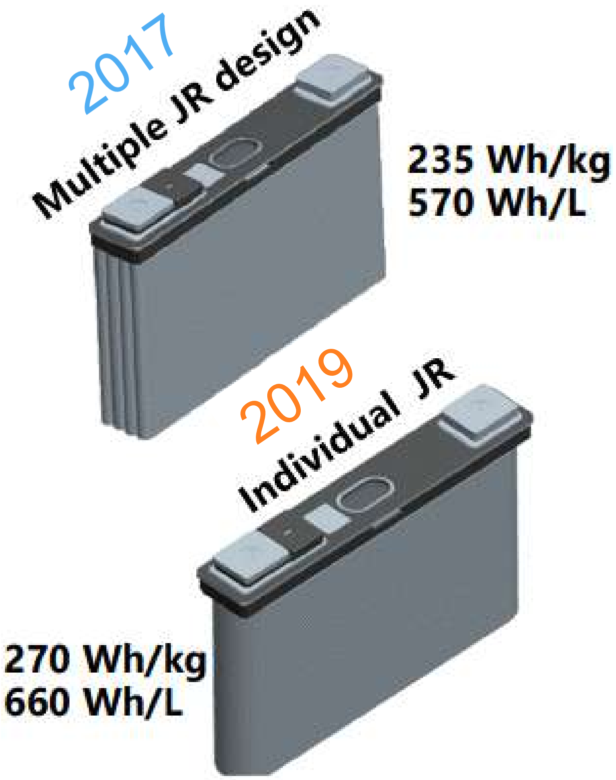
CATL have commercialised an 811 chemistry and made energy density gains - 300Wh per kg in 2019.

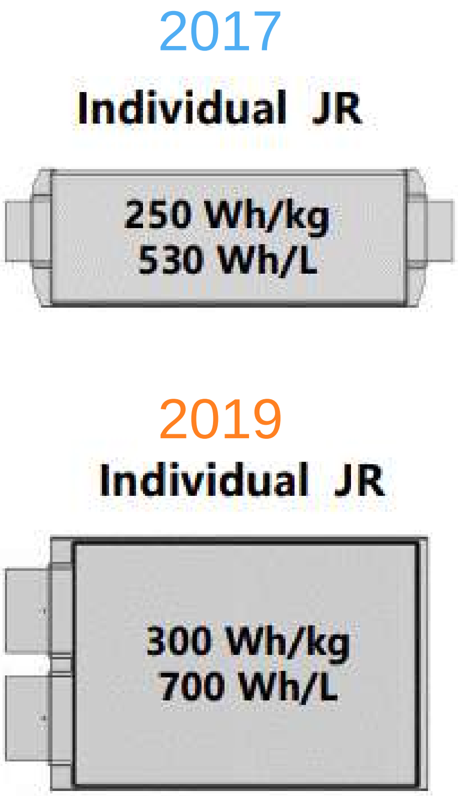


Cathode: Ni-rich materials



Anode: Graphite/Si





20% gravimetric ED improvement 2017-2019

Image source: CATL

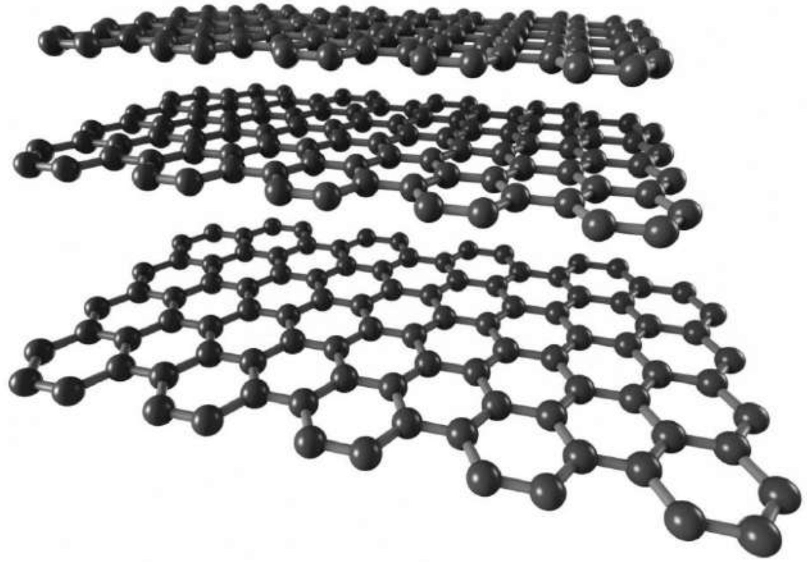
Commercial Anodes: Graphite

Original research into Li-ion batteries made use of lithium metal as the anode. Both then and now, the use of lithium is problematic due to its reactivity leading to dendrite formation and cells that could be cycled maybe 10 times before failure.

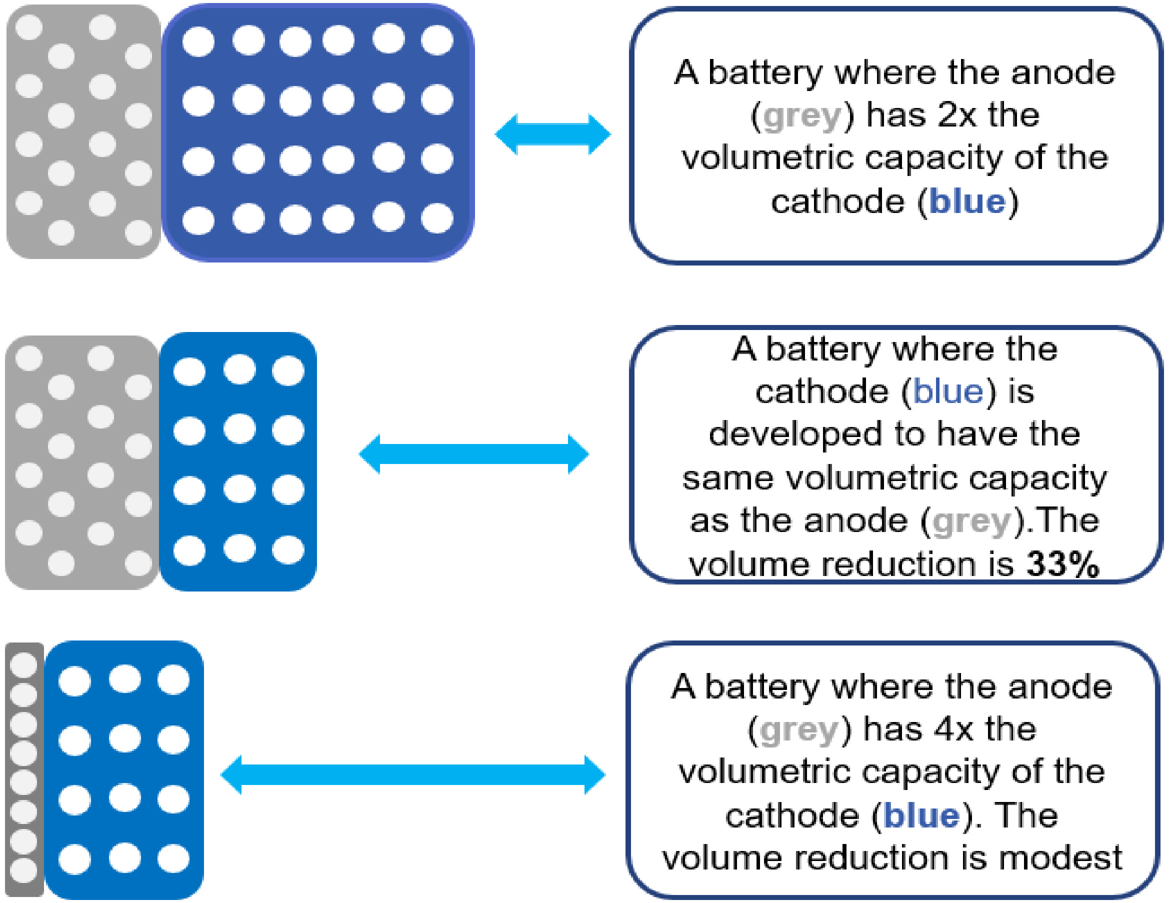
The use of graphite and intercalation materials at both anode and cathode led to cells capable of hundreds of cycles and the thousands possible today. Graphite's use was attributed to work by Asahi Kasei's Akira Yoshino and his initial use of petroleum coke as the anode.

Though the potential of fully lithiated graphite is lower than the stability window of commercial electrolytes, the formation of the solid-electrolyte interphase (SEI) layer protects against excessive decomposition during cycling.

Graphite is still the dominant anode used in commercial Li-ion batteries across applications. The next decade may well see this change.



The Promise of Silicon-based Anodes



The largest increase in cell energy density is achieved through improvements to the cathode, either its capacity or its voltage.

Nevertheless, increasing anode capacity will still result in improved energy density.

Silicon has a theoretical gravimetric capacity of 3590 mAh/g and theoretical volumetric capacity of approximately 2190 mAh/cm^3. The corresponding values for graphite are 372 mAh/g and 830 mAh/cm^3.

The Reality of Silicon

Silicon stores charge through an alloying reaction, which is responsible for its increased capacity but also results in a ca. 300% volume change upon lithiation. For comparison, the volume change of graphite during cycling is 10-15%.

Repeated expansion and contraction has numerous effects. It can result in fracturing and pulverisation of individual particles as well as in the electrode structure, constituting a loss of electrical connection between electrode constituents and between active material and the current collector.

Fresh electrode material is also exposed to the electrolyte, causing further breakdown and material loss upon cycling.

The result is battery makers are adding small amounts of silicon to the graphite anode incrementally in a 'best of both worlds' scenario, detailed on the next slide, and to allow time for R&D to help solve the cycling issue.

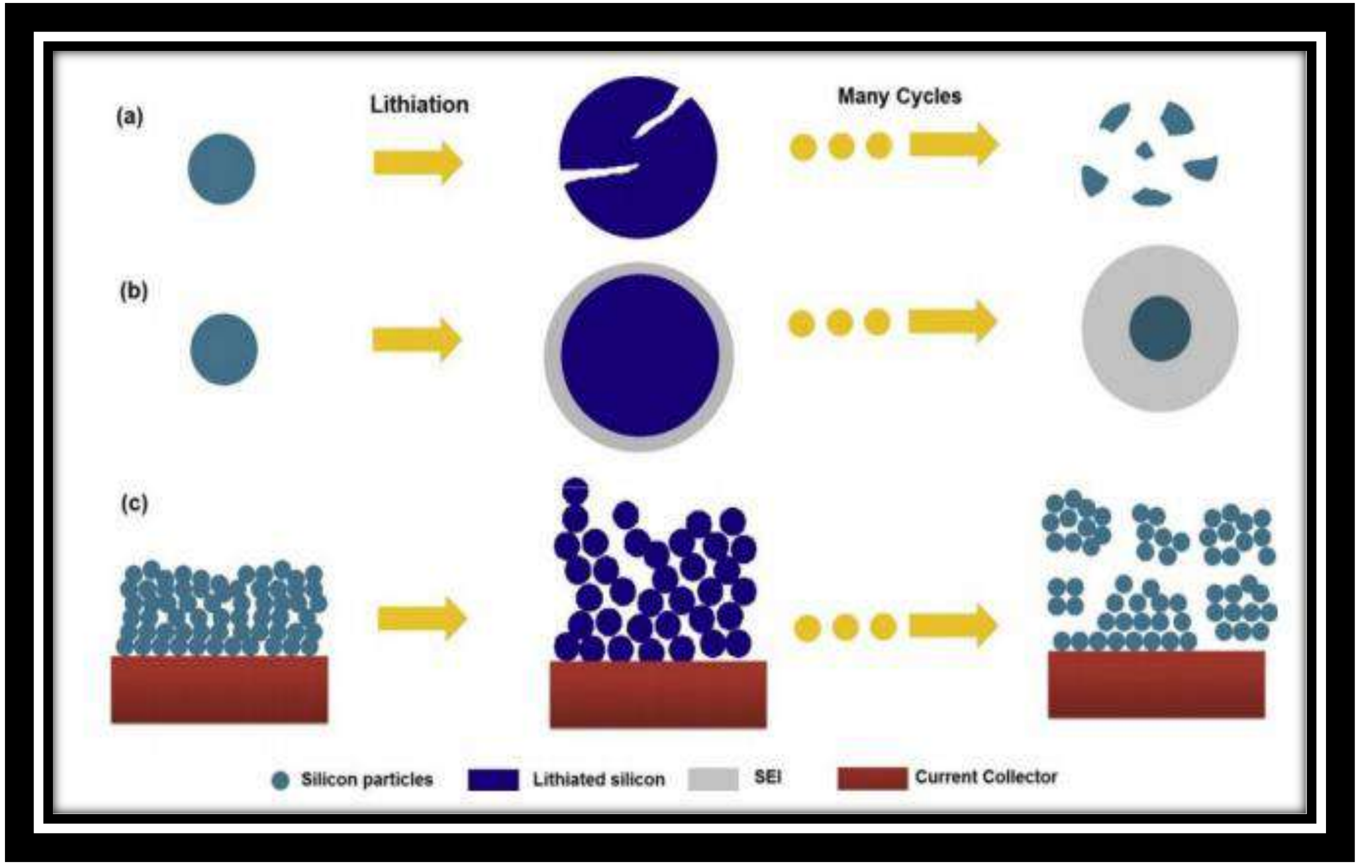


Image source: H Wu et al, 2012

Silicon: Incremental Steps

Graphite-dominant

5-25% Silicon

It's the low-hanging fruit.

Side effects are minimized, but also net gains.

An improvement in specific capacity is not noticeable until amounts higher than 10% are added.

It's a drop-in technology that does not require major process changes.

Tesla is rumored to have included small amounts of silicon in its batteries.

Silicon-rich

26-50% Silicon

It represents the ultimate goal of gradual improvements in graphite-dominant anodes.

Above 30%, the anode's overall capacity is significantly enhanced, **but major changes are also required on the cathode side in terms of electrode thickness in order to harness the full energy density.**

New electrolytes and additives may be needed to manage new side reactions.

Silicon-dominant

51-90% Silicon

It usually represents a setback from pure silicon anodes that suffer from poor cycle life. Graphite is added to increase longevity.

New cathode solutions are necessary for faster kinetics through thicker electrodes.

Pure silicon

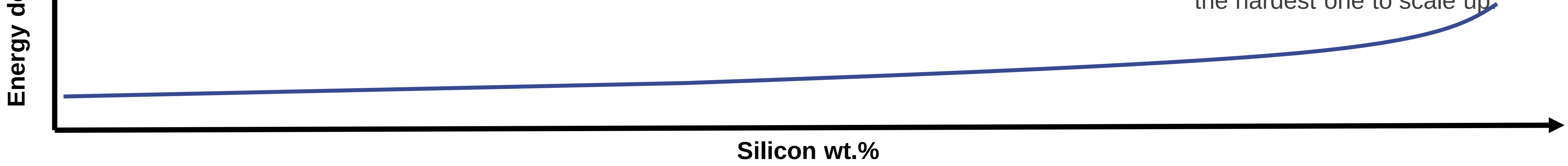
90-99% Silicon

Small amounts of inactive materials like binders and conductive agents are still needed.

Chip manufacturing processes can push that to 100%; this is only possible for microbatteries though.

Cracking phenomena have to be managed by increasing dead space between silicon microstructures; this can have detrimental effects on the overall energy density.

It is the field most of academic research focuses on, but also the hardest one to scale up.



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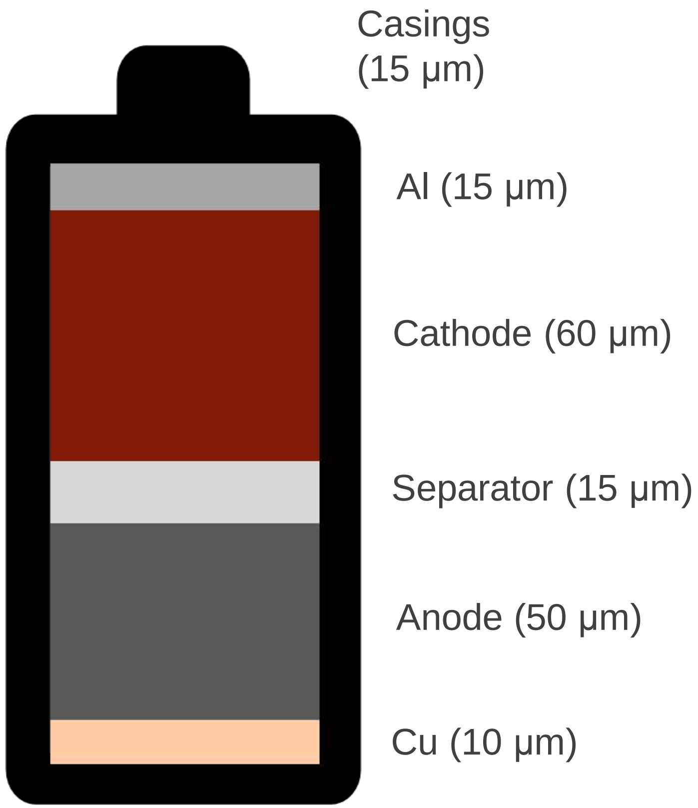
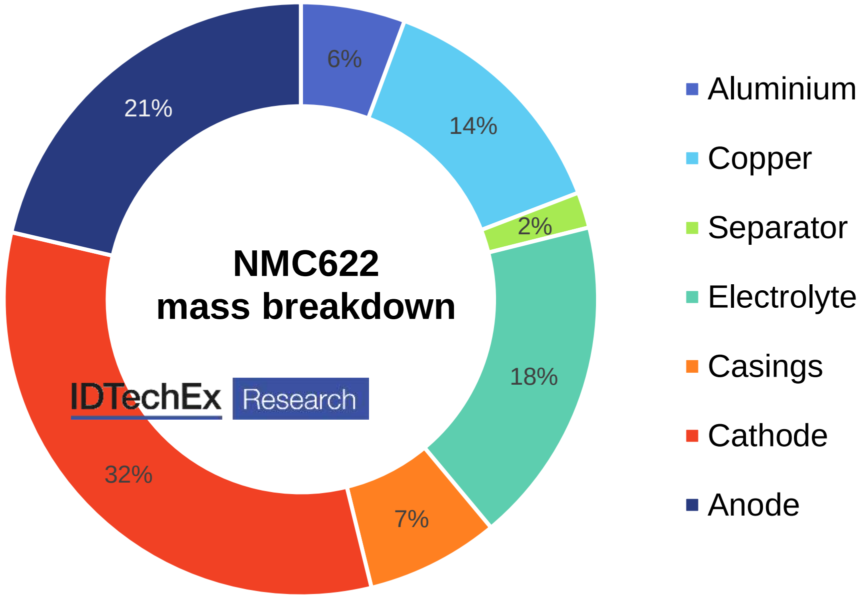
What is in a Cell?

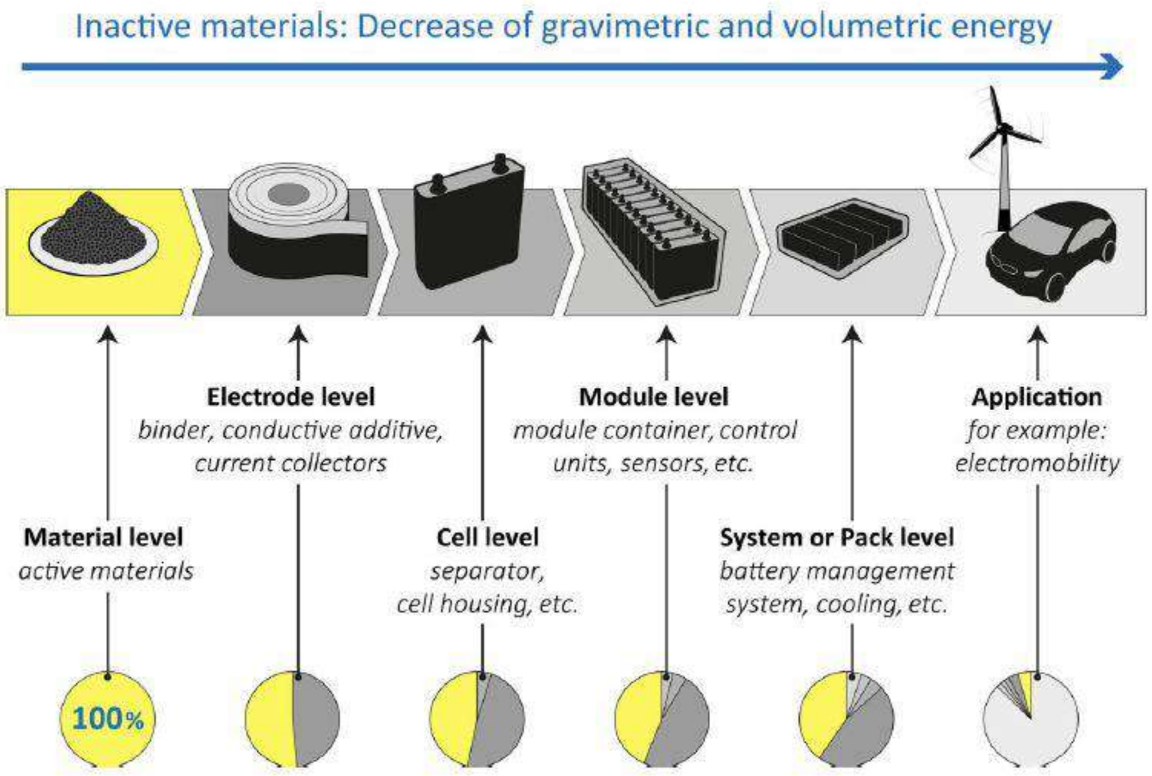
The majority of the cell weight comes from the active materials, but it is important to remember that casings and inactive materials can also play a role in improving energy density.





Inactive Materials Negatively Affect Energy Density

- Just placing an anode and cathode together does not make a battery cell. For it to work, the active materials have to be put in contact by means of an electrolyte and packaged. Additionally, the materials have to be glued together and conductivity ensured homogeneously across the electrodes.
- For all of this, inactive materials are needed. As the infographic to the right shows, these materials have a detrimental effect on the energy density, with the greatest toll being taken the moment the electrodes are prepared (45% drop).
- In the following slides, an overview will be given on what makes inactive materials important and what innovations are being carried out.

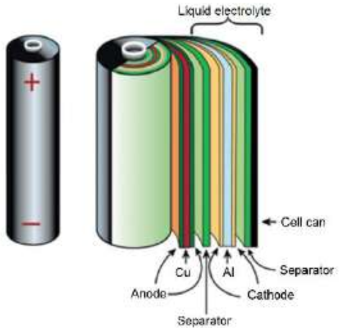


Source: Winter et al., 2017

Commercial Battery Packaging Technologies

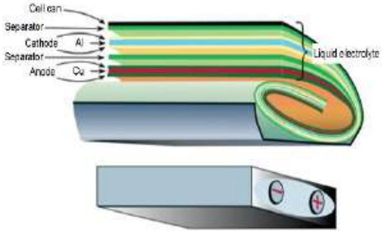
The anode and cathode are sandwiched by the electrolyte/separator to form a stack. The areal capacity of a single stack is about 1-2 mAh/cm2. This can be improved by folding/rolling several stacks to form different designs based on different packaging technologies as shown below. For thin and flexible batteries, the current collectors as well as battery packaging dominate the battery thickness.

Cylindrical



A spirally wound design (jelly-roll). Designated by size, e.g. 18650 cylindrical battery (Diameter: 18.6 mm, length: 65.2 mm; code for cylindrical shape: 0)

Prismatic

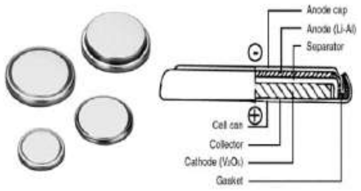


A prismatic design indicate a flat battery design. The stacks can be wound (as shown in the photo) or stacked (with alternating cathode/separator/anode structure). The stacks are usually inserted into rigid casing to form prismatic containers

Pouch

Rather than rigid metallic casing, conductive foil-tabs are welded to the electrodes and seal the battery fully. The stacks inside can be wound or stacked. Swelling and gassing could be a concern for pouch cells.

Coin cell



Also known as button cell. The cells are stacked into a tube. Most coin cells are single-use.

Source: J.M. Tarascon, Nature 2001, Sanyo and Panasonic

Comparison of Commercial Cell Geometries

Cylindrical

Advantages
- Cheap with high volumes
- Established manufacturing processes
- Opposing polarity on opposite ends of cell

Disadvantages
- Lower energy density
- Large numbers required
- Lower reliability?

Tesla

Prismatic

Advantages
- Robust
- Leak resistant
- Easy to replace

Disadvantages
- Expensive container
- More parts needed
- More complicated design
- More complicated processes
- More expensive tooling

BMW, Ford, Toyota

Pouch

Advantages
- Cheap
- Cheaper tooling
- Easy manufacturing processes

Disadvantages
- Easy puncture
- Seal reliability
- Difficult assembly
- Welding required

Chevrolet, Nissan

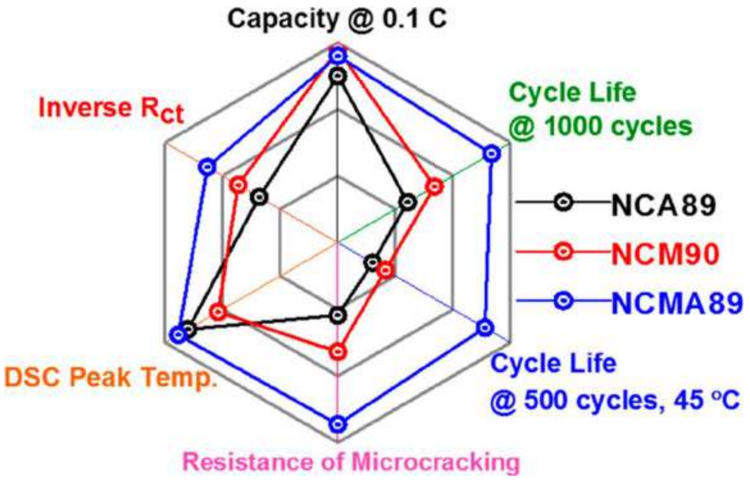
What is NCMA?

GM announced their plan to use an NCMA cathode chemistry, a combination of NMC and NCA (or Al doped NMC), along with a pack design that can reduce wiring by up to 80%.

Very generally, the use of manganese helps to improve thermal stability, while the use of aluminium helps with structural and chemical stability – this is certainly an oversimplification given the complexity of cathode chemistry and degradation in Li-ion cells. Nevertheless, combining both million and Al may well result in the best of both worlds.

A paper published in 2019 by Yang-Kook Sun, who worked extensively on core-shell gradients for high-Ni NMC, shows how NCMA ($LiNi_{0.89}Co_{0.05}Mn_{0.05}Al_{0.01}$) can demonstrate a capacity of 228 mAh/g – approximately 10% higher than current state-of-the-art. This was achieved by cycling the cathode to 4.3 V with a steady 10% drop in capacity over 100 cycles. Cycling to 4.2 V allowed the cathode to maintain 84.5% capacity over 1000 cycles - initial capacity was approximately 195 mAh/g.

The cathode shows improvement over current high-Ni NMC and NCA, though capacity increase is incremental – demonstrating the difficulty of improving cathode performance and suggesting an imminent ceiling to cathode capacity. The true value of NMCA and advanced cathodes will be in improved stability and cycle life.



Source: Yang-Kook Sun, 2019

Lithium-based Batteries Beyond Li-ion

Li-metal

Lithium-metal (Li-metal) batteries are those which replace the graphite anode with pure lithium metal. Using Li-metal rather than lithium ions intercalated into another material has great potential to improve energy density. For example, the theoretical specific energy of lithium-sulphur batteries (LSB) is 2500 Wh/kg, thanks to a cathode specific capacity of 1675 mAh/g. This compares with a theoretical capacity of 200 mAh/g for NMC cathodes and a state of the art 300Wh per kg, an order of magnitude lower. The main problem is lithium is extremely reactive, and difficult to control inside the cell. Cycle life therefore suffers and is currently limited to a few hundred cycles (1000 cycles is the threshold for usefulness in an electric vehicle, depending on energy density).

Solid State

A 'solid-state battery' typically refers to one with a solid inorganic electrolyte, although the definition sometimes also includes polymer electrolytes (which are commercial). This replaces the industry standard LP30, which is a wet electrolyte. Replacing LP30 is an innovation in terms of safety, as it is the wet electrolyte which burns and causes battery fires. Solid-state batteries typically use a Li-metal anode and can therefore make the additional leap in terms of energy density and performance, although conventional electrode materials can also be used. Initial problems such as ionic conductivity no longer a large barrier, but most companies struggle with improving cycle life beyond a few hundred cycles.

The chemistry types above are not yet commercial and are therefore outside the scope of this report. Coverage is included in IDTechEx's extensive portfolio of energy storage research, where we detail technology and market readiness level, key companies involved in developing the technologies, initial applications and more. For more information, please contact your subscription manager and visit www.IDTechEx.com/ESResearch

Li-ion Chemistry Snapshot: 2020, 2025, 2030

- True solid-state electrolytes are still 10 years away from widespread adoption but polymer and composite versions may find applications sooner. Added safety and potential cost benefit will push automotive OEMs toward them. The competition comes from improvements to liquid electrolytes and additives, which can further enhance performance from a system well understood from a manufacturing perspective.
- Electrode processing will shift away from NMP and toward aqueous solvents, already implemented for the anode where binders such as CMC and SBR are used. Various companies have developed dry electrode production techniques which can reduce cost of manufacturing.

2020	2025	2030
Cathode: Mix, Low-Ni cathodes	Cathode: High-Ni	Cathode: High-Ni widespread
Anode: Graphite-dominant	Anode: Graphite-dominant	Anode: Silicon-dominant
Electrolyte: LP30	Electrolyte: LP30 or Polymer	Electrolyte: solid inorganic
Processing: NMP (cathode), water (anode)	Processing: water	Processing: solvent-free

Electric Traction Motors

Electric Traction Motors: Introduction

All the electric motors have the same purpose of converting electrical energy to mechanical energy, but there are many types of motors that derive their names from their construction, principles of operation, or even from the control technique employed on them. The electric traction motors looked at in this report are the following:

- **DC brushless motor (BLDC)**
  - Stepper motor
- **AC induction motor or asynchronous motor (ACIM)**
  - Rotor wound
  - Squirrel cage
- **AC permanent magnet synchronous motor (PMSM)**
- **Wound rotor synchronous motor (WRSM)**
- **Switched reluctance motor (SR)**
- **Permanent magnet assisted reluctance motor (PMAR)**

Electric Traction Motors: Introduction

Each motor technology is scored on the parameters shown in the table below. Parameters were chosen based on what has the greatest overall influence on an OEM to chose a particular motor for a certain market or vehicle. Each parameter is given a score out of 10, where 10 represents best in class and 1 is poor (relative only to motor types considered in this study). Alongside each score we have provided comments which explain our reasoning. The 'Value' metric is a quick indicator of the quantitative score, where 1-5 is 'Poor', 6-8 is 'Good' and 9-10 is 'Excellent'. There are nine parameters, so each motor has a total out of 90; the totals are compared for each motor type at the end of this section.

Example Scoring Table

Parameter	Value	Comments	Score
Power Density (kWp per kg)	Poor	Poor compared to brushless motors.	3
Torque Density (Nm per kg)	Poor		4
Efficiency	Poor	< 85%. Poor compared to brushless motors.	3
Ease of Manufacture	Good	Cheapest to manufacture initially.	7
Scalability	Poor	The motors typically remain for low power and torque applications due to reliability issues.	4
Low Cost ($ per kW)	Excellent	Cheapest type of motor for initial manufacture.	10
Controllability	Excellent	Relatively simple to control versus non permanent magnet traction motors.	10
Reliability	Poor	Torque ripple; brushes wear out and need to be replaced often.	3
Low Noise	Poor	Noisy due to brush contacts and torque ripple.	3
Total			47

Brushless DC Motors (BLDC): Working Principle

Summary

- Permanent magnets on the rotor, electromagnets on the stator (Cu windings).
- ‘Reversing DC’, Synchronous.

Working Principle

- A DC current is constantly switched between adjacent coils (concentrated winding) which creates an electromagnet that attracts the permanent magnets on the rotor in steps, producing a torque. The more sets of coils in the motor, the more continuous the rotating field will appear. However, due to the discrete steps in the field there will always be an element of ‘torque ripple’.
- The rotor moves at the speed of the rotating radial field from the stator, so it is a synchronous machine. Varying the current through the stator varies the motor speed.
- Hall effect sensors are used to detect the rotors position so that the stator coils can be energised at the correct time. Three sensors are typically used for BLDC motors with six phases of excitation across the stator coils.
- Back EMF is trapezoidal.

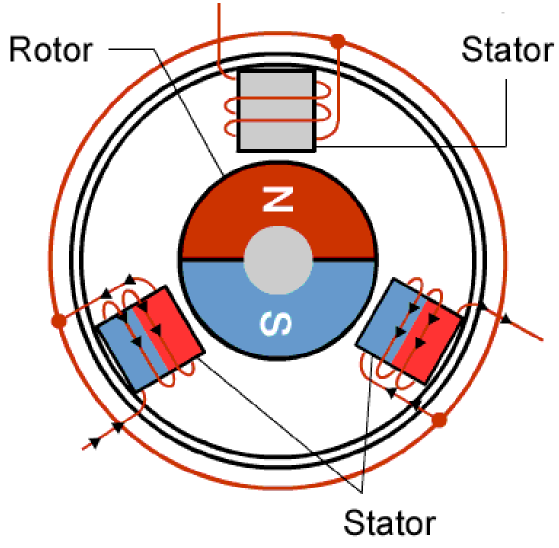


Image source: Renesas Electronics

The Stepper Motor
A stepper motor is a type of BLDC motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any position sensor for feedback, as long as the motor is carefully sized to the application in respect to torque and speed. It is typically used only if precise positioning is required, and is suitable for use with computer-controlled systems. Some key applications are in tape drives, floppy disc drives, printers and electric watches.

BLDC Motors: Advantages, Disadvantages

Advantages

- Higher speeds and longer life span than brushed.
- Cheap (mass produced in China).
- Low maintenance.
- Good response at high speeds.
- Easy to control.
- Ability to self start.
- Better torque to weight than brushed.

Disadvantages

- Electronic speed controller is needed.
- Short constant power range.
- Permanent magnets increase cost, and potential for magnets to denature at higher temperatures.
- 85-90 % efficiency.
- Torque ripple.

BLDC Motors: Benchmarking Scores

Markets - Two-wheelers, Three-wheelers

- Many non-vehicle applications: computer hard drives and disk players, industrial robots, CNC machine tools, simple belt driven systems, washing machines, compressors, dryers, fans, pumps and blowers.
- As micro electric vehicle markets tend to be very price-sensitive and require compact power-dense motors (less space on the vehicle itself), BLDC motors are typically used due to their compact size and lower cost than PMSM. They are replaced by PMSM for larger vehicles due to their improved power density, noise and reduced torque ripple.

Parameter	Value	Comments	Score
Power Density (kWp per kg)	Good	Better than brushed motors but less than other types as typically sold off the shelf (not fine-tuned to the application).	8
Torque Density (Nm per kg)	Good		8
Efficiency	Poor	< 90%. Worst amongst the electric traction motors widely adopted in electric vehicles.	5
Ease of Manufacture	Good	Relatively difficult: magnets have to be glued, banded and assembled with fine tolerances between the rotor surface magnets and the stator.	7
Scalability	Good	Permanent magnet motors are harder to scale as it generally involves more gluing and banding of magnets on a larger rotor.	7
Low Cost ($ per kW)	Excellent	Cheap because of high manufacturing volume in China. Off-the-shelf BLDC motors are sold globally from China.	9
Controllability	Good	Relatively simple to control versus non permanent magnet traction motors, more difficult than PMSM due to torque ripple, depending on motor design.	7
Reliability	Average	Torque ripple and risk of denaturing magnets during overvoltage.	6
Low Noise	Good	Noise produced by torque ripple.	7
Total			64

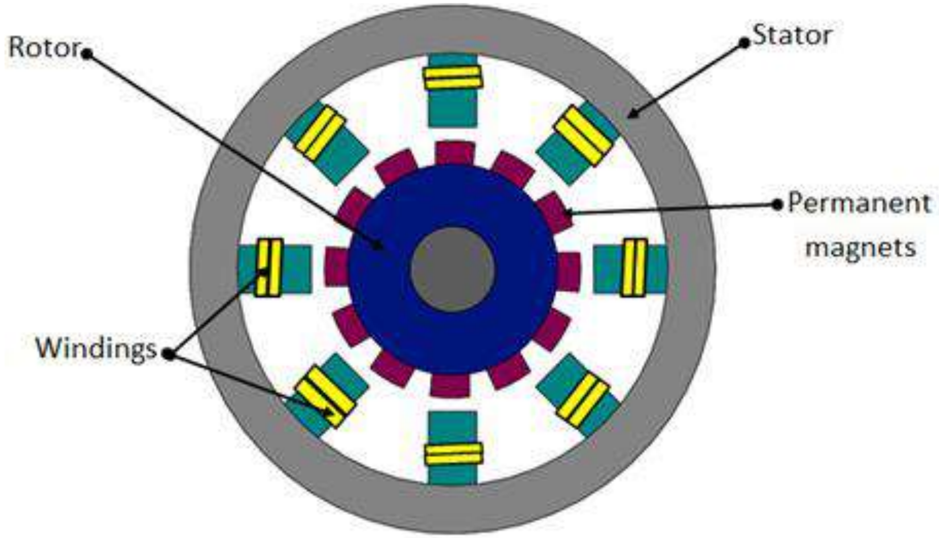
Permanent Magnet Synchronous Motors (PMSM): Working Principle

Summary

- Permanent magnets on the rotor, electromagnets on the stator (Cu windings).
- AC, Synchronous.

Working Principle

- The operating principle of PMSM is very similar to the BLDC, but the key difference is that a three-phase AC current is fed to the distributed stator windings which produces a continuously rotating radial field ('sinusoidal waveform'). Permanent magnets on the rotor continuously follow this field.
- One Hall effect sensor can be used to detect the rotor position as the commutation is continuous (in comparison to BLDC motors, where the commutation has small breaks).
- The Back EMF is also sinusoidal.
- The rotor rotates at the same speed as the electromagnetic field produced by the stator, so the motor is synchronous.



Source: Embitel

PMSM: Advantages, Disadvantages

Advantages

- High efficiency, up to 95%.
- AC drive current reduces noise.
- No torque ripple.
- Highest power and torque density.
- More reliable and less noisy than asynchronous motors.
- High performance at low speeds.
- Lower weight and size compared to BLDC, ACIM.

Disadvantages

- More expensive than BLDC as more complex construction.
- More expensive than ACIM.
- Susceptible to neodymium price hikes (China controls neodymium supply).
- High temperatures can denature magnets (does not deal well with over-voltage).
- Potential to spin out of control.

PMSM: Benchmarking Scores

Markets - Cars, LCVs, Trucks, Buses, Two-wheelers

- Most hybrid and pure electric vehicles (EVs) by land, water and air use PMSM.
- 62% of PHEV & BEV passenger cars used PMSM motors in 2019.
- Used most due to best power density, efficiency and noise.
- Perform best at partial loads which makes them particularly suitable for cars.

Parameter	Value	Comments	Score
Power Density (kWp per kg)	Excellent	Highest power and torque density of motor types for a sustained period due to most use of magnetic material.	10
Torque Density (Nm per kg)	Excellent		10
Efficiency	Excellent	< 95%. Excellent efficiency compared to other motors; second only to PMAR.	9
Ease of Manufacture	Average	Relatively difficult: magnets can be glued, banded and assembled with fine tolerances between the rotor surface magnets and the stator.	7
Scalability	Good	Permanent magnet motors are harder to scale as it generally involves more gluing and banding of magnets on a larger rotor.	7
Low Cost ($ per kW)	Average	Most expensive type of motor, mainly due to more use of magnetic material than other motor types.	6
Controllability	Good	Relatively simple to control versus non permanent magnet traction motors.	8
Reliability	Good	Risk of denaturing magnets during overvoltage.	7
Low Noise	Excellent	No contact between the rotor and stator; little to no torque ripple.	10
Total			74

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Wound Rotor Synchronous Motor (WRSM): Working Principle

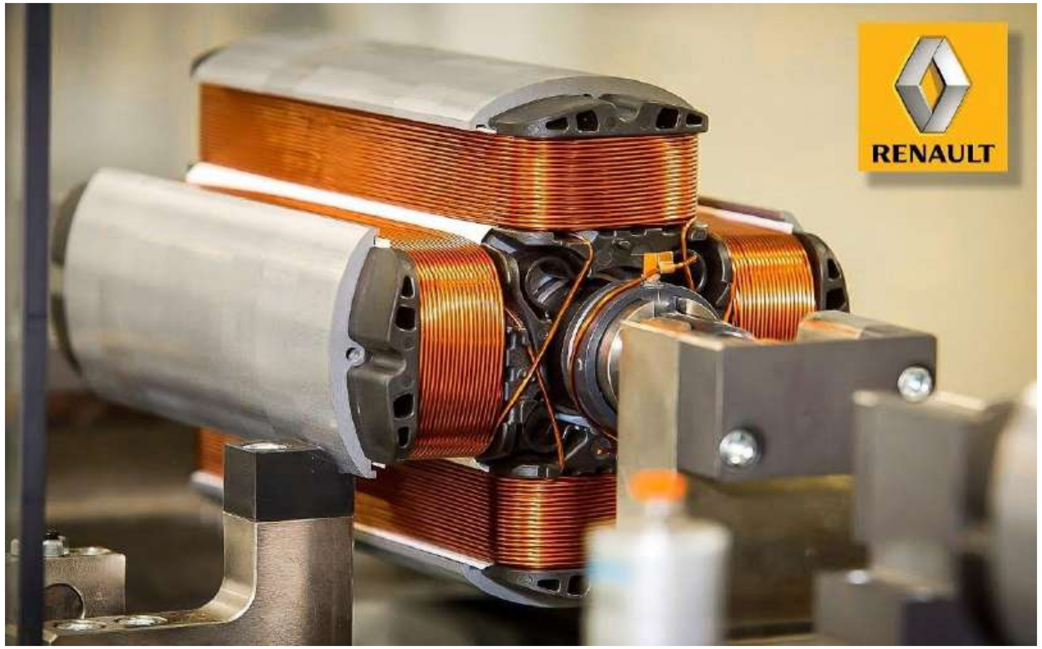
Summary

- Electromagnets on the rotor, electromagnets on the stator (Cu windings).
- AC (Stator), DC (Rotor), Synchronous.

Working Principle

A WRSM operates very similarly to the PMSM with an AC current fed to the distributed copper windings in the stator.

- The difference comes in the rotor where the permanent magnets are replaced with copper coils, supplied with a DC source to turn them into permanent electromagnets.
- This eliminates the rare-earth magnets and allows more precise control of the rotor field.
- Renault are the only automaker using this type of electric traction motor in electric vehicles.



Renault WRSM Rotor. Image source: GommeBlog.it

WRSM Motors: Benchmarking Scores

Markets - Cars, LCVs

- Renault are the main manufacturer using this type of motor.
- The WRSM motor was originally supplied by Continental, however Renault now manufacture this themselves.
- The Renault Zoe took 13% of total PHEV & BEV passenger car sales in Europe for 2019 and ≈ 3.5% of electric car sales worldwide.
- Renault's offerings took 43% of the total eLCV market in Europe for 2019.

Parameter	Value	Comments	Score
Power Density (kWp per kg)	Good	Worst of all electric traction motor types widely adopted due to high use of copper.	7
Torque Density (Nm per kg)	Good		7
Efficiency	Good	Can be lower than permanent magnet variants due to Joule losses in the rotor.	7
Ease of Manufacture	Good	Both rotor and stator have copper windings on Si-Steel; don't have to assemble small magnets, but they do have extra copper on rotor and electrical connections to it.	8
Scalability	Excellent	Both rotor and stator have copper windings on Si-Steel, although greater amounts of copper required on the rotor could increase rotor weight significantly.	9
Low cost ($ per kW)	Good	Does not require expensive rare-earth magnets but does require more copper than permanent magnet motors and induction motors.	8
Controllability	Good	Relatively simple to control: rotor becomes an electromagnet with a controllable magnetic field.	7
Reliability	Excellent	Copper and Si-Steel, no risk of denaturing any magnets.	9
Low Noise	Good	No contact between the rotor and stator; little to no torque ripple.	8
Total			70

WRSM: Advantages, Disadvantages

Advantages

- No torque ripple.
- More reliable.
- Does not require rare-earth metals.
- No risk of denaturing magnets with higher temperatures.
- Possible to finely control rotor magnetic field.

Disadvantages

- Heavy as most use of copper.
- More difficult to control than DC motors.
- Requires extra electronics to supply rotor windings with DC current.

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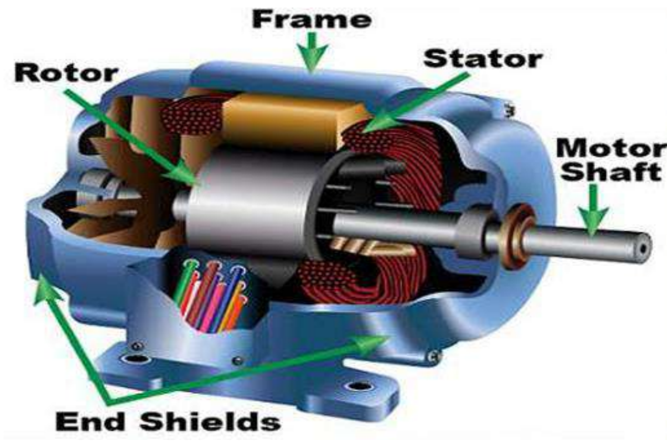
AC Induction Motors (ACIM): Working Principle

Summary

- Copper windings / bars in laminated slots of Si-Steel rotor, or copper bars form short circuits with end rings (‘squirrel cage’).
- Electromagnets on the stator (Cu windings).
- AC, Asynchronous.

Working Principle

- In a typical induction motor, the stator consists of three-coil distributed windings fed with three-phase AC power. This produces a rotating radial magnetic field (sinusoidal waveform).
- The rotating field induces currents into the closed circuit loops on the rotor, which in turn produces a magnetic field that is attracted to / repelled from the radial field from the stator windings. Thus, a torque is developed by the interaction of axial currents induced on the rotor and a radial magnetic field produced by the stator.
- Since the rotor’s torque-producing currents are induced by electromagnetic action (rather than fed in with a current from the stator), the motors are ‘induction’ motors.
- The rotor is ‘dragged’ by the rotating magnetic field but never moves fast enough to catch it, meaning it is an asynchronous motor.



Source: Polytechnic hub

AC Induction Motor (ACIM)

- The stator of the induction motor is very similar to that of the PMSM and drives with copper coils wound throughout. Three-phase AC is typically applied to the stator windings.

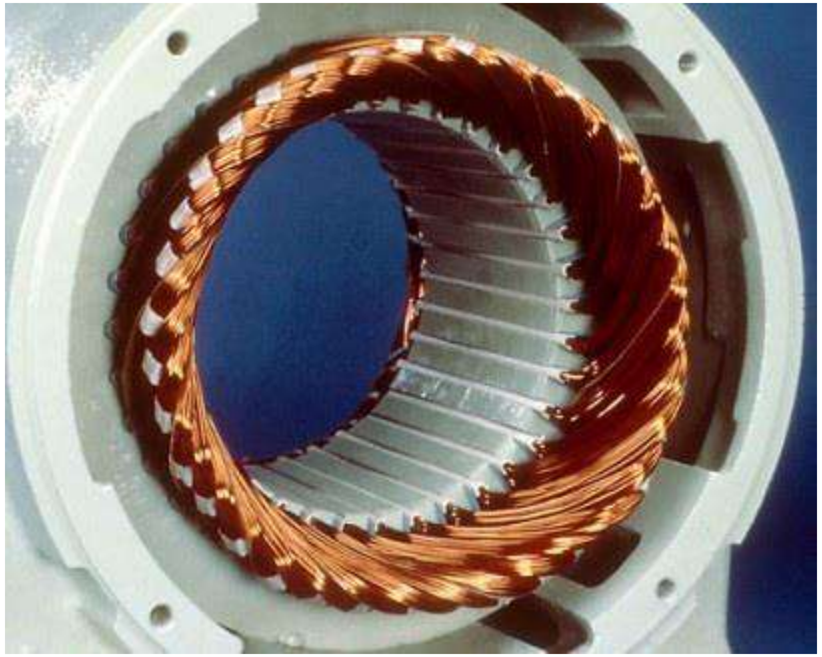


Image source: Quora

- Rotor of an induction motor: silicon steel with evenly spaced slots (left) is inserted with copper windings or bars, or rotor bars (with end links) is made of copper or aluminium (right).
- The rotation of the rotor is produced by the currents induced in the bars or windings by the varying magnetic field from the stator.

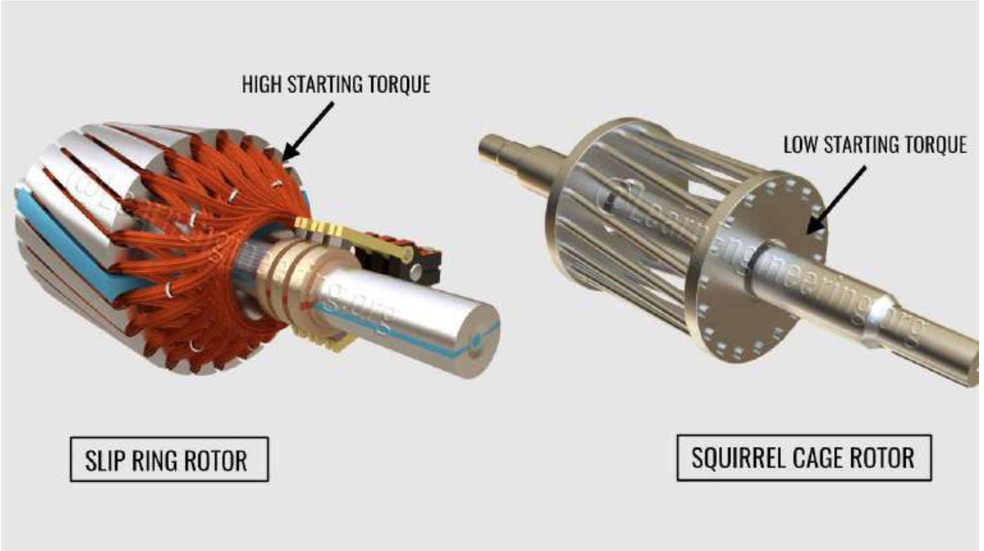


Image source: Learn Engineering

AC Induction Motors: Benchmarking Scores

Markets - Off-road, Cars, LCVs, some Buses

- Very common for fixed speed applications.
- Used in most forklifts, construction, agriculture, mining vehicles and a handful of car models.
- Tesla used induction motors for all their vehicles until the Model 3 where a PMAR is used in the rear, but an ACIM is still present on the front axle of all wheel drive variants.
- NIO, the China-based electric car start-up, use ACIMs.
- The Audi e-tron uses an ACIM.

Parameter	Value	Comments	Score
Power Density (kWp per kg)	Excellent	Peak values are above permanent magnet motors due to ability to overvoltage for short periods. Continuous values will be lower than PMSM.	9
Torque Density (Nm per kg)	Excellent		9
Efficiency	Good	< 93%. Less efficient than permanent magnet motors due to Joule losses in the rotor.	6
Ease of Manufacture	Good	No assembly of magnets required, simple copper rotor bars or windings are used instead.	8
Scalability	Good	No permanent magnets, it is easy to scale windings and Si-Steel.	9
Low cost ($ per kW)	Excellent	Induction motors are usually cheapest due to no magnetic material, simple construction and high production volumes (widespread industrial use).	9
Controllability	Excellent	Relatively simple to control, low controller cost.	9
Reliability	Excellent	Copper windings or bars and Si-Steel, no risk of denaturing any magnets.	9
Low Noise	Good	Physical size can be larger than PMSM for a given power density.	7
Total			75

AC Induction Motor: Advantages, Disadvantages

Advantages

- Simple construction.
- Cheaper (simple construction, economies of scale).
- No sliding mechanical contacts = big savings in maintenance cost.
- Rugged.
- No permanent magnets (which are expensive and can de-nature).
- Overvoltage possible (the Tesla S and X use for superb acceleration).
- More historical use / experience.

Disadvantages

- Only for fixed speed as fast control of torque difficult.
- Load-dependent slip of the rotor.
- Less efficient (relative to PM).
- Can be larger than equivalent PMSM.
- Higher power to weight ratio due to increased use of copper.
- Not suitable for racing cars or other enduring high performance.

Reluctance Motors

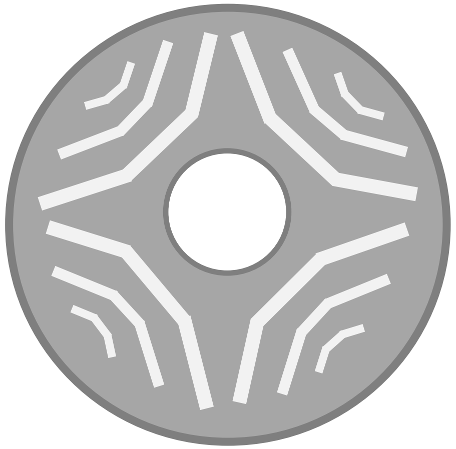
Summary

- Electromagnets on the stator (Cu windings) fed with DC.
- Laminated Si-Steel rotor.
- DC, Synchronous.

Operating Principle

- Reluctance motors are fundamentally different to other electric traction motors since there are no permanent magnets or electromagnets (induced or otherwise) present on the rotor.
- The fundamental principle behind the ‘reluctance’ motor is minimising energy. Since steel has a very low reluctance (‘magnetic resistance’) compared with air gaps, the magnetic flux will preferentially travel through the steel whilst at the same time attempting to shorten its flux path. The reluctance motor uses this principle by creating flux pathways (of steel) in the rotor. At speed, a rotating radial magnetic field produces torque by making the rotor constantly move to try to shorten its flux paths.
- The switched reluctance motor is a type of stepper motor that uses the principle of minimising reluctance rather than permanent magnets.

Synchronous Reluctance Rotor

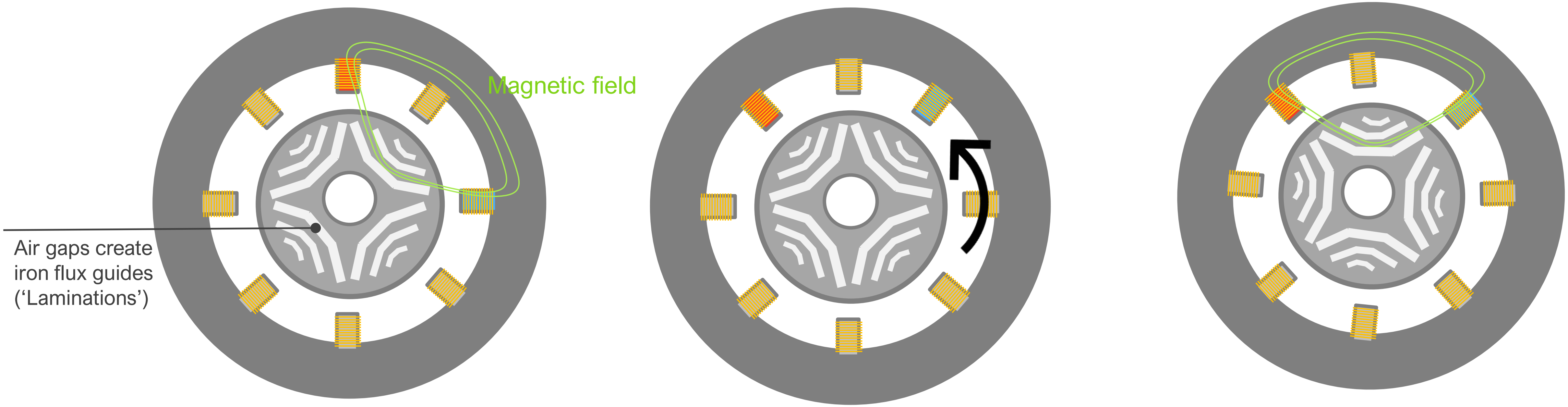


Switched Reluctance Rotor

Image source: IDTechEx

Reluctance Motor: Working Principle

As demonstrated below, the reluctance motor creates short flux pathways in the rotor via laminations in the Si-Steel. At speed, a rotating radial magnetic field produces torque by forcing the rotor to constantly rotate to shorten its flux paths.



Magnetic flux takes shortest iron pathway through rotor.

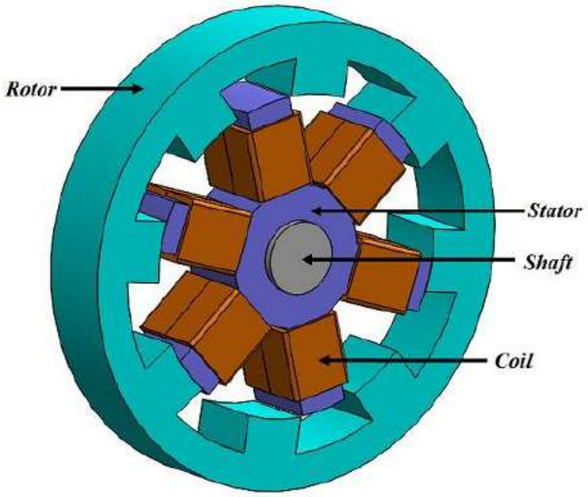
Adjacent set of coils activate and field lines lengthen to travel through longer iron pathways.

Rotor rotates to shorten field lines.

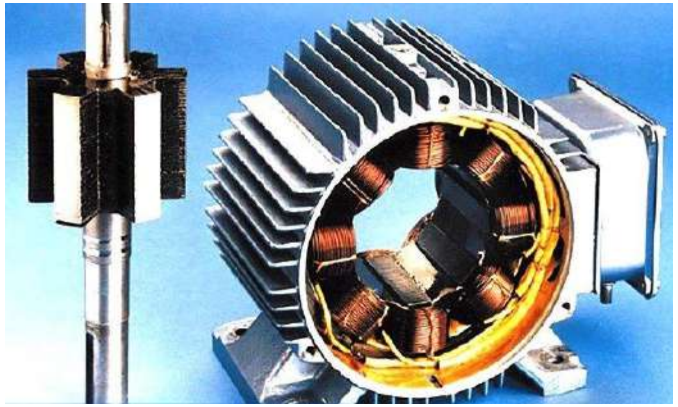
Image source: IDTechEx

Switched Reluctance Motor (SRM)

- Because the rotor of SRMs is just a slotted rod of metal, without even the simple copper windings of induction or WRSM rotors, they are the cheapest and most reliable of all the motors.
- While this is promising, there are some significant drawbacks: they can be acoustically noisy and difficult to make perform the complex, silent requirements of a car. SRMs tend to be used in huge construction, mining and agricultural EVs where noise is not as much of an issue.
- Torque ripple is also a significant issue and a more complicated and expensive controller is required to operate SRMs.



Source: EMWorks



Source: Electrical Engineering Portal

Switched Reluctance Motors: Benchmarking Scores

Markets - Off-road vehicles, Industrial

- Some use in heavy-duty off-road vehicles.
- Used in John Deere agricultural hybrids.
- Limited use in automotive applications due to noise and difficulty obtaining a smooth driving experience.

Advantages

- Extremely simple rotor construction.
- Independent of rare-earth prices.
- Reduced copper versus induction and WRSM.
- Robust to wear, temperature, shock and vibration.
- Fast response.

Disadvantages

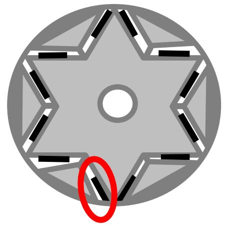
- Noisy.
- Twice as much circuitry needed to get required torque / revolutions / smoothness characteristics.
- Fine tolerances.
- Torque ripple.
- Lower power density.

Parameter	Value	Comments	Score
Power Density (kWp per kg)	Good	Can be lower than permanent magnet motors due to torque ripple, but this can be mitigated if well designed / controlled.	7
Torque Density (Nm per kg)	Good		8
Efficiency	Good		8
Ease of Manufacture	Excellent	Similar stator to other motor types but an extremely simple rotor.	9
Scalability	Excellent	Easy to scale copper windings and laminated Si-Steel.	10
Low cost ($ per kW)	Excellent	Cu windings on stator are similar to other motor types, whereas the rotor is a slotted rod of steel with no copper or rare-earth magnets.	9
Controllability	Poor	Twice as much circuitry needed to get required torque / revolutions / smoothness characteristics.	5
Reliability	Excellent	Copper and Si-Steel, no risk of denaturing any magnets.	9
Low Noise	Poor	Torque ripple can lead to high levels of acoustic noise which limits its use in on-road vehicles.	4
Total			69

Permanent Magnet Assisted Reluctance (PMAR)

Tesla claims to have introduced a ‘permanent magnet switched reluctance’ (PMSR) motor in the Model 3, which as the name suggests is a hybrid of permanent magnet synchronous motors and reluctance motors. However, industry interviews conducted by IDTechEx suggest Tesla’s motor design is better described as a ‘permanent magnet-assisted reluctance’ (PMAR), rather than a PMSR. This is because it has a standard three-phase voltage source inverter which is coupled to a standard V-shape interior permanent magnet synchronous reluctance rotor.

‘Switched reluctance motors use special asymmetric half-bridge converters and no magnets in the rotor. Only very rarely do SR motors have magnets in the stator, for very specific applications’ Cleef Thackweel, lead motor designer for Jaguar Land Rover, revealed to IDTechEx. Tesla’s adoption of PMAR boosted their efficiency to 97% (from 93% in their old induction motor) - the highest known of any electric traction motor on the market.



Tesla Model 3. Image sources: IDTechEx, Tesla

PMAR Motors: Benchmarking Scores

Markets - Cars, LCVs, Trucks

- Tesla have shifted to using PMAR in their Model 3, the front motor remains ACIM for now, but newer versions of the Model S and X, plus the Cybertruck, Model Y and Semi will be using this type of motor.
- BMW have been using a similar hybrid of PM and SR in their electric drive system since the i3.
- PMSR is likely to take a much larger stake in the passenger car market due to reduced rare-earths, costs, increased efficiency and similar performance to PMSM.

Advantages

- Less torque ripple when compared to pure SR motor.
- Similar power and torque density to PMSM.
- High efficiency (Tesla Model 3 at 97 %).

Disadvantages

- Still utilises similar level of magnetic materials.

Parameter	Value	Comments	Score
Power Density (kWp per kg)	Excellent	On par or slightly lower than PMSM but higher than all others.	9
Torque Density (Nm per kg)	Excellent		9
Efficiency	Excellent	< 97%. Better than ACIM and can be as good or better than PMSM by combining the benefits of reluctance and permanent magnet motors.	10
Ease of Manufacture	Good	Easier than PMSM as permanent magnets are predominantly interior to the rotor which reduces need for gluing and banding as well as fine tolerances.	8
Scalability	Good	Harder to scale versus ACIM, SR and WRSM due to the magnetic material required.	7
Low cost ($ per kW)	Average	Similar amount of magnetic material and therefore cost to PMSM.	7
Controllability	Good	Reluctance elements will require more circuitry in the controller, but combining this with magnets mitigates this compared to pure SR.	7
Reliability	Good	Still a risk of denaturing magnets during overvoltage and seriously damaging motor performance, if not completely.	7
Low Noise	Excellent	Greater than PMSM, but less torque ripple than SR due to magnetic material.	9
Total			73

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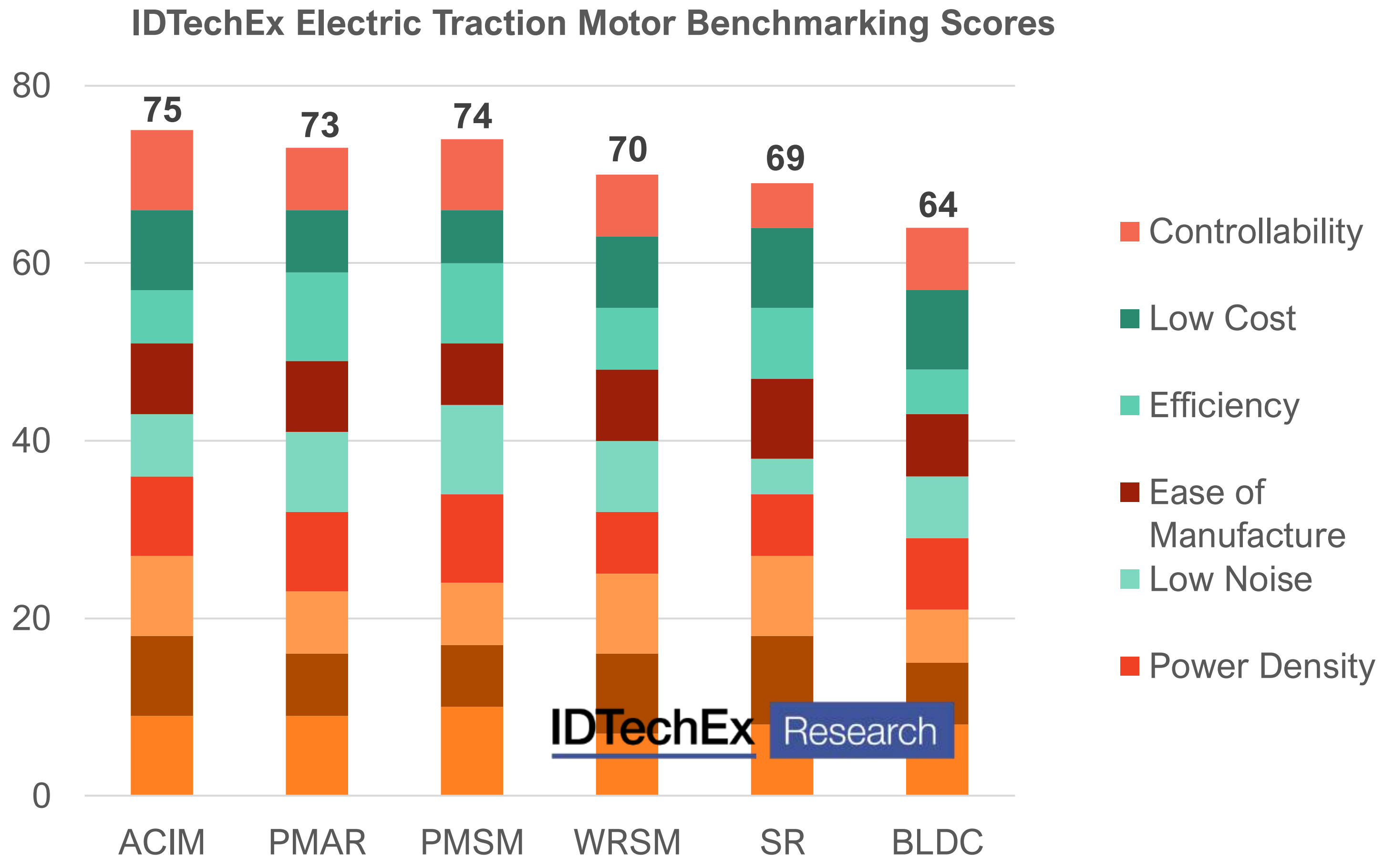
Electric Traction Motors: Summary and Benchmarking Results

Comparison of Traction Motor Construction and Merits

Motor	Operation	Rotor construction	Advantages	Limitations
Brushless DC Motor (BLDC)	DC, Synchronous	A solid rotor with permanent magnets mounted on its surface or interior.	• Low cost due to mass production in China. • Good power density (compact enough for micro electric vehicle applications). • Good speed control.	• Lowest efficiency (85%-90%). • Contains rare-earth magnets. • Significant torque ripple. • Less smooth control vs PMSM due to DC input.
AC Induction (ACIM)	AC, Asynchronous	Copper windings or bars in slots of Si-Steel ('Slip-Ring'), or copper bars which form short circuits with end rings ('squirrel cage').	• Good efficiency < 93%. • Rugged. • Relatively easy to manufacture and scale. • Excellent peak power and torque density due to overvoltage. • Overvoltage possible due to lack of PMs. • Lower cost and low risk of cost volatility (no PMs).	• Lower efficiency and power density compared with PMSM. • More copper required than PMSM, PMSR.
Permanent Magnet Synchronous (PMSM)	AC, Synchronous	A solid rotor with permanent magnets mounted on its surface or interior.	• Excellent efficiency (< 95%). • Highest power density. • Highest torque density.	• High cost. • Contains rare-earth PM. • Hard to make the largest motors for industrial applications due to PMs.
Wound Rotor Synchronous Motor (WRSM)	AC, Synchronous	Copper windings on the rotor are fed with DC to create an electromagnet.	• No rare-earth PMs required. • Low cost and low risk of cost volatility (no PM). • Relatively easy to manufacture and scale.	• Extra electronics and connections required to provide current to rotor. • More copper required than PMSM, PMSR, ACIM (therefore heavier).
Switched Reluctance Motor (SRM)	DC, Synchronous	Laminated Si-Steel with no permanent magnets or windings.	• Low cost and low risk of cost volatility (less copper and no PM). • Rugged and reliable. • Relatively easy to manufacture and scale.	• Significant torque ripple. • Noisy. • More complicated motor controllers required.
Permanent Magnet Assisted Reluctance (PMAR)	AC, Synchronous	Laminated Si-Steel having some paths in the rotors which are partially filled with magnets.	• Highest efficiency (< 97%). • Less torque ripple than pure SRMs.	• More complicated motor controllers required versus PMSM. • Still contains magnetic material.

Benchmarking Electric Traction Motors

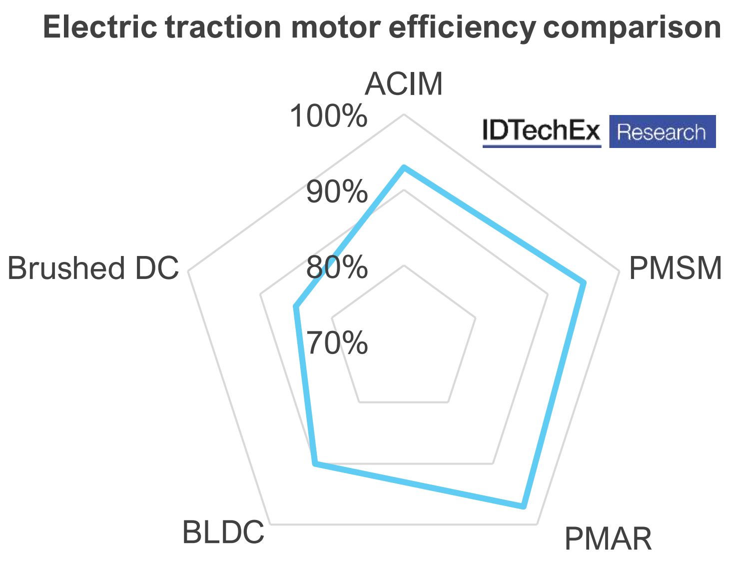
- PMAR, PMSM and ACIM have very similar scores, each with slightly different strengths over the other such as efficiency or reliability.
- In the markets, PMSM and PMAR currently take the lead due to the importance of having higher power density and efficiency. However, they can be sensitive to price hikes of permanent magnets found predominantly in China.
- A major trend IDTechEx see is towards PMAR type motors with high efficiency.



Notes: Each parameter scored out of ten (1- poor 10 - best in class). Source: IDTechEx

Motor Efficiency Comparison

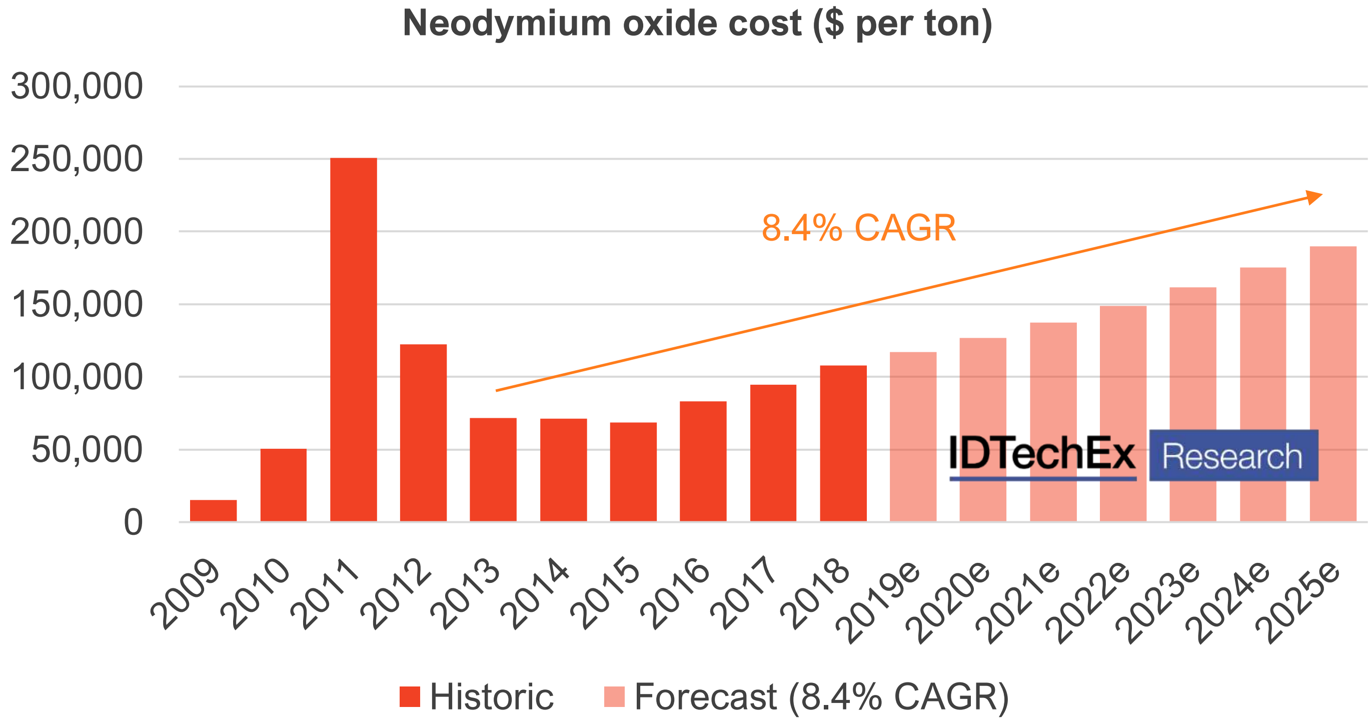
In the markets, PMSM and PMAR currently take the lead due to the importance of having higher power density and efficiency. Efficiency is important because it increases vehicle range (a key metric to sell and differentiate an electric vehicle) without needing to increase the battery capacity. We show the efficiency advantage of permanent magnet motors below.



Source: IDTechEx

Magnet Price Increase?

The cost of Neodymium, the main ingredient in the permanent magnets used for electric traction motors, has been steadily increasing for the past few years. The slow cost increase shown below could result in a 'boiling the frog' scenario for motor manufacturers, and create opportunities for non-permanent magnet motors such as ACIM and SR. However, if the cost stabilises, permanent magnet motors are unlikely to be displaced.



Data source: Statista, IDTechEx forecast

After the cost hike in 2011 increased the heat for OEMs, they leapt out the pot, avoiding PM motor designs. Costs have since declined and stabilised: as the industry converges on PMSM and PMAR, a slow cost increase in magnets could result in a 'boiling of the frog' scenario for motor manufacturers and OEMs.

Multiple Motors: Explained

Single Motor

A single motor setup is the most basic and typically consists of a PMSM motor front-mounted for range and efficiency or rear-mounted for performance. It is the most cost-effective option, but sacrifices optimizing acceleration, efficiency and handling.

Dual Motor (two traction motors) - the mainstream for LCVs

The typical dual-motor setup is permanent-magnet at the front for city-driving, and an AC Induction Motor (ACIM) on the rear for acceleration (inactive most of the time, and able to free-wheel when not in use without losses). ACIMs are typically beneficial for acceleration as they can over-voltage for short periods of time with no risk of denaturing permanent magnets. Moving to a dual-motor set-up strikes a balance of cost and (noticeable) performance advantages: we believe most mass-market electric cars and LCVs will eventually converge on a dual motor setup.

Quad Motor (four traction motors)

In four-wheelers, the choice to move to quad motors (one per wheel) is to reach the highest level of performance (acceleration, efficiency, handling etc.). It also brings redundancy advantages: if one motor fails the others continue relatively easily. We believe quad motors will be limited to premium segments because of the added cost and low benefit for the average user (law of diminishing returns over dual motors). There are two technology options: in-wheel, which will likely require permanent magnet axial flux motors for their power density (fitted inside a compact wheel), and near-wheel which can rely on conventional radial flux permanent magnet motors (lower cost). Rivian and Lightyear plan to release quad motor cars.

Tri Motor (three traction motors)

A tri-motor setup is a more cost-effective way of achieving most of the benefits of the quad-motor. Typically two near-wheel motors are mounted on the rear to achieve performance while one motor is front-mounted. Providing more power to the rear wheels is important for performance because, as the vehicle accelerates, more weight is loaded on the rear tires (roughly 2:1). One motor at the front also allows more space for steering.

LCVs & Trucks

The majority of electric LCV and truck sales is split between China and Europe. In China, the vast majority of the electric LCV and truck market are utilising PMSM drives, similar to the electric car market.

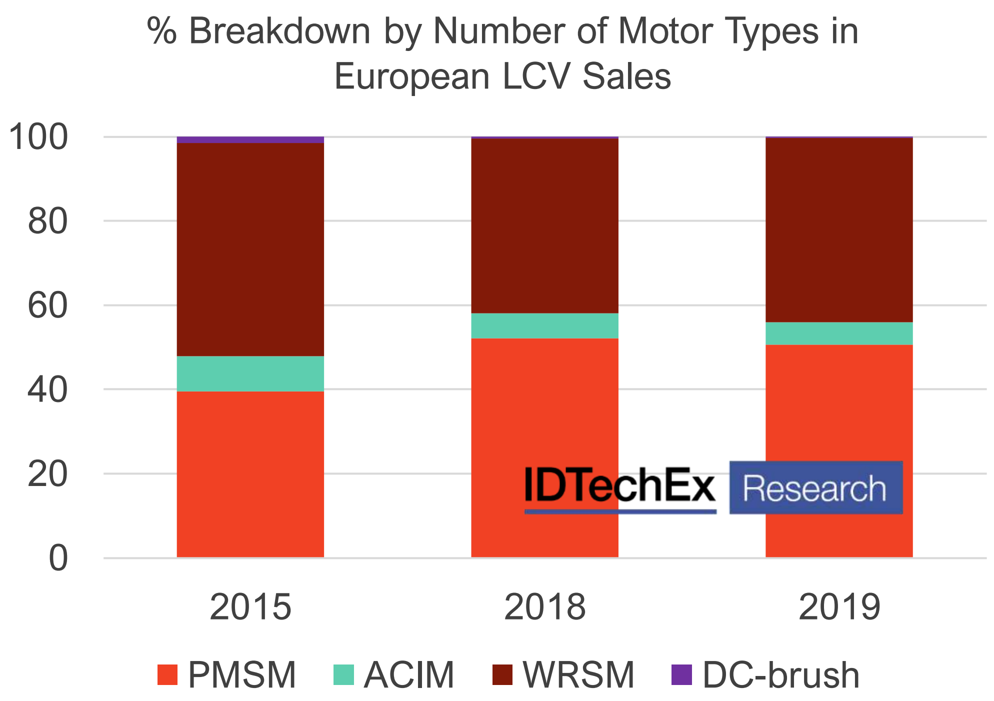
Installed motors in China are 98% PMSM and 2% ACIM with special purpose vehicles accounting for approximately 10% of the total market share. The story is different for Europe, largely due to the prevalence of Renault in this market. Renault utilise a WRSM motor.

In Europe, Renault's offerings took 43% of the total electric LCV sales in 2019. Hence WRSM motors have a significant share here. However, the rest of the market belongs to PMSM and as other manufactures create more offerings in this segment, we expect this trend to continue.

The new Tesla Semi utilises four PMSR motors from the Model 3 and hence PMSR will likely take a significant market share in the US.

There are some offerings utilising ACIM and DC-brushed motors but these are small and have been decreasing from 2015 through 2019.

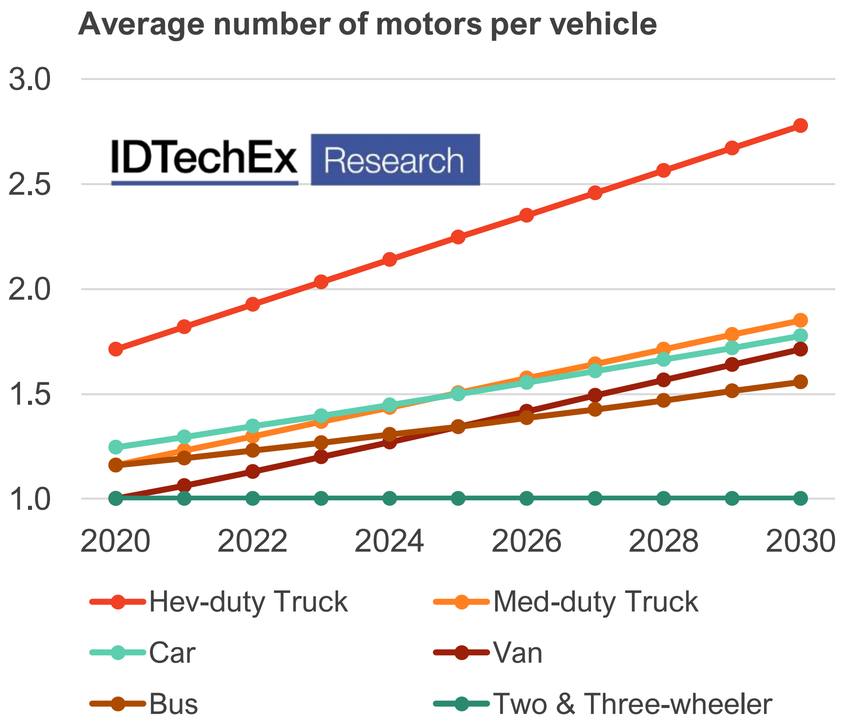
We assume electric traction motors in LCVs will be similar to those used in electric cars, with a similar level of copper intensity.



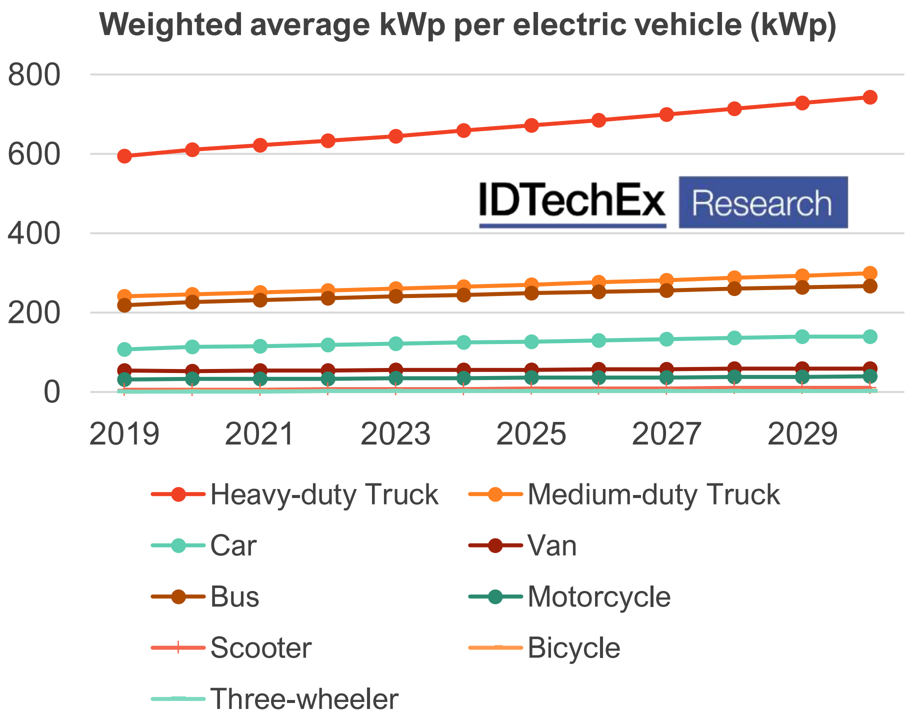
Source: IDTechEx

Motors per Vehicle and kWp per Vehicle Assumptions

For four-wheelers, we assume the market share of dual-motor vehicles steadily increases over the period (left); the main driver is incremental performance gains. Cars and LCVs / LCVs have similar performance requirements and will use similar motor technologies and configurations over the period.



Source: IDTechEx



Source: IDTechEx

IDTechEx

Brushed DC: Small Presence in LCVs

Brushed DC motors in general are not suitable for electric vehicles because of their low performance (similar to BLDC) and the fact that the brushes and contacts wear out, meaning they require more maintenance and have short lifetimes.

We have seen that a very small number of Brushed DC motors have been adopted by Italian OEM Piaggio in some LCVs (product overview found here). The vehicles also use lead-acid batteries. This is unusual, but it reflects the nascent stage of the electric LCV market in Europe. We expect, once demand for electric LCVs rises (driven by emissions policy), Brushed DC motors will be phased out very quickly in order to properly compete on the market.

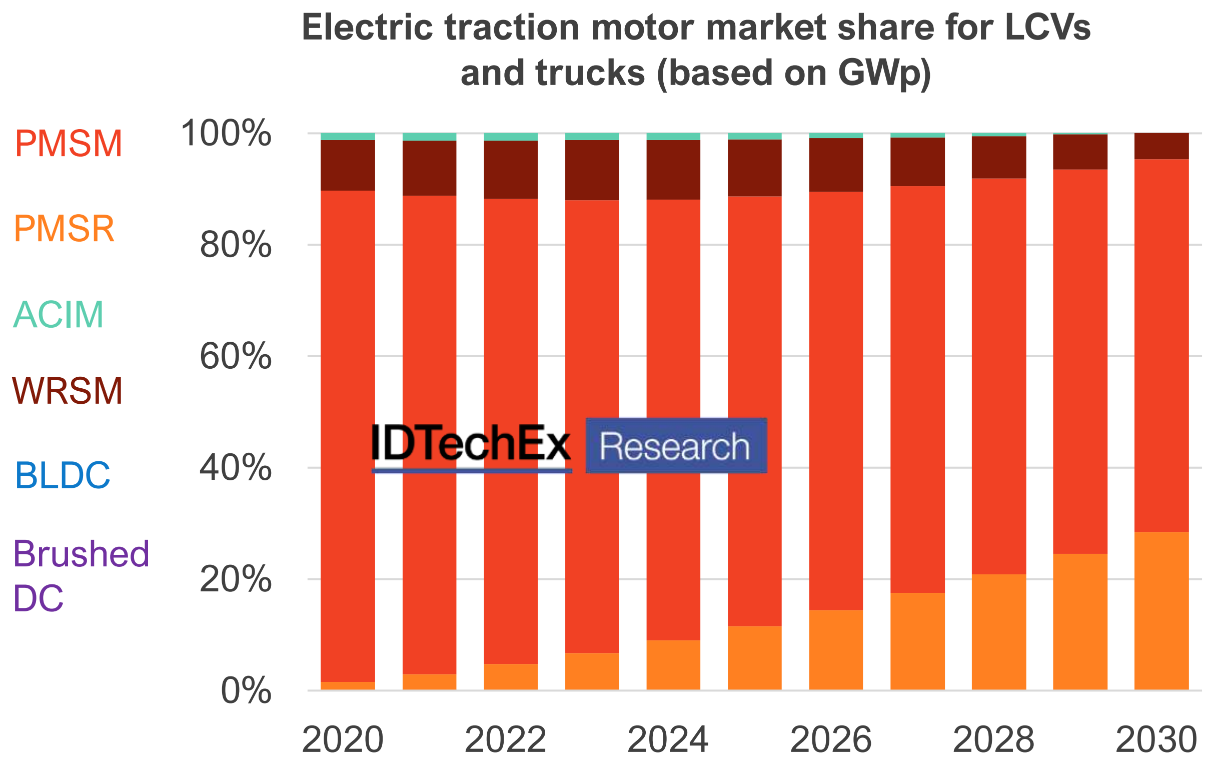
TECHNICAL SPECIFICATIONS	PORTER ElectricPower
Engine	Separate excitation direct current brush engine
Fuel system	Electric
Nominal power	10.5 kW 96 Volt
Nominal torque	55 Nm at 1,800 rpm
Peak torque	215 Nm
Operating current	124 A
Insulation Class	(F) Tmax=100°C ±15°C
Environmental Protection Rating	IP20
Max speed	55 Km/h
Max range	up to 110 Km

1.5kg total Cu
0.15kW per kg Cu

Image sources: Piaggio

LCVs and Trucks Motor Outlook

WRSMs in LCVs and trucks will continue to have a minority share over the period; we do not expect other automakers to adopt this motor type, but Renault is also bringing this motor type in house. Because WRSM is dependent on one automaker, it is at risk of a sudden exit from the market. Permanent magnet motors dominate, with a steady uptake of PMSR at the expense of PMSM; the Tesla Semi will use the same PMSR motors as the Model 3.



Fuel Cells

Proton Exchange Membrane Fuel Cells

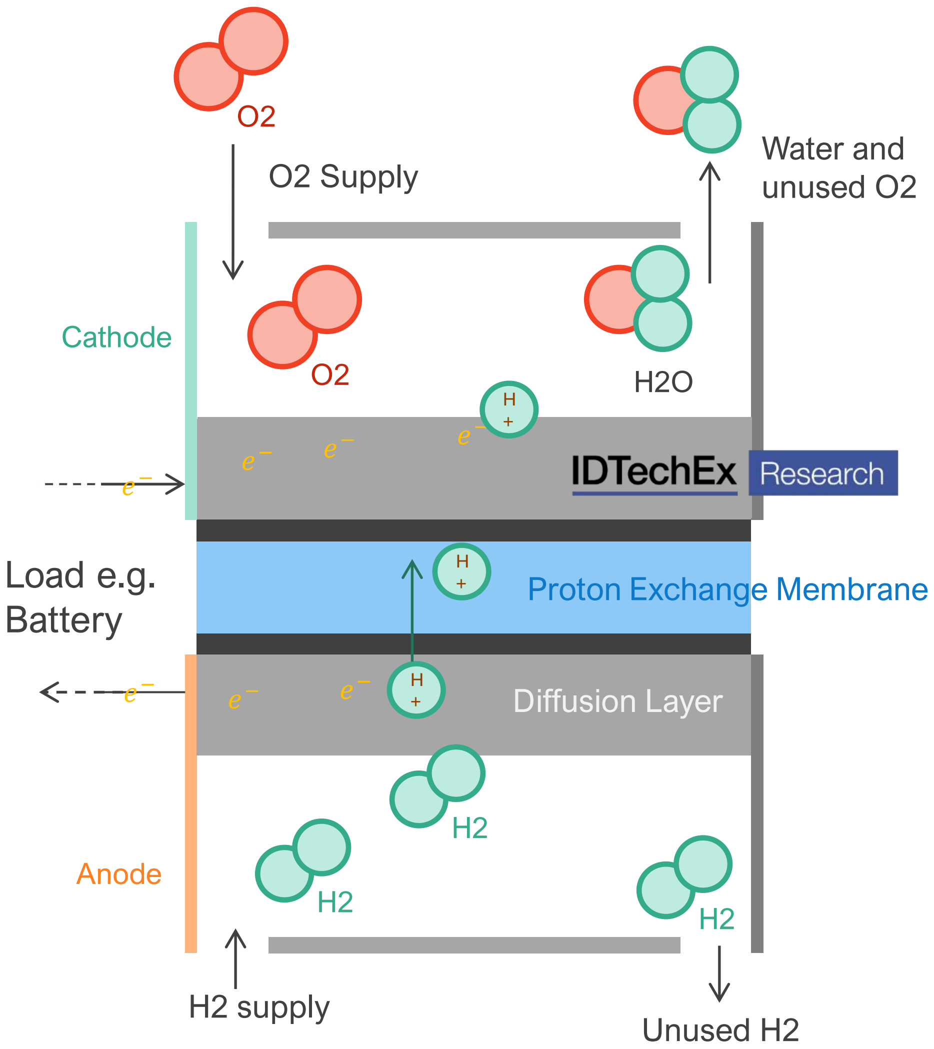
The Proton Exchange Membrane (PEM) is the most adopted fuel cell (FC) type due to its high energy density, compact design, quick start-up and moderate operational temperature (80 degrees C), making it applicable to a wide range of applications. It is the only fuel cell technology adopted for on-road electric vehicles, and is therefore our focus.

Operating principle

The PEM fuel cell employs gaseous hydrogen (H2) as fuel on the anode side, and gaseous oxygen (typically air) as oxidant on the cathode side. The oxidation of hydrogen at the anode forms a pair of electrons and a pair of protons (H^+) for each supplied hydrogen molecule. The hydrogen ions (single protons) diffuse from the anode to the cathode through the polymer electrolyte, reaching the cathode surface (hence 'proton exchange membrane'). On the cathode surface, the protons react with the incoming oxygen and electrons to produce water (H2O), closing the circuit.

The anodic and cathodic reactions are :

$$\text{Anode:} \quad 2H_2 \rightarrow 4H^+ + 4e^-$$
$$\text{Cathode:} \quad O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$



Fuel Cell Inefficiency and Cooling Methods

Fuel cell systems are typically 50%-60% efficient. While this is nearly double that of the internal combustion engine, it is much lower than a battery which reaches more than 90% round-trip efficiency. The energy which is not converted is predominantly wasted as heat.

The working temperature of the fuel cell affects performance and cell lifetime, so managing temperature is critical. Depending on power requirements, different methods can be used. Most electric vehicles require more than 5kW of power, so will be liquid cooled.

Fuel cells greater than 5kW require Liquid Cooling: adopting liquid cooling, in most cases water, allows better heat exchange and can allow a simpler design of the fuel cell due to the smaller channels required for the coolant (versus air cooling). Another advantage of liquid cooling is potential to recover heat, for example in a small CHP system.

Managing the fuel cell working temperature is the main method to manage the water content within the fuel cell stack. While a lower amount of water would increase the ohmic resistance within the stack, affecting the stack performances, high water content would flood the electrodes, again affecting the cell performance.

To balance the water content in the stack, a humidifier is generally employed, together with the aforementioned cooling system. These two extra devices are of fundamental importance to allow the proper functioning of the fuel cells.

Challenges for Fuel Cells

The fundamental problem fuel cells face competing with batteries is the additional and highly inefficient energy-conversion steps: first converting water to H2 with electricity, and then the fuel cell itself is roughly 60% efficient when converting H2 back to electricity and water for the vehicle (as stated before, due to the large heat losses). This electricity could instead go straight into a battery. As a result, fuel cells need an abundance of renewable energy to operate cleanly, which in itself is a challenge.

What's more, fuel cell vehicles still need a sizable battery for high-power and energy harvesting (the Nikola One Truck will have a 320kWh Li-ion battery alongside the fuel cell); they have moving parts (= maintenance); hydrogen charging infrastructure costs many multiples that of a fast charger; they rely on expensive raw materials; there is no easy roadmap to economies of scale, and so on.

Infrastructure Costs

The table below shows the IDTechEx cost assumptions for the installation of different types of electric charging infrastructure. Costs range from $1000 for a < 10kW private charger to $200,000 for a 350+ kW truck charger. In contrast, the cost to construct a hydrogen fuelling station is between $1 million and $2 million, according to the Hydrogen Council. As a result, it is harder to convince companies in the charging value chain to install hydrogen refuelling infrastructure. A Toyota executive was recently quoted as saying ‘we're not happy with the pace of [FCEV] adoption, because we're not happy with the state of the infrastructure. If the infrastructure would manifest itself, we would be happier’. Hydrogen refuelling infrastructure faces the same chicken and egg scenario as FCEV cars: there is not enough volume to bring costs down, and costs are too high to create any volume. It is increasingly difficult to ‘manifest itself’ as BEVs race ahead.

IDTechEx Research

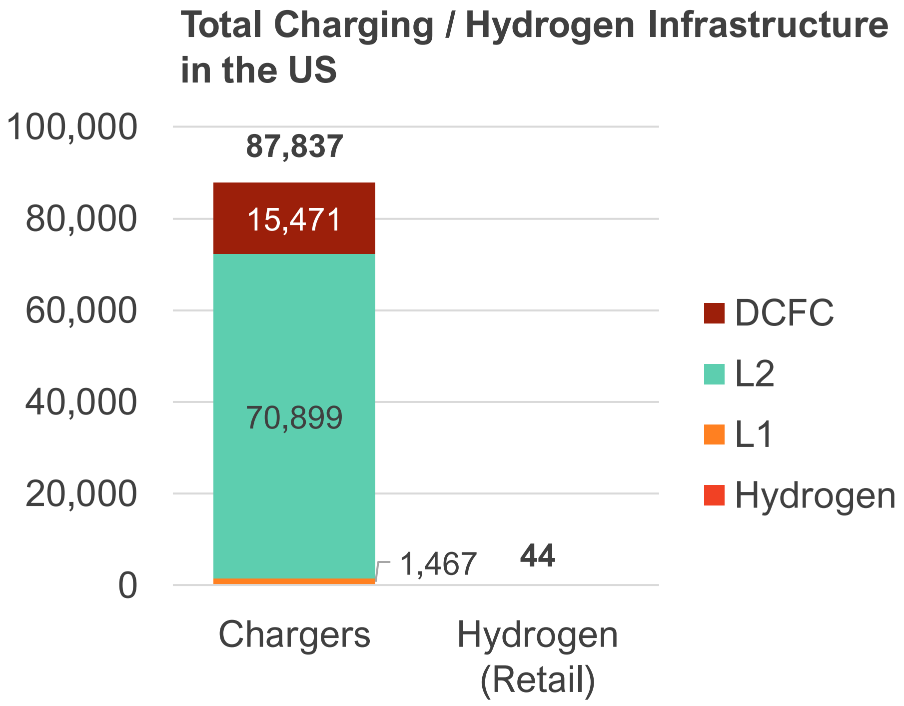
Type	Installation Cost Assumption
Private	$1,000
Public - AC	$2,000
Public - DCFC	$25,000
LCV	$25,000
Truck	$40,000 - $200,000
Hydrogen	$1000,000+

Power

Source: IDTechEx, Hydrogen Council

Fuel Cell Charging Infrastructure in the US

There are 44 retail hydrogen re-fuelling stations for fuel cells in the US, compared with over 87,000 for battery and plug-in hybrid electric vehicles. 42 of these stations are in California. Although fuel cell cars have a longer range than BEVs, wide-spread availability of charging infrastructure is also needed to reduce range anxiety. This is difficult because of the already-high cost of the vehicle and high cost of the infrastructure.

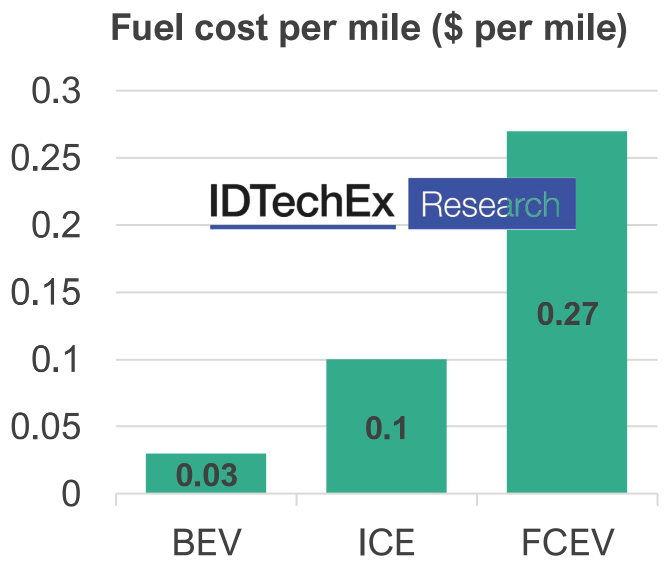


As of September 2020. Source: AFDC

Fuel Cost per Mile: FCEV, BEV, internal-combustion

At $3.50 per gallon of gasoline, a conventional vehicle costs roughly $0.10 per mile to operate. A FCEV car using $6 per kg hydrogen fuel would equal this cost of $0.10 per mile.

However, current average prices for hydrogen are much higher in the US at $16.5 per kg. In other words, the consumer pays twice the price for the vehicle and over twice the price for the fuel. The result is it is very difficult to justify buying a fuel cell vehicle, even for early adopters.



Tesla Model 3 (BEV)	
Miles per kWh (from Tesla)	4.1
Retail electricity price - $ per kWh	0.13
Average $ per mile (BEV)	**0.03**

Internal Combustion Engine	
Average miles per gallon	25.62
USA Retail Fuel Price - $ per gallon	2.64
Average $ per mile (internal-combustion)	**0.10**

Toyota Mirai (FCEV)	
Miles per kg H2	61.3
Average retail price $ per kg H2	16.5
Average $ per mile (FCEV)	**0.27**

Source: Automaker specifications, AFDC, IDTechEx

Fuel Cell LCVs

In a fuel cell vehicle, the fuel cell charges a battery or supercapacitor which then provides the electrical energy to a motor-generator to power the wheels.

Renault in Europe and SAIC in China currently offer the only commercially available fuel cell powered LCV vehicles. Several other OEMs including Mercedes, VW and Hyundai have built concept vehicles to demonstrate the technology.

The attraction of Fuel Cell Electric Vehicles (FCEV) is that they offer a zero on-road emission solution with a greater range than battery-only vehicles and can be refuelled more quickly. This could give FCEV LCVs the operational flexibility to meet arduous high mileage duty schedules which are currently difficult to deliver with BEV LCVs.

Hyundai H350 FC Concept

Source: Hyundai

VW Crafter HyMotion Concept

Source: parkers

Mercedes Sprinter F-Cell Concept

Source: Electrive

SAIC MAXUS FCV80

Source: Autonews

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Example Fuel Cell LCV Specifications

Fuel Cell LCV	Market	Fuel Cell Power (kW)	Battery Capacity (kWh)	Range (km)	Available
Kangoo ZE Hydrogen	Europe	10	33	370	2019
Master ZE Hydrogen	Europe	10	33	350	2020
StreetScooter Work XL H2	Europe	26	40	500	N/A
Mercedes Sprinter F-Cell	Europe	75	13.5	700	2018 Concept
VW Crafter HyMotion	Europe	30	13.1	350	2018 Concept
SAIC Maxus FCV80	China	115	30	500	2017
Hyundai H350 FC Concept	RoW	95	24	422	2016 Concept

In October 2019, Renault introduced hydrogen fuel cell options into its production eLCV range, becoming the first OEM to do so. The KANGOO and MASTER LCVs have been in development with Michelin and Faurecia owned Symbio since 2014. The Renault FCEVs are equipped with a range extending fuel cell than provides additional energy to the battery, which greatly enhances the range of the vehicles over the battery only option. The Kangoo FC is available in France at 48,300 euros ex VAT ($56.7k) [for reference the battery only Kangoo is available starting from around $30k]. The price of the MASTER FC is yet to be announced. Aside from increased price a further potential downside is that the FC system adds 200kg of weight to the MASTER and 110kg to the Kangoo, reducing payload capacity. Around 170 of the Renault vehicles have been deployed in Europe as part of the EU's Hydrogen Mobility Europe (H2ME) 100 million euro fuel cell demonstration project.

Renault MASTER Z.E. Hydrogen

Source: Symbio

Renault KANGOO Z.E. Hydrogen

Source: Fuelcellworks

Outlook for Fuel Cell LCVs

Although fuel cell vehicles are attracting attention, with some countries committing significant investment into developing the needed hydrogen infrastructure, FCEV technology is chasing a moving target, with BEV technologies improving rapidly (batteries, charging infrastructure, and software for duty cycle schedule optimisation). FCEV will find it difficult to catch up. As a result IDTechEx forecast a low penetration of FCEV LCV in the short to medium term, restricted to a limited number of countries that are investing heavily in building hydrogen infrastructure and to those long range duty cycles which are unfeasible for BEV LCV to operate.

Whilst the short average duty cycles of LCV do not lend themselves to the use of H2 as a fuel, for some applications such as long-haul trucking which have a greater range requirement, hydrogen fuel cells may offer a practical avenue to meet the demand. As the H2 infrastructure develops for other applications, then OEMs may choose to offer FC LCV options, but IDTechEx do not believe that the LCV market will be the driver for the growth of the H2 industry. Given the relative efficiency of BEV vs FCEV, if the required daily duty cycle can be delivered with a BEV then a BEV should be used.

Opportunities for FCEVs will be skewed towards countries working towards a broader Hydrogen economy. These countries will develop the necessary Hydrogen production and infrastructure within overall industrial goals to make FCEVs viable. Adoption of fuel cells will not be a global phenomenon.

9. Forecasts

Forecast Assumptions

Below we list our eLCV forecast assumptions.

- There are no battery-supply shortages; battery supply is not a bottle neck.
- Sufficient charging infrastructure is built to support uptake of electric vehicles; charging infrastructure is not a bottle neck.
- Fuel cells do not become mainstream due to high cost / low volume, more expensive charging infrastructure, dependence on grey hydrogen, more moving parts (more maintenance), dependence on batteries for high power / short-range travel, and so on.
- Existing official or legislated fossil fuel bans do not change and drive national electrification roadmaps, policy, and automaker investment.
- 'Total cost of ownership' parity is the main cost barrier, and is already achieved in most regional markets.
- Markets recover from covid-19 by H2 2020 in the top auto markets. A 'second wave' of covid-19 causing equivalent national lockdowns and economic damage as H1 2020 does not occur.
- PHEVs continue to be phased out of markets globally at their current rate. We argue that the main benefit of the PHEV is addressing range anxiety, which each year becomes a smaller problem as batteries and motors improve and range increases. Given the added engineering complexity, lower value towards meeting emissions targets and similar if not equivalent range and price to BEVs in the short-term, governments don't want to incentivise PHEVs, automakers don't want to make them and consumers don't want to buy them.

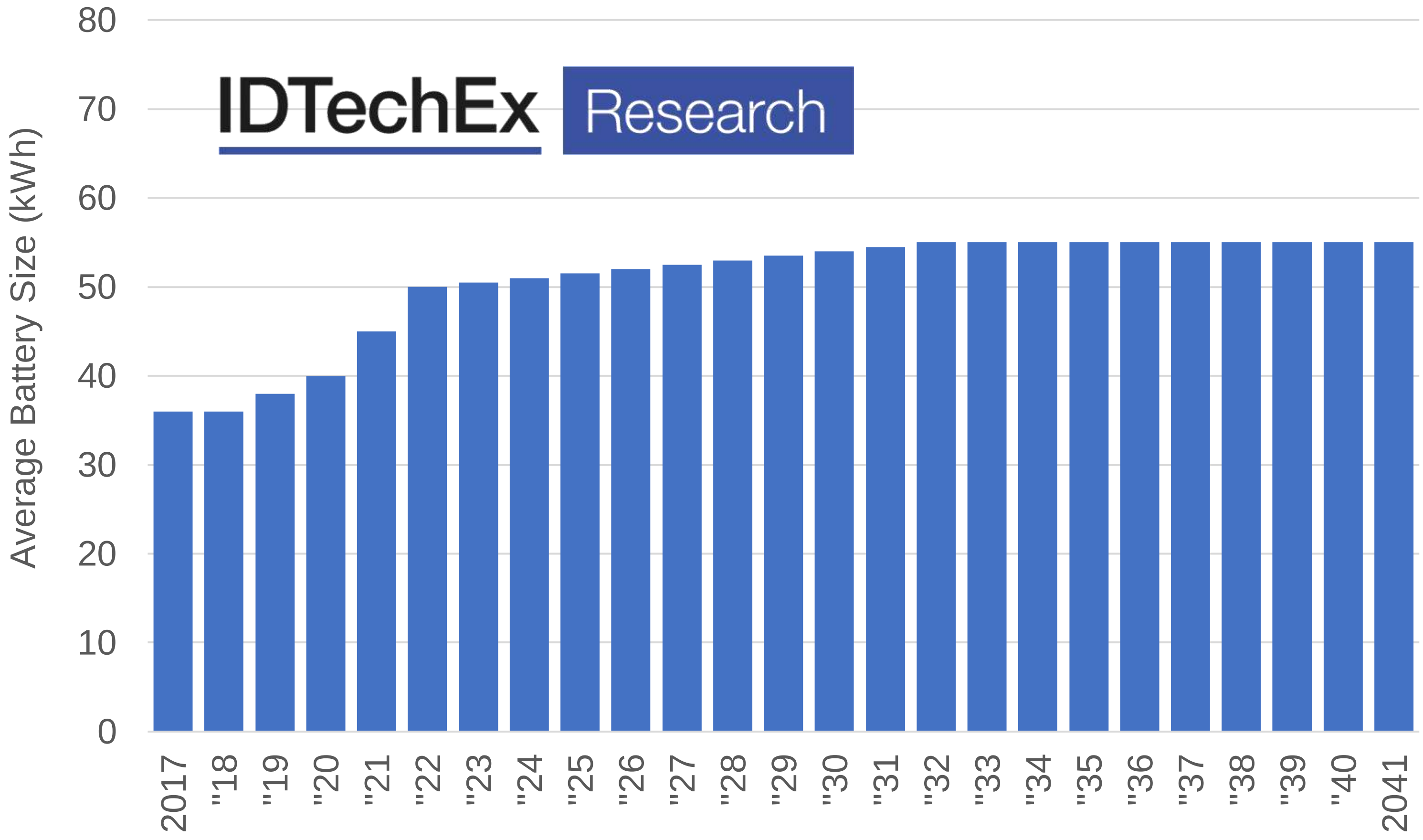
Forecast Methodology

We first established the historical eLCV uptake in individual countries over the past 4-years. We focussed on forecasting the key regions, China, Europe, and US, with the remaining countries grouped into the 'Rest of World' section. We looked at industrial policy in support of electric vehicles (fossil fuel bans, purchase subsidies, tax incentives etc) in each of these regions.

It is not always clear in the policy documents whether the targets for bans on new combustion vehicle sales refer to purely cars or include LCVs (as is the case in the UK). In these cases, we have assumed that the targets also include LCVs. In the case of the most aggressive target dates, we make some allowance that it may not be possible to deliver 100% electrified LCV in all applications. For Europe individual country forecasts have been aggregated to form the overall forecast.

The eLCV markets are at a more nascent stage than electric cars and as a result less high-quality historic data is available. As a result, it was difficult to apply a standard diffusion forecast model. Our approach was instead to devise an S-curve for each region with an initial growth rate informed by the sales data and an inflection point determined by fossil fuel bans, as well as our judgement which stems from our knowledge of forecasting other electric vehicle markets.

Market forecast: Average battery capacity for eLCV (kWh) in Europe 2021-2041

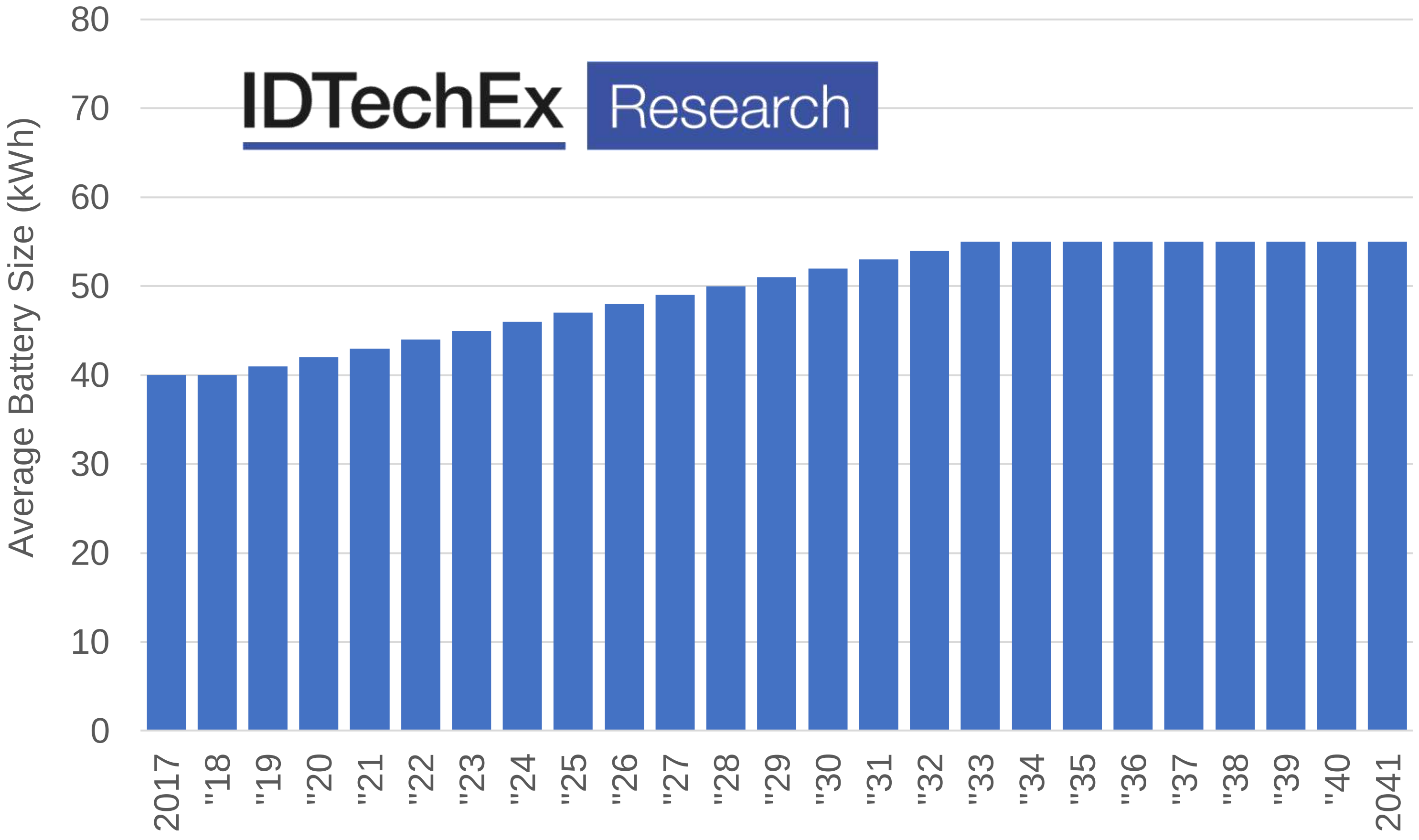


This graph shows the forecast average kWh battery capacity incorporated into eLCVs in Europe for the years 2021-2041.

In the short term, the most popular electric vehicles in Europe will remain the smaller LCVs used for urban logistics, both because the offer the most compelling TCO argument and because there are a lack of larger electric LCVs on the market. The Renault Kangoo, Peugeot Partner, Nissan e-NV200, Citroen Berlingo eLCVs are available with battery capacities in the range of 20 to 40 kWh. 2021-2022 sees major OEMs, Ford, Fiat and Mercedes release larger LCV models with battery capacities of 45-70 kWh. Given the popularity of the Ford Transit, this is likely to increase the average LCV battery size.

Decreasing battery price and energy density improvements see a slow upward trend in increased battery size over the decade.

Market forecast: Average battery capacity for eLCV (kWh) in China 2021-2041



This graph shows the forecast average kWh battery capacity incorporated into eLCVs in China for the years 2021-2041.

Analysis of the current eLCV market in China, with popular vehicles manufactured by Kairui New Energy, Dongfeng, RuiChi New Energy, Shaanix and Beiqui, amongst others, suggests a battery size for smaller LCVs in the range of 35 to 50 kWh with a few larger LCVs providing a capacity between 50 to 90 kWh.

Over the decade as the uptake and confidence in the technology grows, falling battery price and energy density improvements, alongside the trend to deliver increasingly demanding duty cycles with eLCV, will result in an increase in average battery size. Chinese EV policy is currently incentivising EV vehicles with greater range, this policy may also drive greater battery capacity in eLCV, even though increased electric range may not be necessary to deliver the LCV duty cycles.

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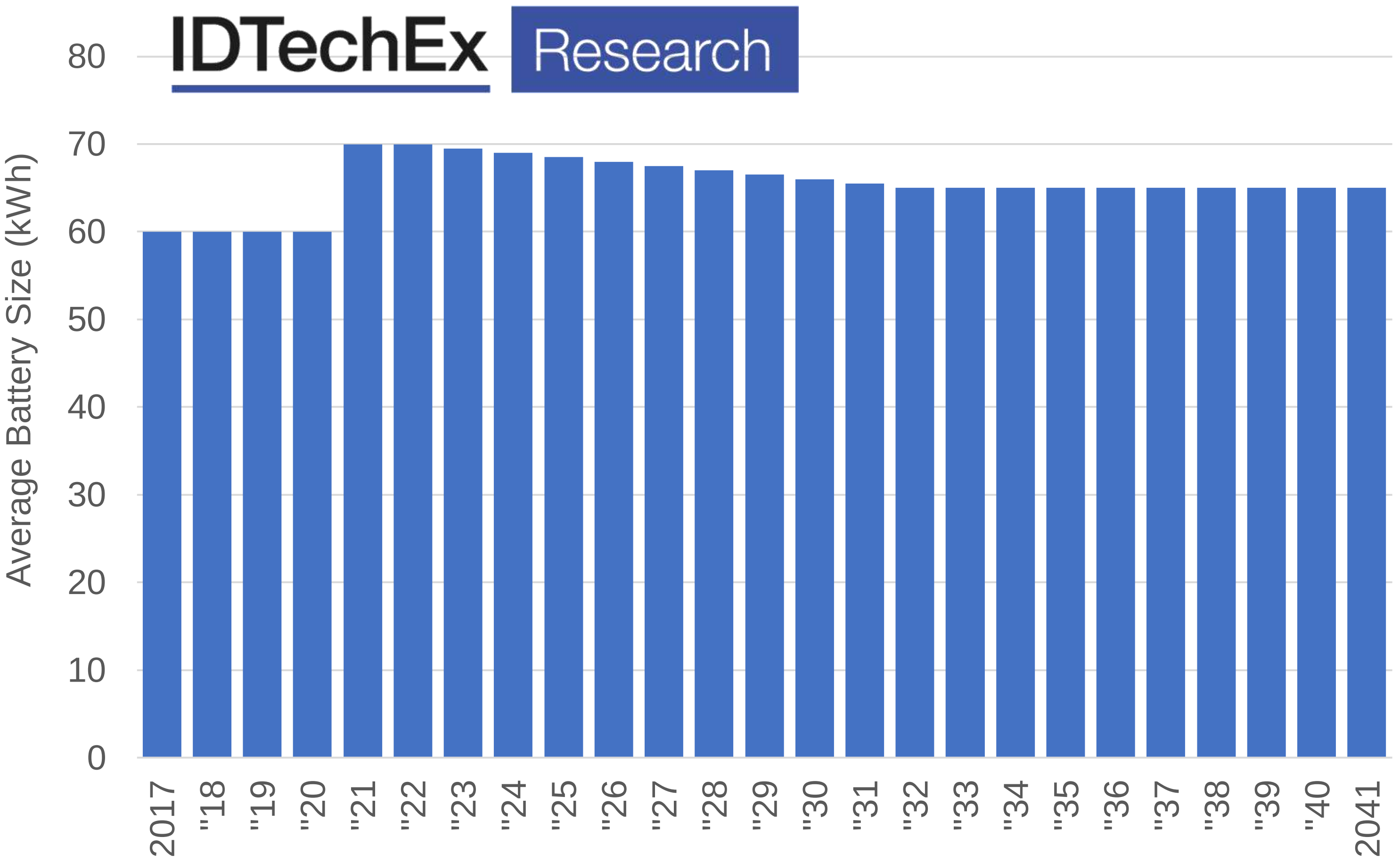
Market forecast: Average battery capacity for eLCV (kWh) in the US 2021-2041

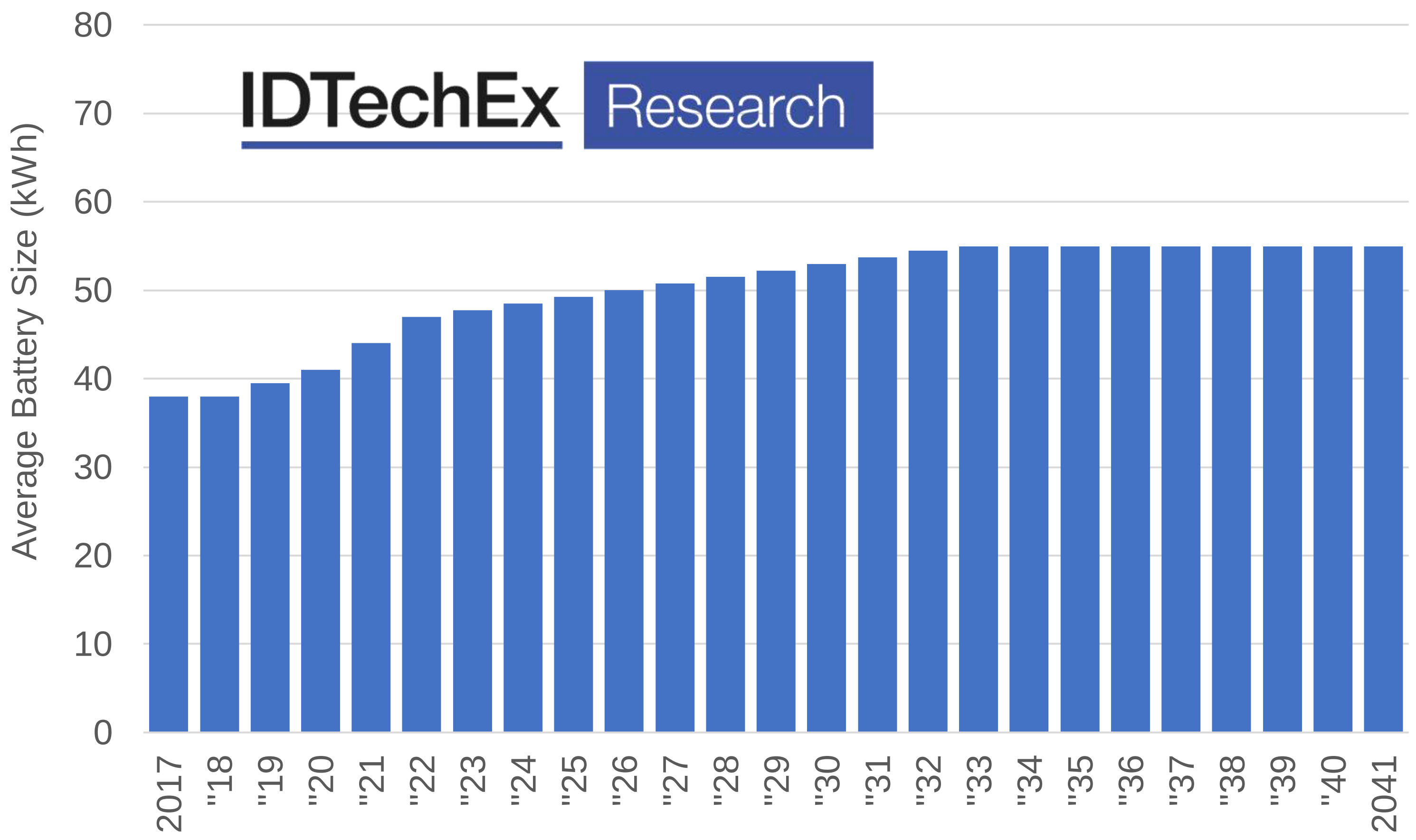


This graph shows the average kWh battery capacity incorporated into US eLCV 2021-2041 forecasts. This forecast excludes the pickup market. Given the very limited current volumes in the eLCV market in the US (with no large OEM currently offering an eLCV) this forecast is subject to a significant degree of uncertainty, and will be updated as further data becomes available.

The greater daily duty cycle requirements in the US market, likely necessitate a larger battery size than the European and Chinese eLCV markets. The eLCVs currently being designed specifically for the US market (Workhorse, Rivian, Bollinger) suggest battery capacities in the range of 60 to 105 kWh (potentially more).

The large OEMs are producing eLCVs in the European market with smaller batteries, these models are likely also to be launched at a later date in the US market. As confidence in the technology grows and duty cycles / charging strategies become more clearly understood, the average battery capacity is forecast to decrease.

Market forecast: Average battery capacity for eLCV (kWh) in the RoW 2021-2041



This graph shows the forecast average kWh battery capacity incorporated into eLCVs in the rest of the world (RoW) for the years 2021-2041.

The RoW incorporates several significant LCV producing nations, including Japan, Korea, Thailand, Indonesia, Russia, Argentina, Brazil and South Africa.

The average RoW battery capacity is broadly expected to follow a similar path to Europe and China, with a gradual increase in capacity as battery prices decrease over the decade, with initial uptake for smaller eLCV, followed relatively rapidly by larger models.

There are currently relatively few data points for this forecast. The forecast will be updated as further models become available and global automotive OEMs increasingly produce eLCVs in the RoW markets.

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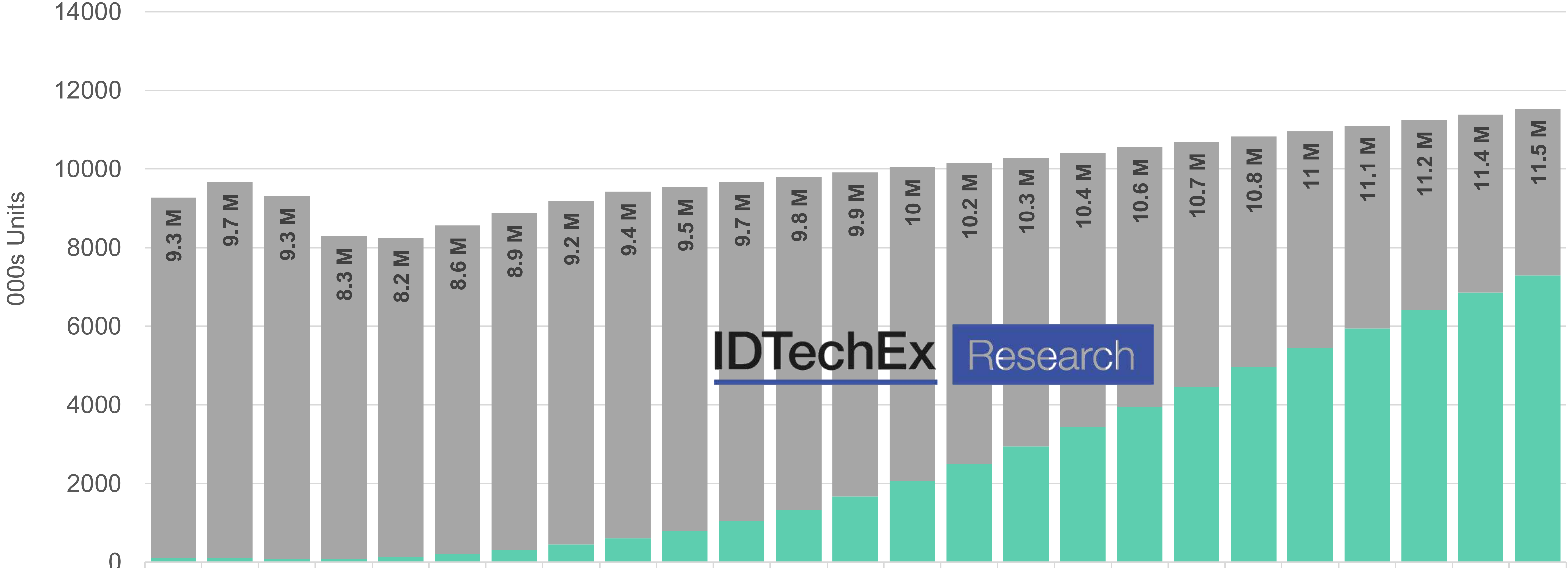
LCV Market Forecasts 2017-2041

LCV global sales (000s units) 2017-2041



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
LCV (ICE)	9177	9573	9235	8217	8115	8353	8565	8746	8825	8747	8625	8456	8240	7978	7676	7342	6984	6612	6234	5861	5499	5160	4837	4532	4242
LCV (eLCV)	99	95	78	79	130	206	307	439	604	801	1042	1333	1672	2058	2487	2949	3438	3942	4453	4963	5462	5941	6406	6854	7289
LCV (All)	9276	9668	9313	8295	8245	8558	8872	9185	9429	9547	9667	9789	9912	10037	10163	10292	10422	10554	10688	10823	10961	11101	11242	11386	11531

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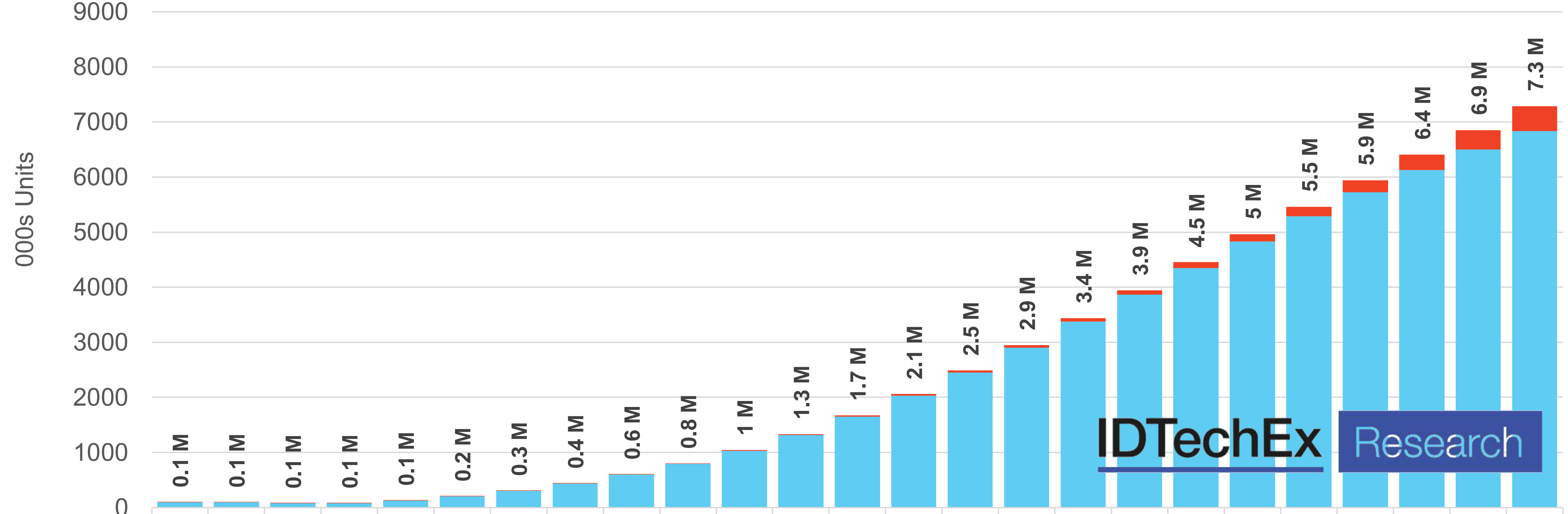
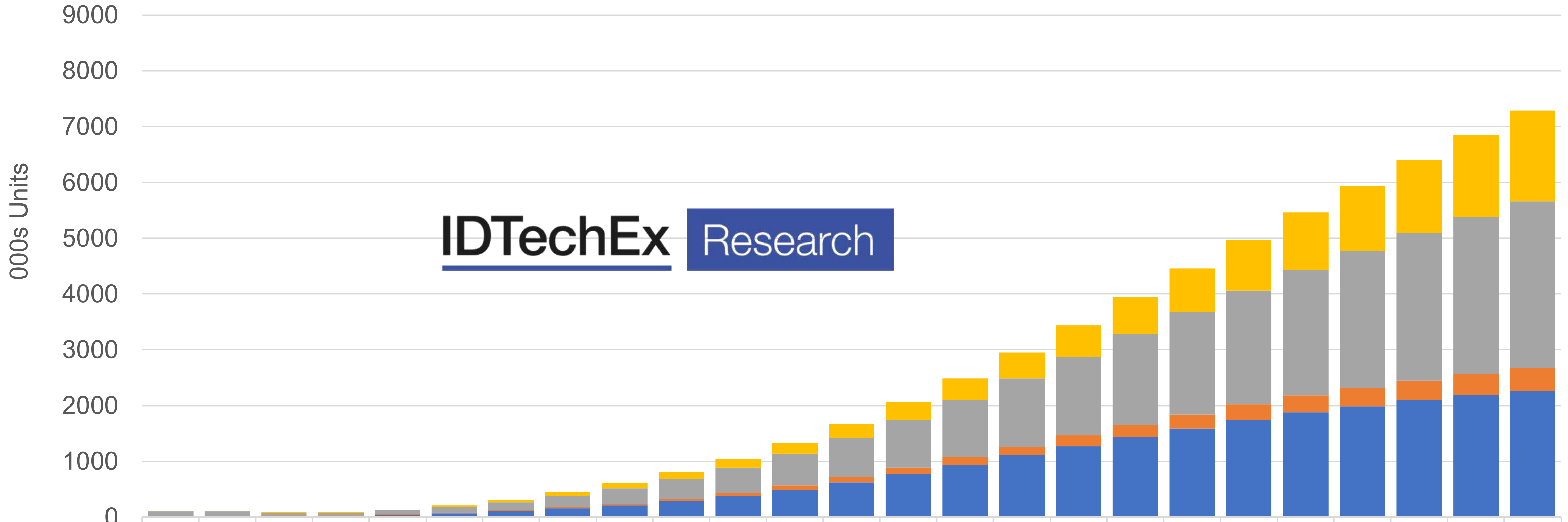
eLCV (BEV, PHEV, FCEV) global sales 2017-2041



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
eLCV (FCEV)	0	0	0	0	1	2	3	4	6	8	11	15	20	27	35	46	61	79	102	132	170	218	279	355	451
eLCV (PHEV)	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
eLCV (BEV)	98	95	77	78	128	203	304	435	598	792	1031	1317	1652	2031	2452	2903	3377	3863	4351	4831	5292	5723	6126	6499	6839
eLCV Total	99	95	78	79	130	206	307	439	604	801	1042	1333	1672	2058	2487	2949	3438	3942	4453	4963	5462	5941	6406	6854	7289

eLCV (BEV, PHEV, FCEV) sales by region 2017-2041



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
RoW	0	0	1	1	11	25	41	62	89	120	157	201	254	315	387	469	561	665	779	902	1034	1174	1320	1473	1630
China	82	71	48	47	69	104	147	203	274	355	453	569	704	858	1030	1217	1417	1625	1836	2046	2251	2448	2638	2819	2994
US	0	0	0	0	3	8	14	22	31	43	56	73	91	113	137	163	190	219	248	276	304	330	355	379	401
EU + EFTA + UK	16	23	29	31	46	69	104	152	210	283	376	490	623	772	934	1101	1269	1434	1591	1739	1873	1989	2092	2184	2264
eLCV Total	99	95	78	79	130	206	307	439	604	801	1042	1333	1672	2058	2487	2949	3438	3942	4453	4963	5462	5941	6406	6854	7289

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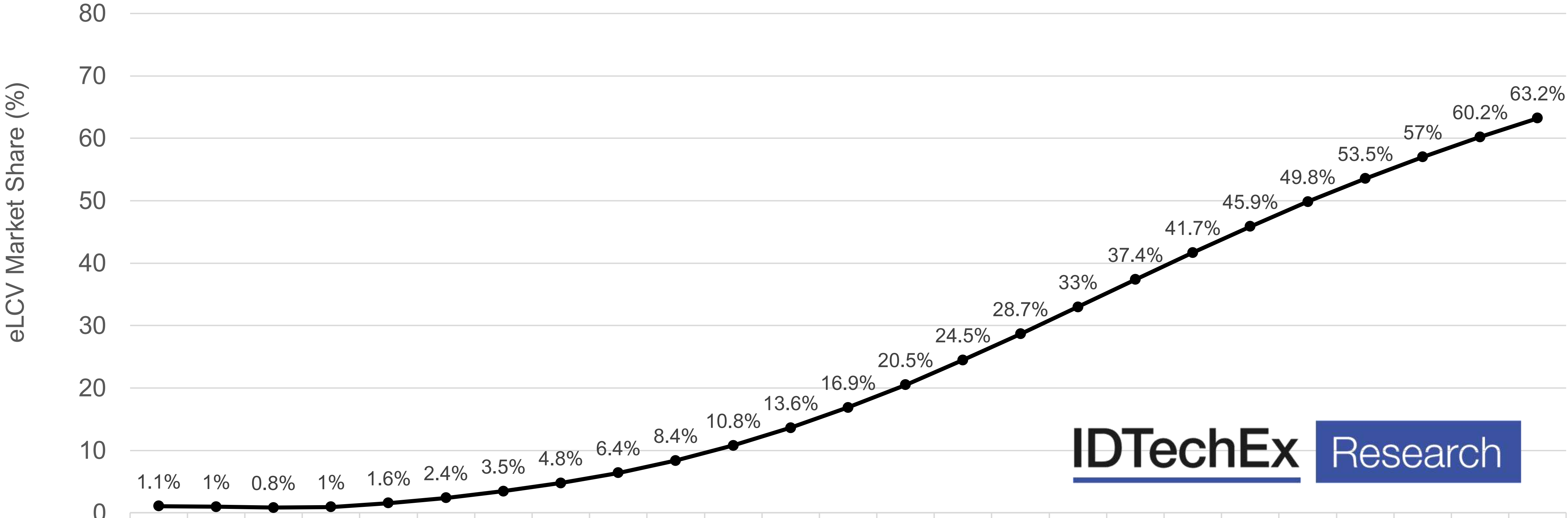
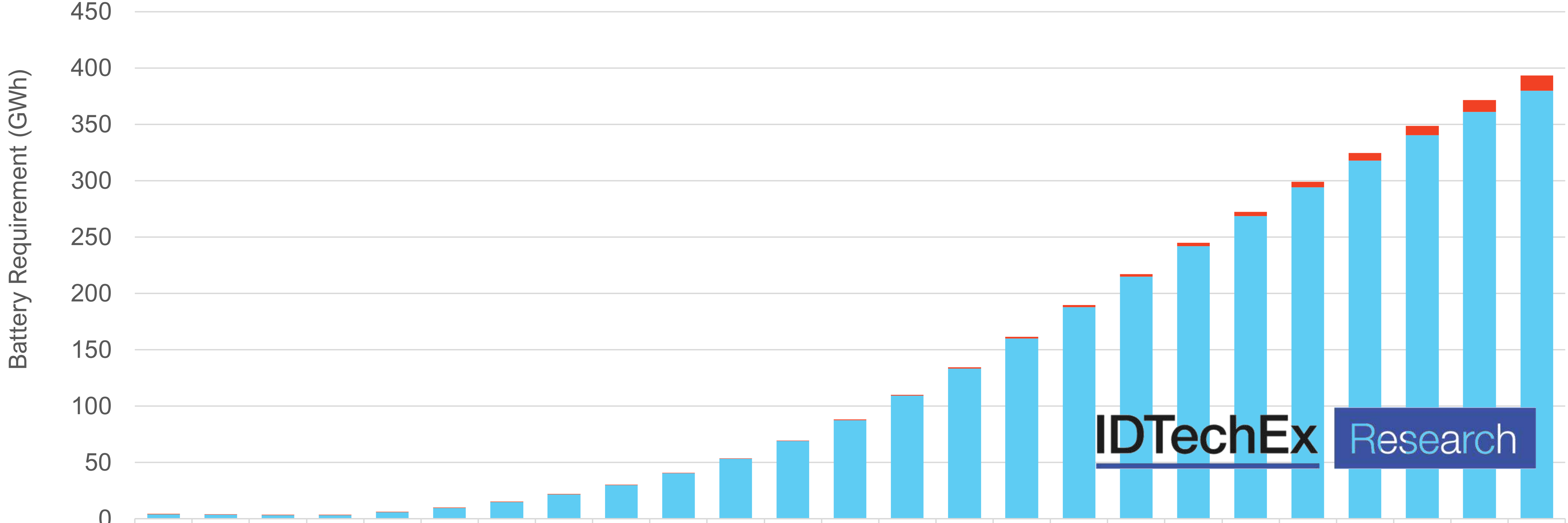
Global LCV market share forecast for eLCV 2017-2041



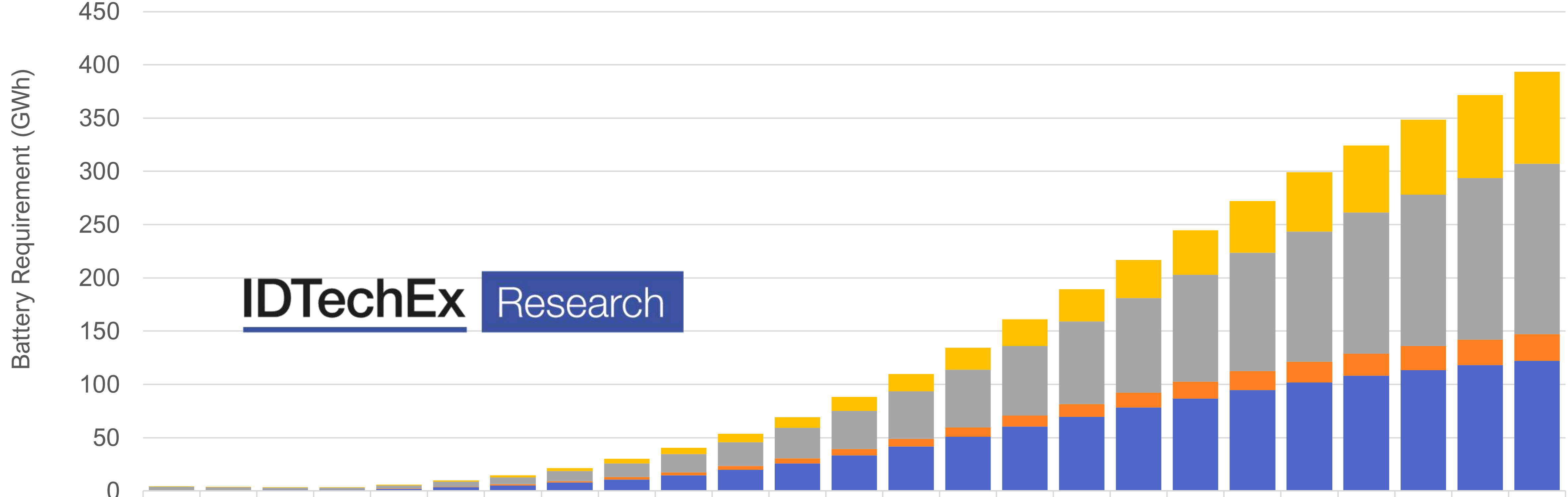
	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2040
eLCV BEV (%)	1.1	1.0	0.8	0.9	1.6	2.4	3.4	4.7	6.3	8.3	10.7	13.5	16.7	20.2	24.1	28.2	32.4	36.6	40.7	44.6	48.3	51.6	54.5	57.1	59.3
eLCV FCEV (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.5	0.6	0.7	1.0	1.2	1.6	2.0	2.5	3.1	3.9
eLCV PHEV (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
eLCV Total (%)	1.1	1.0	0.8	1.0	1.6	2.4	3.5	4.8	6.4	8.4	10.8	13.6	16.9	20.5	24.5	28.7	33.0	37.4	41.7	45.9	49.8	53.5	57.0	60.2	63.2

Global eLCV battery requirement (GWh) 2017-2041



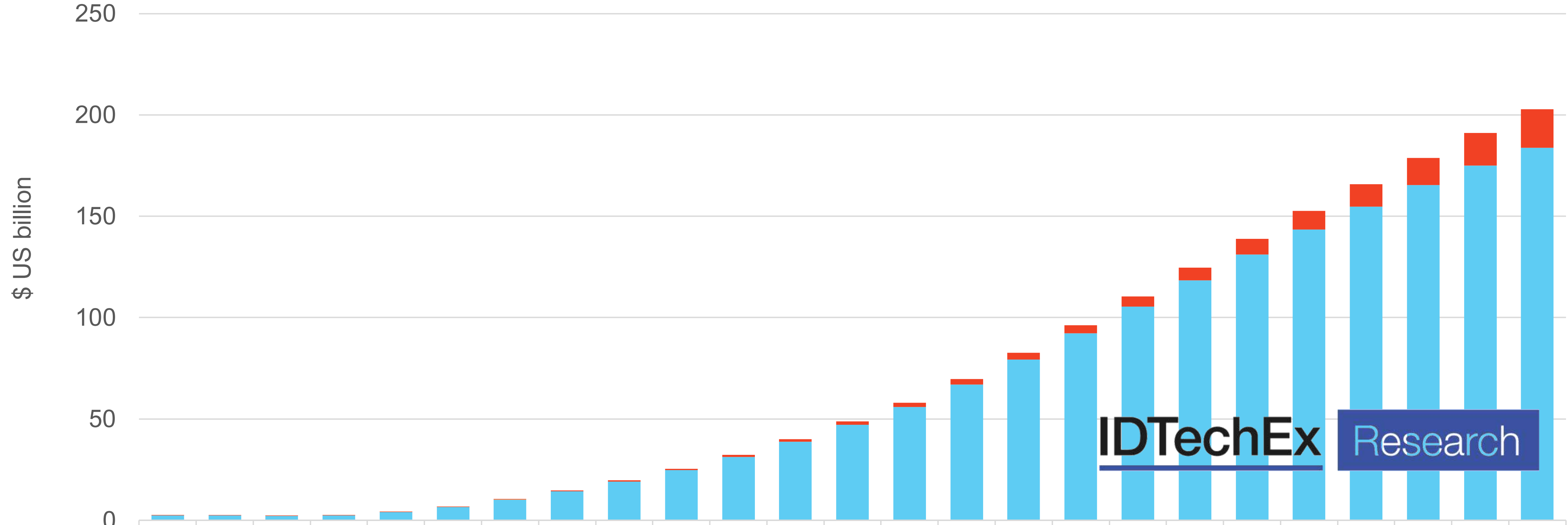
	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
eLCV (FCEV)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.5	0.6	0.8	1.1	1.4	1.8	2.4	3.1	4.0	5.1	6.6	8.4	10.7	13.5
eLCV (PHEV)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
eLCV (BEV)	3.9	3.7	3.1	3.2	5.7	9.6	14.7	21.4	29.9	40.2	53.1	68.8	87.5	109.0	133.3	159.8	187.6	214.6	241.7	268.3	294.0	317.9	340.3	361.0	379.9
eLCV Total	3.9	3.7	3.1	3.2	5.7	9.7	14.8	21.5	30.1	40.5	53.5	69.3	88.1	109.8	134.4	161.2	189.4	217.0	244.8	272.3	299.1	324.5	348.7	371.7	393.4

eLCV (BEV, PHEV, FCEV) battery forecast by region (GWh) 2017-2041



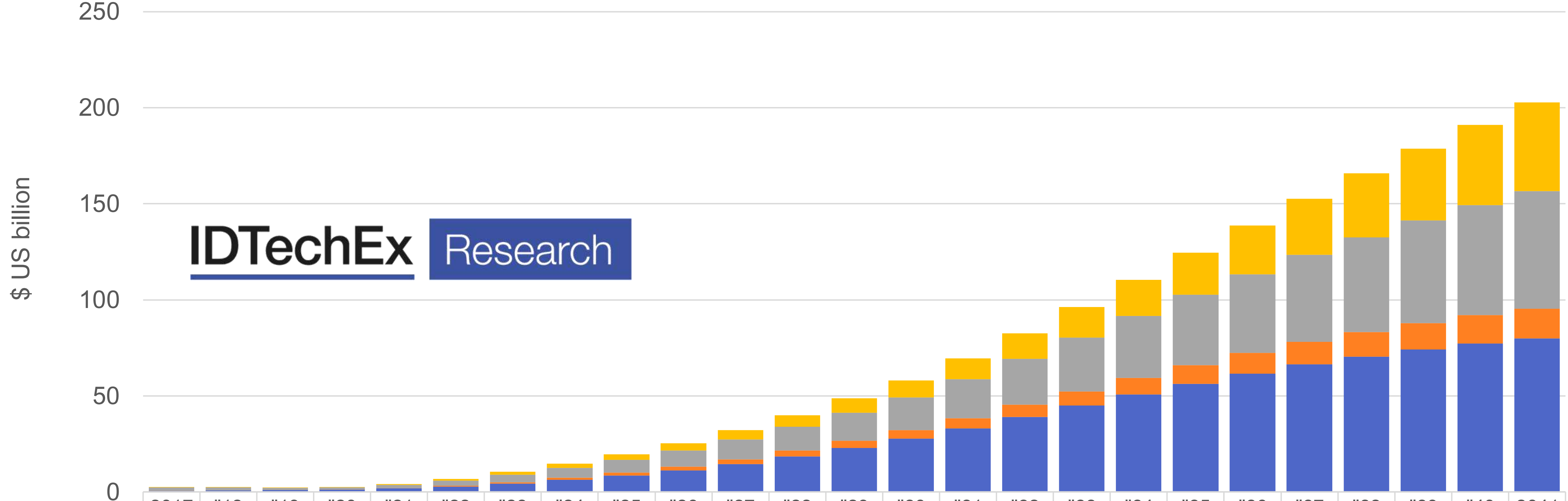
	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
RoW	0.0	0.0	0.0	0.0	0.5	1.2	2.0	3.0	4.3	5.9	7.9	10.3	13.1	16.5	20.6	25.2	30.5	36.0	42.1	48.7	55.6	62.9	70.5	78.2	86.0
China	3.3	2.9	2.0	2.0	3.0	4.5	6.6	9.3	12.8	17.0	22.1	28.3	35.7	44.4	54.3	65.3	77.4	88.6	100.0	111.2	122.1	132.5	142.3	151.5	160.1
US	0.0	0.0	0.0	0.0	0.2	0.6	1.0	1.5	2.1	2.9	3.8	4.8	6.0	7.4	8.9	10.5	12.2	14.0	15.9	17.6	19.3	21.0	22.5	23.9	25.2
EU+EFTA+UK	0.6	0.8	1.1	1.2	2.0	3.4	5.2	7.7	10.8	14.7	19.7	25.9	33.2	41.5	50.7	60.2	69.4	78.3	86.9	94.8	102.0	108.1	113.5	118.1	122.1
eLCV Total	3.9	3.7	3.1	3.2	5.7	9.7	14.8	21.5	30.1	40.5	53.5	69.3	88.1	109.8	134.4	161.2	189.4	217.0	244.8	272.3	299.1	324.5	348.7	371.7	393.4

eLCV market revenue forecast ($ Billion) 2017-2041



	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
eLCV (FCEV)	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.2	1.6	2.1	2.6	3.3	4.1	5.1	6.2	7.6	9.2	11.1	13.4	16.0	19.0
eLCV (PHEV)	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
eLCV (BEV)	2.3	2.4	2.2	2.3	4.0	6.6	10.2	14.3	19.1	24.7	31.2	38.8	47.1	56.0	67.0	79.3	92.2	105.3	118.4	131.2	143.4	154.7	165.3	175.0	183.8
eLCV Total	2.3	2.4	2.2	2.4	4.1	6.8	10.5	14.7	19.7	25.4	32.2	40.0	48.7	58.0	69.6	82.6	96.3	110.4	124.6	138.8	152.6	165.9	178.7	191.0	202.8

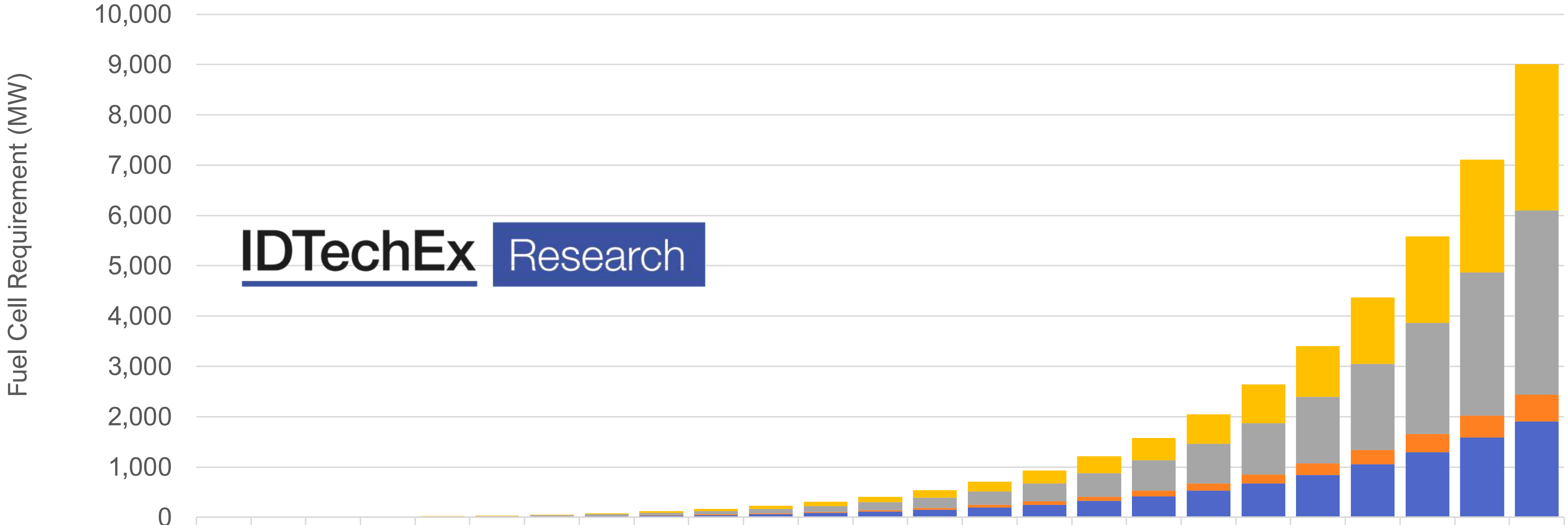
eLCV market revenue forecast by region ($ billion) 2017-2041



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29
RoW	0.0	0.0	0.0	0.0	0.4	0.8	1.5	2.1	2.9	3.9	4.9	6.1	7.4
China	1.7	1.5	1.1	1.1	1.7	2.6	3.9	5.2	6.7	8.4	10.2	12.3	14.5
US	0.0	0.0	0.0	0.0	0.2	0.4	0.7	1.0	1.4	1.9	2.4	3.0	3.7
EU+EFTA+UK	0.6	0.9	1.1	1.2	1.9	2.9	4.5	6.4	8.6	11.3	14.6	18.6	23.0
eLCV Total	2.3	2.4	2.2	2.4	4.1	6.8	10.5	14.7	19.7	25.4	32.2	40.0	48.7

	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
RoW	9.0	10.9	13.2	15.8	18.8	22.0	25.5	29.3	33.3	37.5	41.8	46.2
China	16.9	20.3	24.0	28.0	32.2	36.5	40.8	45.1	49.3	53.3	57.3	61.1
US	4.5	5.4	6.4	7.5	8.6	9.7	10.8	11.9	12.9	13.8	14.7	15.5
EU+EFTA+UK	27.7	33.1	39.0	44.9	50.8	56.4	61.6	66.4	70.4	74.1	77.2	79.9
eLCV Total	58.0	69.6	82.6	96.3	110.4	124.6	138.8	152.6	165.9	178.7	191.0	202.8

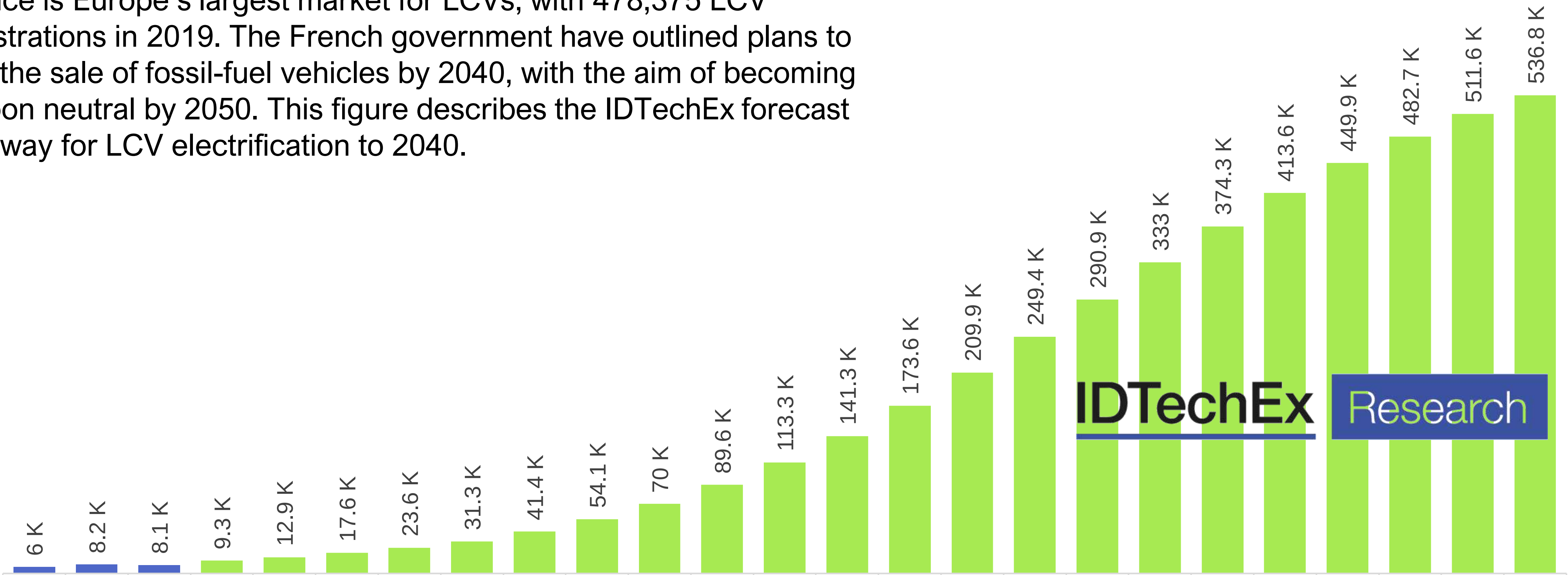
eLCV (FCEV) installed fuel cell forecast by region (MW)



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
RoW (FCEV)	0	0	0	0	3	7	13	20	30	42	59	81	109	146	195	258	341	449	589	773	1011	1321	1722	2240	2908
China (FCEV)	2	1	11	6	10	16	24	34	48	66	89	118	157	207	271	355	463	603	784	1018	1320	1709	2209	2850	3669
US (FCEV)	0	0	0	0	1	2	3	6	8	12	16	22	29	39	51	66	86	111	143	182	230	288	357	437	529
EU+EFTA+UK (FCEV)	1	2	0	0	3	7	13	22	32	45	62	84	112	147	193	250	324	415	530	671	844	1052	1297	1582	1905
eLCV Total (FCEV)	3	3	11	6	16	32	53	82	118	165	226	304	406	539	709	930	1214	1579	2047	2644	3405	4369	5584	7109	9012

France eLCV penetration and sales, pathway to 2041

France is Europe's largest market for LCVs, with 478,375 LCV registrations in 2019. The French government have outlined plans to ban the sale of fossil-fuel vehicles by 2040, with the aim of becoming carbon neutral by 2050. This figure describes the IDTechEx forecast pathway for LCV electrification to 2040.



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
% of LCV	1.4%	1.8%	1.7%	2.6%	3.3%	4.2%	5.3%	6.6%	8.6%	11%	14%	18%	23%	28%	34%	41%	49%	56%	64%	71%	78%	84%	90%	94%	98%

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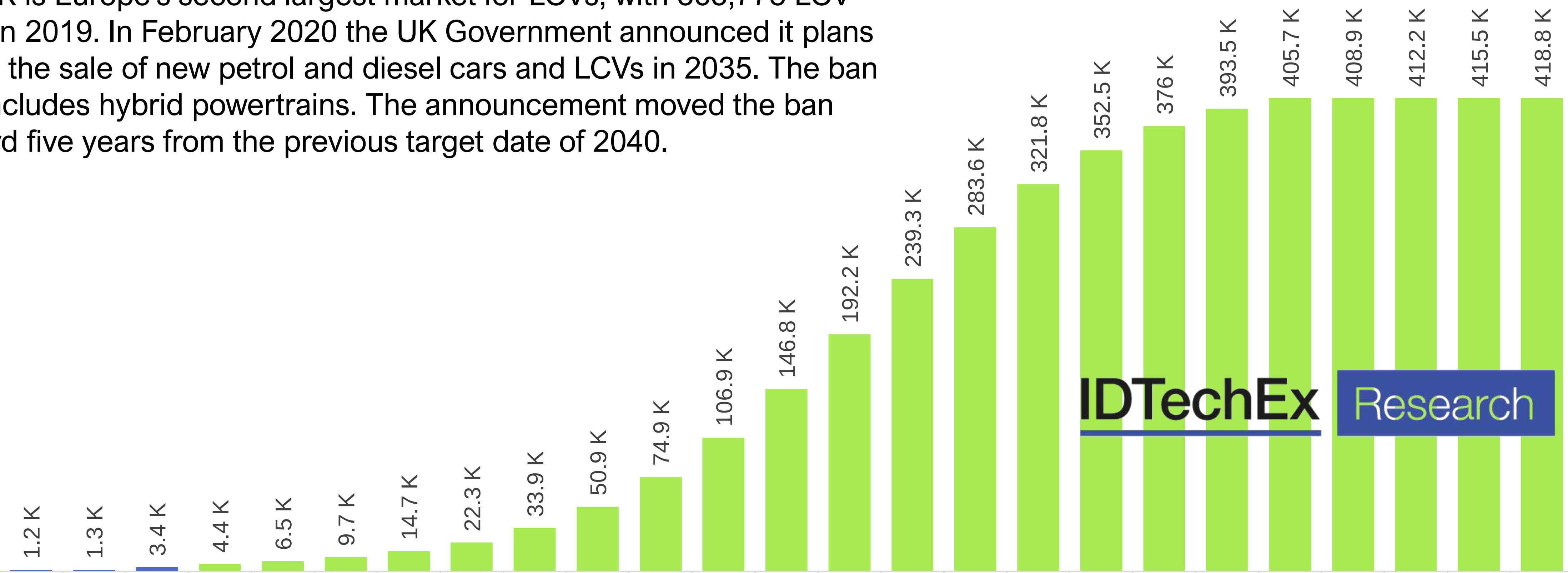
UK eLCV penetration and sales, pathway to 2041

The UK is Europe's second largest market for LCVs, with 365,778 LCV sales in 2019. In February 2020 the UK Government announced it plans to ban the sale of new petrol and diesel cars and LCVs in 2035. The ban also includes hybrid powertrains. The announcement moved the ban forward five years from the previous target date of 2040.



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
% of LCV	0.3%	0.4%	0.9%	1.6%	2.2%	3.0%	4.3%	6.1%	9.2%	14%	20%	28%	39%	50%	62%	73%	82%	89%	94%	98%	100%	100%	100%	100%	100%

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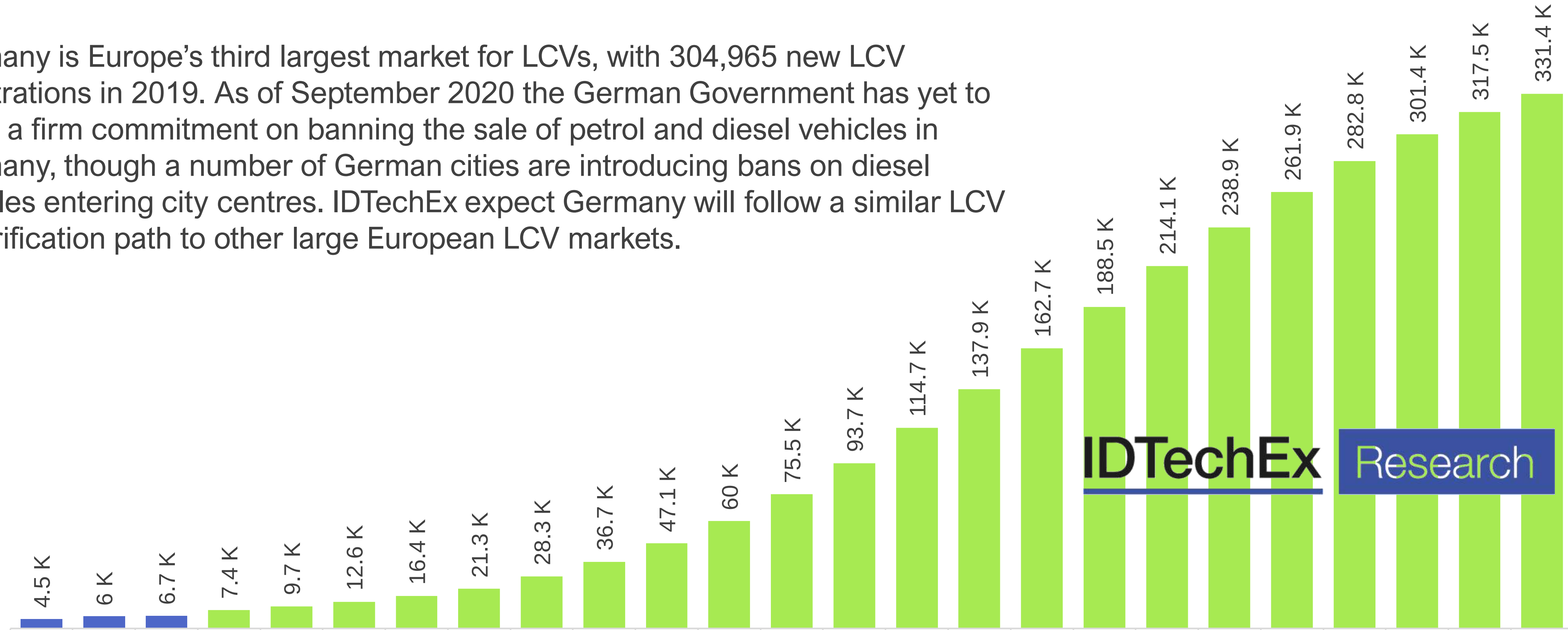
Germany eLCV penetration and sales, pathway to 2041

Germany is Europe's third largest market for LCVs, with 304,965 new LCV registrations in 2019. As of September 2020 the German Government has yet to make a firm commitment on banning the sale of petrol and diesel vehicles in Germany, though a number of German cities are introducing bans on diesel vehicles entering city centres. IDTechEx expect Germany will follow a similar LCV electrification path to other large European LCV markets.



	2017	"18	"19	"20	"21	"22	"23	"24	"25	"26	"27	"28	"29	"30	"31	"32	"33	"34	"35	"36	"37	"38	"39	"40	2041
% of LCV	1.7%	2.1%	2.2%	3.2%	3.9%	4.7%	5.8%	7.0%	9.2%	12%	15%	19%	24%	29%	36%	42%	50%	57%	64%	71%	77%	83%	88%	92%	95%

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