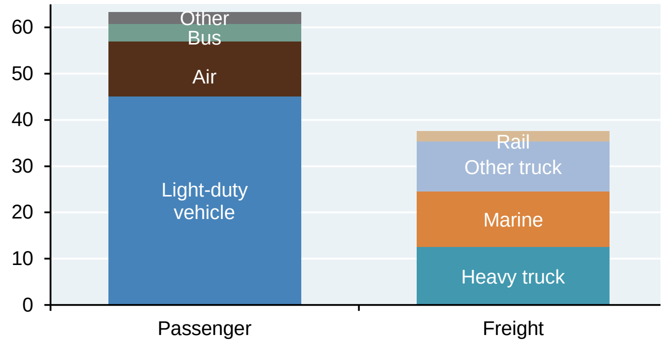
[1] Electric vehicles: a 2% or a 20% solution?

While the share of renewable power generation has grown tenfold since 2004, the world still uses fossil fuels for 85% of its primary energy. Without displacement of direct fossil fuel use in transportation and industry, climate goals may not be reached within desired timeframes. Since road transportation accounts for 50% of global oil consumption, a key component of decarbonization is the speed of electric vehicle (EV) adoption. Forecasters are now jockeying for position with geometric projections. However, the transition to EVs is likely to be gradual, once again confounding the expectations of futurists.

World transportation energy consumption by mode
Quadrillion Btu



Source: Energy Information Administration. 2016.

Global consumption of oil products	mtoe*	% of total
Road transportation	1,823	50%
Feedstocks	588	16%
Other transportation (air, marine)	539	15%
Heating	313	8%
Industry	303	8%
Agriculture	116	3%

Source: IEA Statistics, 2015. Mtoe = million tons of oil equivalents

Let's start with public policy and manufacturer goals. The table on the left shows countries that have announced dates by which internal combustion engine (ICE) sales are banned, and countries with less binding EV sales targets. Automakers have announced EV sales targets as well.

Government policy goals

Country	Announced goal for vehicle sales	2017 light vehicle sales (MM)
China	ICE ban pending; cap-trade policy targets EV sales of 5% by 2020	28.3
U.S.	No stated goal	17.2
Japan	EVs 30% of sales by 2030	5.1
Germany	End ICE sales by 2030	3.7
India	End ICE sales by 2030	3.2
U.K.	End ICE sales by 2040	2.9
France	End ICE sales by 2040	2.5
Brazil	EVs 30% of sales by 2030	2.2
Italy	EVs 30% of sales by 2030	2.1
Canada	EVs 30% of sales by 2030	2.0
South Korea	EVs 30% of sales by 2030	1.8
Mexico	EVs 30% of sales by 2030	1.5
Netherlands	End ICE sales by 2025	0.5
Norway	End ICE sales by 2025	0.2

Source: IEA Global EV Outlook, Vox, Clean Energy Ministerial, Focus2move. 2018.

Company policy goals

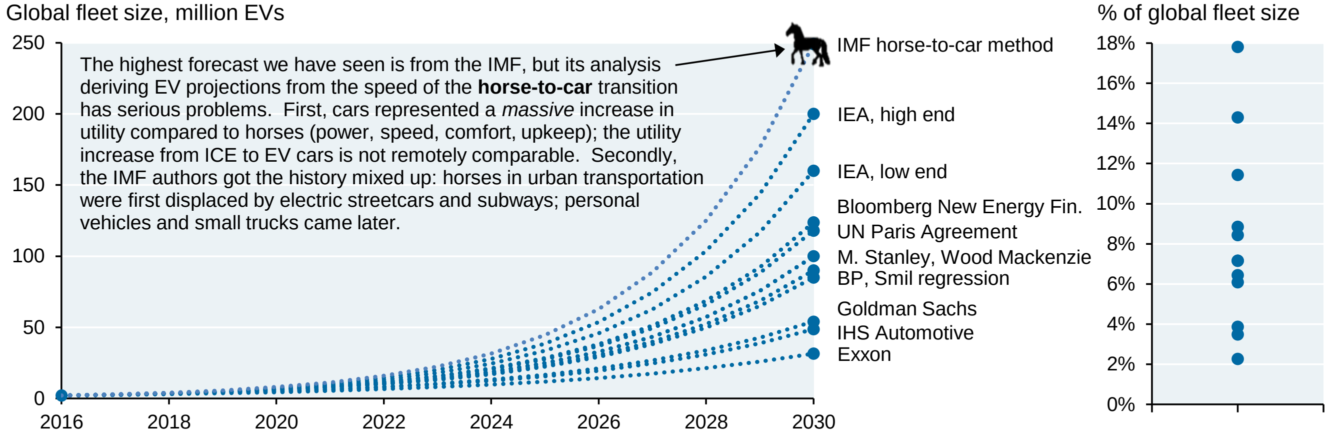
Company	Announced electric car ambitions	2016 light vehicle prod. (MM)
Chinese OEMs	4.5mm annual EV sales by 2020	11.9
Toyota	5.5mm annual EV sales by 2030	10.2
Volkswagen	2-3mm annual EV sales by 2025	10.1
Renault-Nissan	1.5mm cumulative EV sales 2020	8.9
Hyundai	38 new electric models by 2035	7.9
GM	1mm annual EV sales by 2026	7.8
Ford	40 new electric models by 2022	6.4
Honda	2/3 of 2030 sales to be EVs	5.0
Fiat-Chrysler	No stated goal	4.7
Daimler	0.1mm annual EV sales by 2020	2.5
BMW	15-25% of BMW group sales by 2025	2.4
Volvo	100% EV sales by ~2024	0.5
Tesla	0.5mm EV sales by 2018, 1mm by 2020	0.1

Source: IEA Global EV Outlook, OICA, Reuters, NYT, Bloomberg, listed companies. 2018.

How fast? Governmental agencies, economists, research analysts and futurists have all chimed in with EV projections. As shown below, there's a *very* wide range of projections for the global EV fleet size by the year 2030[5]. Assuming a global fleet of 1.4 billion cars in 2030 (up from ~1 billion today), the projections range from 2% to 20% of the future projected fleet[6]. In most cases, these projections continue growing at a rapid pace to 2040 and beyond.

Electric vehicle projections for the year 2030: from 2% to 20% of the global fleet
Global fleet size, million EVs

2030 EV penetration
% of global fleet size

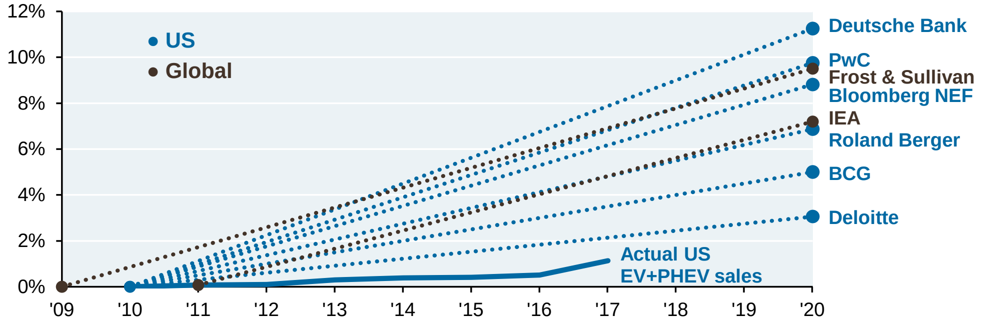


The highest forecast we have seen is from the IMF, but its analysis deriving EV projections from the speed of the **horse-to-car** transition has serious problems. First, cars represented a *massive* increase in utility compared to horses (power, speed, comfort, upkeep); the utility increase from ICE to EV cars is not remotely comparable. Secondly, the IMF authors got the history mixed up: horses in urban transportation were first displaced by electric streetcars and subways; personal vehicles and small trucks came later.

Sources: IEA, IHS, BNEF, MS, GS, UN, Wood Mackenzie, BP, Smil, Exxon, IMF. 2018.

When looking at these projections, it's worth recalling the **overly optimistic EV projections made by some of the same forecasters a decade ago** (see below). Yes, these forecasts took place before the decline in lithium ion battery prices, before subsidies for EV buyers and before government targets were established. However, they're still useful as a reminder that many forecasters vote with their hearts instead of their minds, and often don't incorporate real-life barriers to product displacement. Cars are not smartphones: they have higher upfront and ongoing maintenance costs, complex supply chains, refueling requirements and higher standards for performance and safety. The EV revolution is now upon us, but the important question for investors is the pace. The median forecast is ~125 million EVs by 2030; I'm taking the "under" rather than the "over".

Prior generation of electric car projections out of sync with reality
EV+PHEV sales as % of total car sales



Source: DOE, BEA, hybridcars.com, and listed organizations. 2017. Note: global EV+PHEV sales in 2016 were also around 1.1%.

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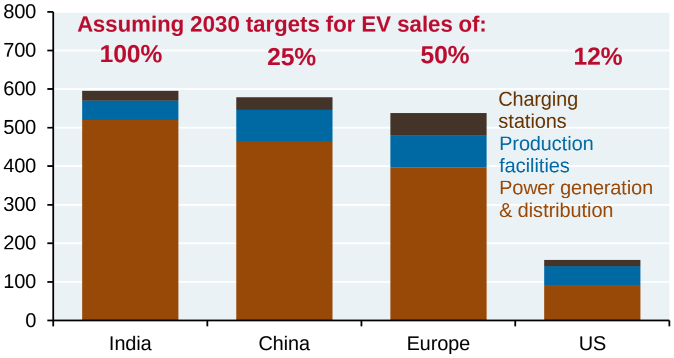
[5] The World Economic Forum forecast is derived differently: by electrifying fleets, taxis and other public transport rather than personal vehicles (which are on the road less than 5% of the time), 35% of US vehicle miles travelled could be electrified by 2030, even though the vehicle stock might remain 85% internal combustion engine cars.

[6] We assumed a lower growth rate (2.8%) for light vehicles to 2030 compared to the historical 2005-2015 growth rate (3.8%) given the potential impact of more efficiently used autonomous cars.

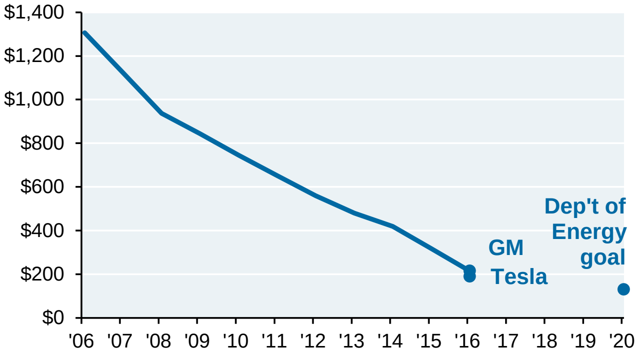
Why might the EV revolution occur at slower speeds rather than faster ones? First, related infrastructure needs are not just charging stations and production factories. Large power generation and transmission investments would be needed as well. According to one analysis we have seen, India, China and Europe would face a combined $1.7 trillion in required capital investment. These are imprecise estimates, but could be quite large and require tough decisions in aging societies with growing unfunded pension and healthcare costs.

Total investment required through 2030 to meet EV policy targets, US$ billions, cumulative



Source: Bridgewater Associates. February 2018.

Lithium ion energy storage costs: EV battery packs, capital cost per kWh



Source: Nykvist, et. al, Albertus et al. January 2018.

Another challenge: how far can lithium ion battery costs fall? There has been a sharp decline in the capital cost of lithium ion battery packs over the last decade to around $200 per kWh. The US Department of Energy has a stated goal of $100 per kWh on a cell basis (around $130 for the pack) in the next few years, a level often cited as the point at which mass-marketed EVs could reach parity with some ICE vehicles. However, in a January 2018 paper, ARPA researchers concluded that the DoE target could be hard to reach using current battery design[7]. While they outline manufacturing processes and materials that might reduce costs, these approaches do not yet meet required performance standards. This DoE table compares current and future possible technologies:

Vehicle energy storage technology overview

Current technology: lithium ion battery (graphite/NMC)	
Current cost	$235 / kWh
Potential cost	$100-$160 / kWh
Current cycle life	1000-5000
R&D needs	High voltage cathode/electrolyte; Lower cost electrode processing technology; Extreme fast charging
Next generation technology: lithium ion battery based on silicon composite/high voltage NMC	
Current cost	$256 / kWh
Potential cost	$90-$125 / kWh
Current cycle life	500-700
R&D needs	High voltage cathode/electrolyte; Lower cost electrode processing technology; Extreme fast charging; Durable silicon anode
Longer term: lithium metal	
Current cost	$320 / kWh
Potential cost	$70-$120 / kWh
Current cycle life	50-100
R&D needs	High voltage cathode; Lithium protection; High conductive solid electrolyte

Source: "*Electrochemical Energy Storage R&D Overview*", US Department of Energy, D. Howell, 2017.

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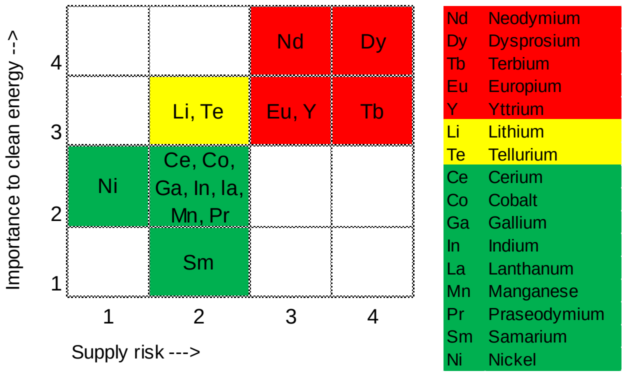
[7] "*Status and challenges in enabling the lithium metal electrode for high-energy and low-cost rechargeable batteries*", Albertus et al (US Department of Energy Advanced Research Projects Agency), *Nature Energy*, Jan 2018.

What about **rare earth metals and other critical materials?** Most research we've seen projects that there will be enough lithium, graphite and other minerals to meet growing demand. It's a bit dated, but in 2011, the US Department of Energy published a report on critical materials supply and found that with the exception of dysprosium, neodymium and terbium, most did not present a medium term supply risk. In 2017, researchers from the University of Science and Technology in Beijing looked at the same question[8], perhaps since China is the world's largest EV market. Here's what they found:

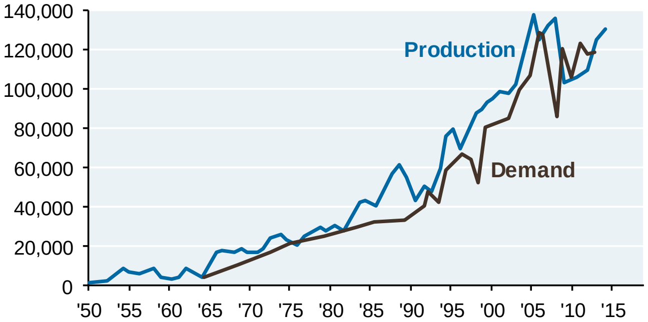
- Demand from electric vehicles is expected to reach 68% of all rare earth demand in 2030 (compared to 50% today)
- While current rare earth elements are mined primarily by China and Australia, there are 478 megatons of rare earth oxides widely distributed around the world which could sustain current global rare earth production for over 100 years
- However, the largest increases in demand are expected to be for **neodymium and dysprosium** (as in the 2011 DoE study), whose shortages could become an issue for supply chains

Medium Term Criticality Matrix



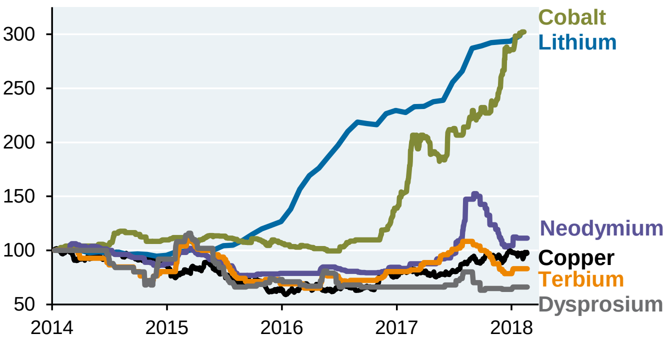
Source: US Department of Energy, 2011.

Global rare earth production and demand
Metric tons



Source: "*Global Potential of Rare Earth Resources and Rare Earth Demand from Clean Technologies*", Zhou, Li, Chen, October 2017.

EV battery metals prices
Index = January 2014



Source: Bloomberg. February 2018.

A brief comment on autonomous car energy use

Researchers from the University of Michigan Center for Sustainable Systems looked at autonomous car energy use vs passenger-controlled EVs and ICE cars. For some vehicles, energy benefits from autonomous driving more than offset its incremental energy drag due to computing power needs, additional weight and vehicle drag. But for larger applications (e.g., Waymo installed in a minivan), autonomous car tests showed *higher* net energy use. We will keep an eye on this.

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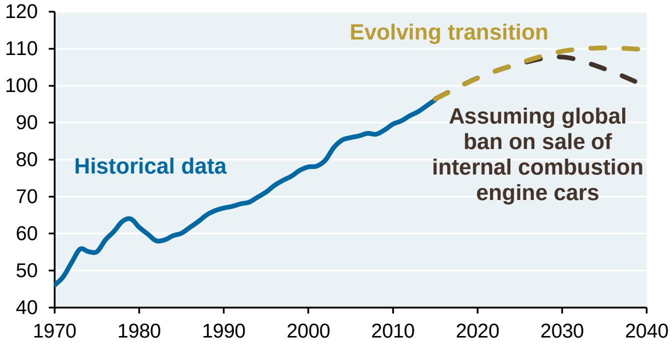
[8] "*Global Potential of Rare Earth Resources and Rare Earth Demand from Clean Technologies*", Zhou, Li and Chen, University of Science and Technology in Beijing, *Minerals* magazine, October 2017.

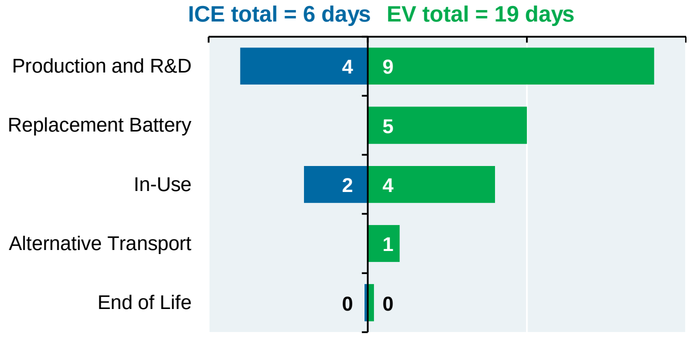
Bottom line: the EV revolution is here, and some manufacturers claim that break-even costs vs ICE vehicles are closing fast (see next page). But some EV forecasts seem too aggressive to us, given the challenges. As a result, we're inclined towards the lower half of the forecasts on page 10, and are dubious that EV demand will exert a material impact on oil prices in the next few years. The concept of "**peak oil extraction due to falling demand**" might exist, but (a) closer to 2030 rather than during this decade, and (b) be more likely if most of the world enacts an outright ban on the sale of ICE cars. As shown earlier, that's not happening, at least not yet. Changes in GDP growth, improvements in the efficiency of the internal combustion engine[9] and the cost/regulation of hydraulic fracturing of shale oil are all likely to have a larger impact on oil prices than EVs for the foreseeable future.

Global liquid fuels use, with BP projections to 2040
Million barrels/day



Source: BP Energy Outlook. 2018.

"Days of life" impact for passenger ICE vs EV
Hypothetical days lost to death or disability due to toxicity



Source: "*Battery Electric Vehicles vs. Internal Combustion Engine Vehicles*", Arthur D Little, November 2016.

EV Appendix I: How green are electric cars?

Most lifecycle analyses agree that EVs reduce global warming risks. Electric motors using natural gas and renewable energy as indirect fuel are more carbon-efficient than ICE cars, reducing emissions by 25%-50%. [Note: in our 2016 energy paper, we showed this chart on the renewable percentage of the electricity grid by country and by US state].

However, environmental impacts are not limited to CO_2 emissions. The chart above from Arthur Little estimates the lifecycle environmental impact of ICEs vs EVs, measured as "days of life lost to toxicity". In this analysis, EV environmental impacts are 3x higher. The primary reason: freshwater and terrestrial exposure to copper, cobalt, nickel and graphite during the mining process. Even if the grid were fully renewable and EV "in-use" toxicity were zero, Arthur Little still estimates a higher environmental impact for EV cars. I doubt this will be a roadblock in the EV revolution, since such risks are borne mostly by countries which have shown less ability/interest to aggressively control them: the Philippines, Russia, the Congo, China, India, Brazil, Vietnam and Turkey. Arthur Little's analysis on EV toxicity draws from a widely cited 2013 paper in the *Journal of Industrial Ecology* from Anders Stromman at the Norwegian University of Science and Technology on EV supply chain eco-toxicity and eutrophication.

I'm not 100% sold on the *relative* aspect of Arthur Little's analysis, since it seems to underestimate toxicity risks from oil production and exploration, as well as from gasoline refining and distribution. One example: a 2016 paper from the Johns Hopkins School of Public Health measured hydrocarbon spills at gas stations, and found that regulations typically do not address subsurface contaminations from chronic gasoline spills, even though they could result in non-negligible exposure to toxic and carcinogenic compounds. Every lifecycle analysis has its own biases, and the Arthur Little version is no exception.

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[9] In its forecasts for 2040, BP estimates that oil displaced by ICE fuel efficiency gains will be **7x** larger than oil displaced by electric vehicles.

EV Appendix II: could Tesla produce an EV truck with a fast payback period?

Taxis, garbage trucks and semi trucks could be good candidates for conversion to electricity or natural gas if fuel savings offset higher upfront costs in a short period of time. Tesla claims that its new semi truck will do just this. However, our estimate of its payback period is longer than some recent forecasts.

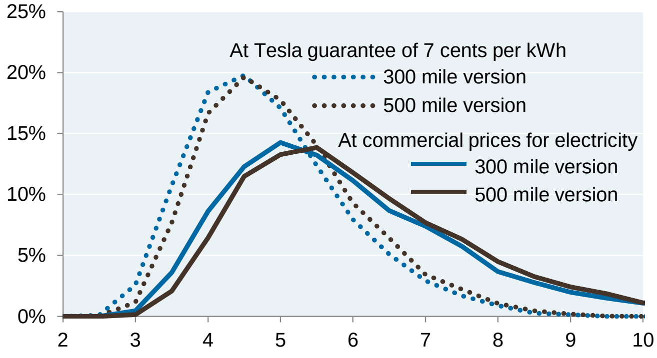
The average short haul diesel truck costs $120k, travels ~90,000 miles per year (~300 per working day and capable of traveling 1,000+), and lasts for around one million miles. Tesla announced two possible substitutes: an EV semi capable of travelling 500 miles per charge at a cost of $180k, and a 300 mile version at $150k. Tesla claims that its EV fuel efficiency will offset higher upfront costs in a short period of time. Some analysts agree, and we have seen estimates as low as a 2 year payback period.

There's a lot that isn't known yet about Tesla's hypothetical truck; the table shows our estimates of factors that affect payback periods, and the chart shows our simulated results. **Our Tesla payback period estimates are higher than 2 years, and are similar for 300 mile and 500 mile versions**. One decision we had to make: what about Tesla's electricity price guarantee of 7 cents per kWh? This guarantee is available to drivers using Tesla's proprietary mega-charging stations (a network that doesn't exist yet), and relies on Tesla remaining a going concern. In any case, we modeled it both ways.

Assumptions	**Fixed**	**Min**	**Mean**	**Max**	**Units**
Battery replacement		$115	$125	$135	$/kWh
Tesla fuel efficiency		1.80	2.00	2.40	kWh/miles
Diesel fuel efficiency		6.00	7.50	8.50	miles/gal
Annual miles driven		80,000	85,000	90,000	miles
Battery cycles (lifetime)		1,500	1,750	2,000	cycles
Diesel price		$2.50	$3.50	$4.25	$/gal
Electricity prices		$0.09	$0.10	$0.13	$/kWh
Electricity prices (guar)	$0.07				$/kWh
Increm. diesel repair		$0.06	$0.10	$0.12	$/mile
Depth of discharge	80%				%
Discount rate	3%				%

Source: JPMAM, 2018. Normal distributions truncated at min/max values.

Payback periods for Tesla EV trucks vs diesel
percentage of observations, n=10,000



Source: JPMAM, 2018.

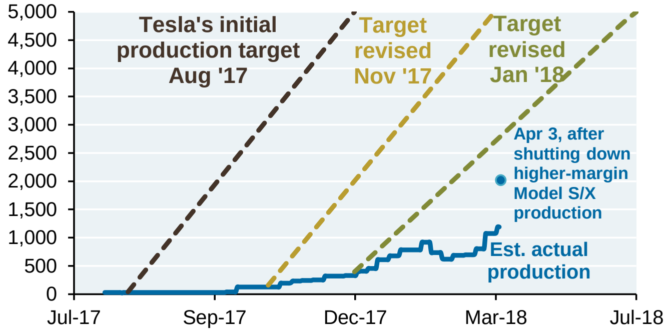
Important notes on our analysis

- Some analysts assume that Tesla's one million mile warranty **includes battery replacement**. There has been no clear messaging from Tesla on this issue. We assume the driver replaces the battery once its cycle lifetime has run its course. The driver could opt instead to relegate the truck to other uses at this point since it would still function, albeit with depleted battery capacity. However, in this case the EV truck is no longer an economic substitute for the diesel, and entails revenue losses that would have to be factored in. **Payback analyses that do not assume that the battery is replaced (either by Tesla or the driver) and do not account for utility loss make little sense to me.**
- We did not include possible losses associated with **reduced Tesla payloads**. Tesla battery packs have energy densities of 160-200 Wh/kg, which include the weight of housing, cooling systems, mechanical support structures, electronics and cell connectors. For the 500 mile version, the weight of the battery could result in a 15%-20% lower max payload than the comparable diesel truck. However, many trucks max out on volume rather than weight, in which case this would be less of an issue.
- Why are payback periods similar for 300 & 500 mile versions? While the former's upfront cost is lower, it requires 2 battery replacements over its million mile life rather than 1, as per our assumptions.
- Tesla's **electricity subsidy** for truck buyers appears substantial, since the company recently increased its Supercharger electricity prices for new model S/X/3 buyers to 24-26¢/kWh in Oregon, California and NY.

Let’s keep some things in mind about **Tesla and its hypothetical truck**:

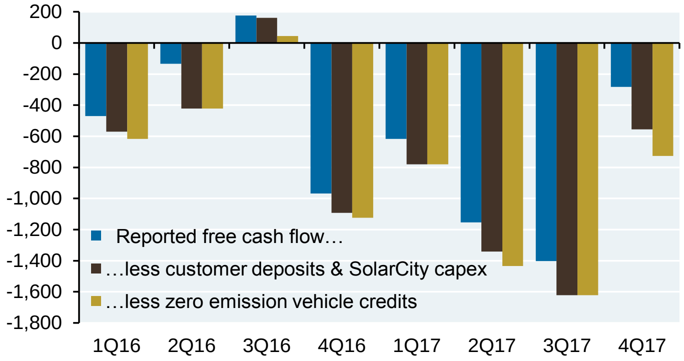
- Tesla’s truck doesn’t exist yet, and neither does its production facility
- Tesla truck prices are indicative and non-binding, and could change
- Our analysis doesn’t incorporate possible impacts of constant driving and fast-charging on battery capacity, safety and useful life
- Payback periods do not incorporate how truck buyers might feel about a company that usually does not allow anyone else to work on their vehicles, and does not sell service manuals or parts either
- Tesla has a history of missing its production targets, just suffered the worst quarterly financial loss in its history as well as an outflow of senior executives, has a high level of junk debt and has a high level of CEO compensation for a loss-generating enterprise.

Consider us skeptical, at least until more details emerge. Here are some charts assessing Tesla as a going concern with long term warranty and electricity price guarantees. For the complete set of our Tesla charts on these and other related topics, please click **here**.



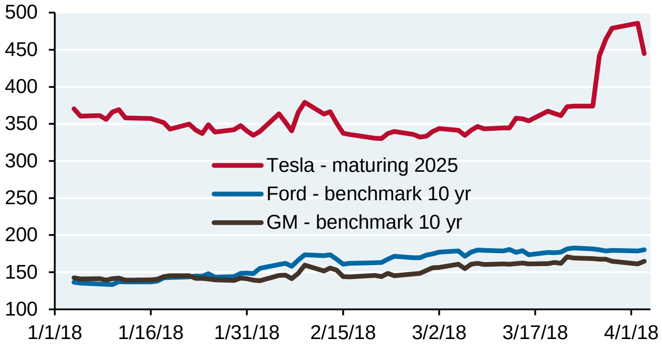
Tesla Model 3 production: targets vs reality
Weekly # of Model 3s manufactured

Source: Bloomberg. April 3, 2018. Actual production estimated based on manufacturer vehicle registrations.



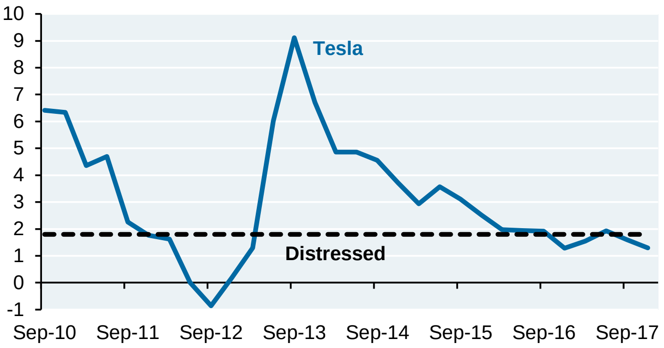
Tesla's cash burn
Free cash flow, US$ millions

Source: Bloomberg. 4Q 2017.



Carmaker credit spreads
Basis points over Treasuries

Source: Bloomberg, April 3, 2018.



Tesla's Altman Z-score
Lower score indicates higher likelihood of bankruptcy

Source: Bloomberg, JPMAM. Quarterly data through December 31, 2017.

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