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ELECTRIC VEHICLES

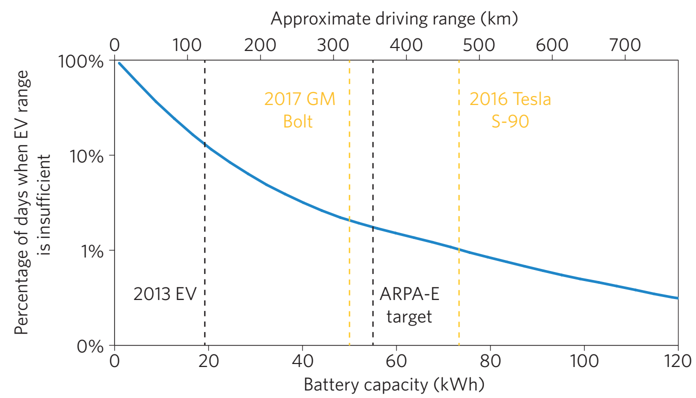
Driving range

For uptake of electric vehicles to increase, consumers' driving-range needs must be fulfilled. Analysis of the driving patterns of personal vehicles in the US now shows that today's electric vehicles can meet all travel needs on almost 90% of days from a single overnight charge.

Willett Kempton

The conversion of the light vehicle fleet from petroleum-based fuels to electricity has benefits in terms of global politics, climate change and human health in urban areas. In most countries, electric vehicles (EVs) are already cost-competitive with petroleum or diesel over their life cycle[1]. Global stock now exceeds 1,000,000 EVs, yet in 2015 less than 1% of new cars sold were EVs, [**Au**: **ok**?] raising the question: why are so few sold? EV introduction is hampered by the high cost of batteries, slow recharge time, limited range per charge and, as a result, the buyer-anticipated inability of EVs to meet all driver needs. Writing in *Nature Energy*, Jessika Trancik and colleagues at MIT and the Santa Fe institute address the latter two of these barriers to widespread adoption[2]. They show that across many regions of the US, considering trip needs, driving patterns and temperature, 87% of vehicle-days (the set of trips taken by a specific vehicle over the course of a day) can be met by existing, affordable EVs. Furthermore, they predict that within the next one to two model-years, larger batteries in affordable EVs will enable over 98% of trips to be made with these vehicles.

The limited range and slow recharge of EVs is typically raised as a problem whose solution is to make EVs replicate liquid-fuel vehicles [**Au: ok?**]; that is, to provide a 400–500 km (about 300 mile) range and a refill time of five minutes. However, imitating liquid fuels would be the solution only if the range they provide is truly required by drivers. To understand if this is the case, Trancik and colleagues analyse daily vehicle travel patterns to model actual vehicle usage. Their method combines information from travel surveys with GPS data on personal vehicle trips made in any personal vehicle (excluding motorcycles and recreational vehicles), not just EVs. A large sample of trips is taken from many vehicles, with each vehicle sampled over a short sequence of days. [**Au: ok?**] They then use a model that includes energy losses from extreme ambient temperature, plus losses from inefficient driving patterns, to infer the energy consumption of each trip. The large sample size, coupled with the model, allows the researchers to calculate days when trips could be met by a fixed-size battery (measured in kWh) across a wider range of conditions than previous methods. It also allows for comparisons between different areas of the country and between current and near-future battery sizes. By comparing their findings to the performance of a 2013 model EV with a relatively small battery, they find that a substantial majority of trips are covered by a single daily charge of the battery. The researchers note that remaining trips could be covered by occasionally borrowing, leasing or car-sharing a vehicle with either greater range or faster refuelling.



an EV with that size battery would

Figure 1 | The effect of battery capacity on potential EV usage. The impact of battery capacity on the fraction of days in which an EV would be required to be charged more than once (for a given usable battery capacity) to satisfy driver needs is considered over multiple locations (urban and rural) across the US. Approximate driving range is also shown on the top axis using a conversion factor of 6.44 km kWh^{-1}. Dashed vertical lines represent battery capacities for the 2013 EV used in ref. 2 and the ARPA-E target, and proposed driving ranges for the 2017 GM Bolt and the 2016 Tesla S-90. Figure adapted from ref. 2, NPG. **[Au: ok?]**

One of the most significant results is the development of a model of battery size, temperature and driving patterns, to predict that most trips can be made in an EV with current battery size, and an even higher fraction could be made, if the battery size target set by the Advanced Research Projects Agency-Energy (ARPA-E) is met[3]. [**Au: ok?**] The International Energy Agency projects almost a doubling of energy density by 2022 and the US Department of Energy projects a halving of cost per kWh (ref. 4). [**Au: ok?**] In that regard, Fig. 1 illustrates that existing and announced EVs are superior to the 2013 model used in the study and highlights that current EVs and even the ARPA-E targets are indicative of a fast ramp, not the end of development.

However, is successfully meeting the demand of most trips adequate for large-scale adoption of EVs? [**Au: ok?**] The 2013 vehicle shown in Fig. 1 would be sufficient for all but 13% of the trips, but since sales of EVs in most countries, including the US, are well below 1%, this measure of adequacy cannot be enough. As the study from Trancik and colleagues suggests but does not fully elaborate, the problem may be that trip needs, which makes continued low uptake a mystery to explain.

but more importantly,

when a car purchase is made, the customer wants to be able to make all of their trips, not just 90%.

An alternative way to slice trip distance data, which was not done in this study, is to divide the population based on their average daily travel. That way, one can see what fraction of the population would be totally satisfied, every day of the year, by a given EV. This approach was taken in an earlier study, which showed that one-quarter of drivers in the US never exceed 240 km (150 miles) per day in a whole year, and that this same quarter of the population drives the shortest average number of miles per day[5]. From both this previous study and the work by Trancik and colleagues, it can be seen that current EVs can satisfy a majority of trips, but importantly, when drivers are divided into quartiles by average daily travel, current EVs can totally satisfy one-quarter of drivers' needs for every single trip that group takes during the year. One-quarter may be a minority, but it is a huge market segment. It must therefore be concluded that there are other barriers to adoption besides the inability of EVs to cover [redacted] journeys [redacted], or EVs would already be above their current 1% of new sales. As with any new technology, social and governmental assistance can speed the transition; national policy has been shown to greatly increase the rate of EV adoption, even with today's small batteries[6].

besides the inability of EVs to cover most journeys for all, or all journeys for a few,

But perhaps trying to make all EVs perform like petroleum-fuelled vehicles — the implied solution in the above analyses — is the wrong approach to increasing EV adoption. Rather, I would suggest that we should think of at least two classes of EVs, consistent with the segmentation of user trip-needs noted above. For example, one EV class might have a 50 kWh battery and a 300 km range (assuming 6 km kWh^{-1} for an efficient new EV). Such a vehicle would meet almost all trip needs for most people. A second class of EV might have, for example, a 185 kWh battery, giving it a range of over 1,000 km, which would allow all-day non-stop driving, assuming a drive time of ten hours, limited by human fatigue, at a speed of 110 km h^{-1}. Charging at 10 kW at home and at work and en route charging of 50 to 100 kW would provide the appropriate recharge rates for both types of users and vehicles and is practical from both the electricity grid [redacted] **[Au: ok?]** En route 50 to 100 kW charging is an adequate recharging rate for typical short meal or rest stops during a long trip. The often discussed recharging at power above 100 kW becomes increasingly unrealistic and expensive, but with two or more battery sizes matched to driver needs, high-power en route charging would be rarely needed.

both the electricity grid perspective and the vehicle systems perspective.

The work by Trancik and colleagues demonstrates how EVs can support most trip needs, d[redacted]: ok?] Other work shows that bigger batteries are already coming, but a more complete approach to increasing EV adoption may include multiple policies, an improved understanding of the differing range needs of different market segments, and — rather than trying to duplicate liquid fuels — creating vehicles with batteries and charging rates appropriate for a diversity of driving requirements. ❐

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