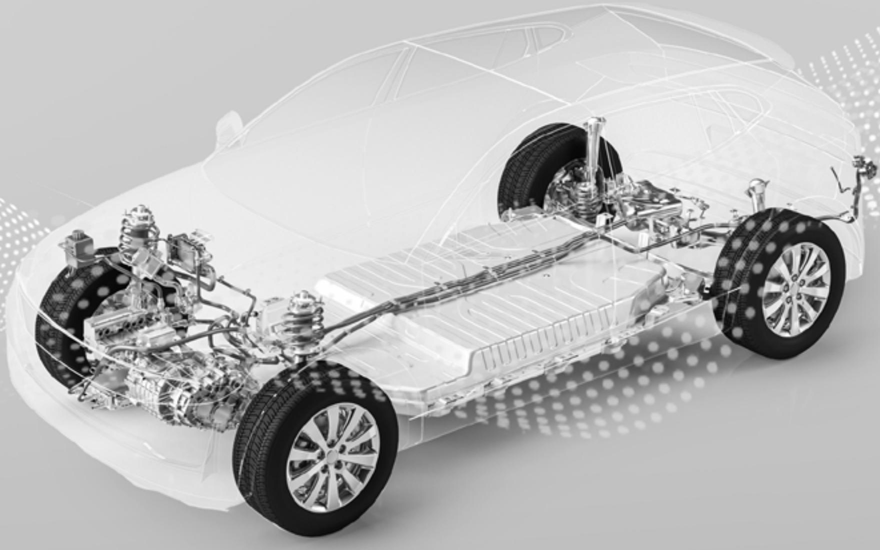
ePROPELLED™

TOWARDS A GREENER FUTURE WITH ELECTRIC VEHICLES

PAST, PRESENT, AND FUTURE CHOICES

Past Actions and Their Results

The International Energy Agency (IEA) estimates that road transport accounts for nearly three-quarters of total transport emissions (with transport in general being responsible for 24% of direct CO_2 emissions from fuel combustion).[1] It's our job to ensure a significant reduction in this single area because it could be a huge boost to the fight against climate change. It could contribute to keeping the cumulative CO_2 emissions for passenger cars (through 2050) to under 45 billion tonnes (45 gigatonnes), which would help hold global temperature increases to under 1.5°C.



1 *Tracking Transport 2020*, Jacob Teter, IEA, 2020

We can't deny the current results of global warming anymore and the temperatures will only keep rising. Ignoring the problem for such a long time has made achieving any meaningful change more difficult now.

Even with stricter environmental goals, we still have a long way to go. The 2030 and 2035 goals for many manufacturers to go all electric are impressive, but seem to be a mad dash to finally catch up to the public need and the demand for greener choices. Not to mention some governments' plans to ban the sale of diesel- and gas-powered cars within the next few decades. The vehicle manufacturers are rushing now, even though the market has been there for a while. It's just the question of creating the product the market is asking for.

Hard truths

We need to be honest. There is no such thing as a completely green car. It might run clean and produce no harmful emissions. But the way it's manufactured and the impact its batteries have on the environment are certainly far from being perfectly green. Across their full life cycle, EVs are more environmentally friendly than their internal combustion engine (ICE) counterparts and, once they're on the market, they will contribute significantly to a drop in carbon dioxide emissions. But to make them as green as possible, we need to make sure that:

- the manufacturing processes are as close to zero-emissions as possible,
- the batteries are made to last a very long time,
- the cars themselves are extremely efficient, preserving the life of the batteries further, and
- we find ways to recycle old batteries for a closed-loop economy.

We can't go back in time and change what's been done, so we need to make even better choices now. Using what we have to the best of our abilities, we can contribute to a significant reduction in greenhouse emissions, while providing the customers with cars that are affordable and environmentally friendly. Making EVs is just the first step. Improving them is going to be an ongoing responsibility for the whole vehicle industry.

The Grid Question

The electrical grids, their reach, and how clean they are varies dramatically depending on their geographical location. Some are cleaner than others, but EVs remain greener than ICE cars within the vast majority of grids.

According to the **International Council for Clean Transportation** (ICCT), even in countries like India and China, where more coal is used in electricity generation than elsewhere, EVs will still have lower overall emissions than ICE cars.[2] Depending on location, EVs can be responsible for emissions that are between 19% and 69% lower than an ICE vehicle (best in Europe, followed closely by the U.S., with China, India, and Australia lagging behind).

And if we manage to make EVs more efficient, then less electricity taken from the grid is good news everywhere, particularly in areas where the grid is not as clean as it could be.

2 *A Global Comparison of the Life-cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars*, Georg Bieker, International Council on Clean Transportation, 2021

Batteries

There is a worry that battery manufacturing and materials sourcing outweigh the positives of the EVs. And there is obviously a lot of truth to the idea that these processes are far from environmentally friendly. However, according to a **Reuters** analysis that factored these datapoints in the calculations, EVs still have less of an environmental impact than ICE vehicles after some time on the road (the "break even" point for an EV will depend on a lot of factors, so it can vary wildly from 8,400 miles for a Tesla 3 in Norway to 78,700 miles for that same car in Poland).[3]

The use of batteries is a huge help in lessening the impact that road transport has on global carbon emissions. But we need to be realistic about the impact the batteries can have due to the way they're produced, used, and disposed.

Production

Batteries don't just appear out of nowhere. The lithium-ion batteries in most electric vehicles are made of raw materials whose mining is sometimes linked to serious **human rights concerns**,[4] including child labor and unsafe working practices.

Mining these materials can also be **environmentally damaging**.[5] The way raw materials are extracted uses a lot of energy and water, mine waste can leach and harm the nearby communities and the environment, and smelting can emit sulphur oxide among other harmful pollutants.

Ensuring that the batteries are made in a responsible way that, ideally, causes no damage (or at least much less damage than it does now) is something to consider if we want to claim EVs to be environmentally friendly or environmentally responsible. Manufacturers can pledge social responsibility and only work with providers who are themselves environmentally responsible and don't violate human rights in pursuit of profit. It's not something that can be faked or swept under the carpet in this world of social media anymore.

Recycling

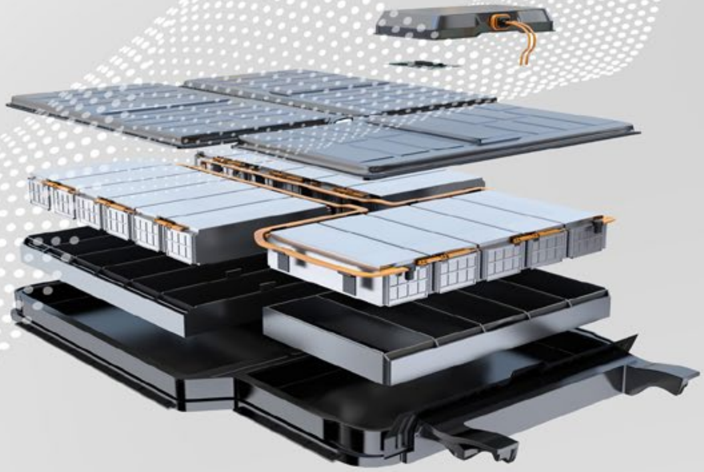
As the EV industry grows and the demand for batteries amps up along with it, recycled materials will need to make a large percentage of the supply chain. Although we'll have to rely on mining for some time to create the batteries necessary to go electric, at some point we'll be able to create a closed-loop economy by **reclaiming the materials** from existing, old batteries.[6]

The IEA estimates that while recycled lithium, cobalt, nickel, and copper currently provide very little of battery materials, by 2040 they will make up an estimated 8.1% of metals demand.[7]

The problem is that the lead-acid battery technology is older than the lithium-ion type used in most electric vehicles. As a result, their **recycling rates** are very different, with the former reaching almost 100% and the latter only about 5%.[8] However, the industry

3 *Analysis: When Do Electric Vehicles Become Cleaner than Gasoline Cars?*, Paul Lienert, Reuters, 2021
4 *Lithium-ion Batteries Need to Be Greener and More Ethical*, Nature.com, June 29th 2021, www.nature.com/articles/d41586-021-01735-z
5 *The Environmental Impact of Lithium Batteries*, Institute for Energy Research, November 12, 2020
6 *Carmakers Try to Head off Supply Crunch with Battery Recycler Investments*, Camille Erickson, S&P Global Market Intelligence, 2021
7 *The Role of Critical Minerals in Clean Energy Transitions*, World Energy Outlook Special Report, International Energy Agency, 2021
8 *Sustainability and Second Life: The case for cobalt and lithium recycling*, Claire Church and Laurin Wuennenberg, International Institute for Sustainable Development, 2019

Used car batteries could be used for **>10 years** as backup storage for solar power



is taking note and investments in lithium-ion recycling facilities are on the rise.

Recycling facilities can recover active materials including plastic, copper, and aluminum, as well as anode and cathode materials that can be refined for high-purity battery chemicals. **Recent tests** show that lithium batteries made with recycled materials are just as good, if not better, than brand new ones.[9] But, depending on the process, recycling batteries can use large amounts of water or emit pollutants. This is why considering giving the batteries a second life is a good idea.

Secondary markets for ex-vehicle batteries are a promising option, notably in the grid storage market where the energy density per volume (or mass) of the battery is less important than it is in a vehicle. This is just the beginning of the road and more testing is needed, but there are promising options out there. Recently, researchers at the **Massachusetts Institute of Technology** found that used car batteries could be used for a decade (or more) as backup storage for solar power.[10]

The longer the batteries can be used safely in any capacity (in a car or in the grid storage market), the greener electric power will become. But cooperation between industries and technological leaders is necessary to make the right choices.

More efficient use

The move towards electric vehicles is an opportunity for different sectors, such as energy and transport, to work together to develop new EV technologies. It would help expand the talent pool and make ground-breaking solutions more likely. This would benefit everyone involved, including the environment.

Cross-sector collaboration is already happening but we must continue to promote and develop it. There is still some belief that this would be going against free-market and competition. But such collaborations are mutually beneficial and don't affect the fundamental relationships of competitors.[11]

9 *Recycled Lithium Batteries as Good as Newly Mined*, Prachi Patel, IEEE Spectrum, 2021
10 *Solar Energy Farms Could Offer Second Life for Electric Vehicle Batteries*, David L. Chandler, MIT News, 2020
11 *Should Industry Competitors Cooperate More to Solve World Problems?*, Sean Silverthorne, Working Knowledge, Harvard Business School, 2017

What's more, this is not the time for industrial secrecy but for improving and expanding cooperation. We simply cannot afford not to work together. Car batteries are far from perfect. They need an improved life (and a smaller size), and combined industry efforts might yield impressive results.

Batteries themselves are not the only issue. New technologies that improve vehicle efficiency and extend battery life (**such as eDTS**,[12] which improves efficiency by at least 15%) will need to be used in all EVs to help them not only overtake ICE vehicles in performance and price but also to improve the EVs themselves.

After all, what's the point of having a great, long-lasting battery, if the vehicle itself uses the battery too quickly and shortens its lifespan? This is a chance to be even greener. A more efficient use of batteries would mean greener EVs. And batteries that last longer take the pressure off raw materials, manufacturing, and recycling.

With the right and more efficient motor technology, manufacturers can reduce the size (and therefore the cost) of the battery pack, meet consumer preferences for size and range, make EVs more affordable to build, and start making profits while making the EVs more environmentally friendly.

Further, Faster, Most Affordable

If the EVs become more affordable, they will be more readily purchased. This is hardly news and yet it is something that manufacturers have been struggling with for years. It's a multifaceted problem that involves vehicle performance, customer preferences, and costs. And all of those issues relate to batteries.

Consumer preferences

Consumers want cars they're used to driving. Ford didn't take in almost **50,000 pre-orders** in 48 hours on their F-150 Lightning because people suddenly changed their minds about EVs. It is because they have been waiting for their type of car to become available. People will keep driving ICE cars because a particular type or model is their preference and an electric version is not available. Consumers want electric vehicles. They just want ones that work for them.

In addition, **being green** and efficient is something that preoccupies many people living in cities.[13] This might mean a willingness to accept a shorter range. City trips are shorter and charging stations can be found with more ease than in rural areas. The option of purchasing home chargers might also influence potential purchasers.

At least **two-thirds of American drivers** are open to buying an EV,[14] but in general, driving range, charging speed (as well as the scarcity of charging stations), and cost have a big influence on purchasing decisions.[15, 16]

All of the above are linked to vehicle efficiency and performance which, in turn, affects the battery pack. And, just as was mentioned above, cooperation and inventiveness are necessary to address these issues.

Currently, charging speeds are being addressed more readily than battery efficiency, and fast-charging batteries are in development, although some won't be

12 *Product Overview: Dynamic Torque Switching*, ePropelled, 2021
13 *Green Transport Set to Overtake Cars In World's Major Cities By 2030*, Sonia Elks, World Economic Forum, 2020
14 *Consumer Reports Survey Shows Strong Interest in Electric Cars*, Benjamin Preston, last updated December 18, 2020, www.consumerreports.org/hybrids-evs/cr-survey-shows-strong-interest-in-evs
15 *Electrifying Insights: How Automakers Can Drive Electrified Vehicle Sales and Profitability*, Russell Hensley, Patrick Hertzke, Stefan M. Knupfer, Nicolaas Kramer, Nicholas Laverty, and Patrick Schaufuss, McKinsey & Company, 2017
16 *Electric Vehicles and Fuel Economy: A Nationally Representative Multi-Mode Survey*, CR Survey Research Department, December 2020

available for **several years**.[17] But, in the meantime, if new technology allowed smaller batteries to be fitted, they would also charge faster to full capacity.

The more challenging problem is the driving range. If we use new technologies to **increase vehicle energy efficiency**, therefore extending the EVs' driving range, it would help combat the so-called "range anxiety" and help consumers trust EVs more.[18]

Cost of EVs

It's not news that most OEMs **barely break even on EVs**.[19] Automakers are trying hard to bring EVs to market to meet the new CO_2 targets and customer demands, but the price of manufacturing makes it almost impossible to make a profit. This is mostly caused by the battery size and price.

And although battery costs have been dropping (rising demand for a product tends to make prices go down), we shouldn't count on prices falling much below $100/kWh. The law of diminishing returns is in full force here—price reductions are no longer as dramatic as they were just 10 years ago and, when looking at any graphs showing battery prices, it's clear that they get smaller by such small increments as to be almost insignificant. The size of car batteries makes their cost prohibitive, and the technology hasn't developed enough to provide large but cheap options.[20]

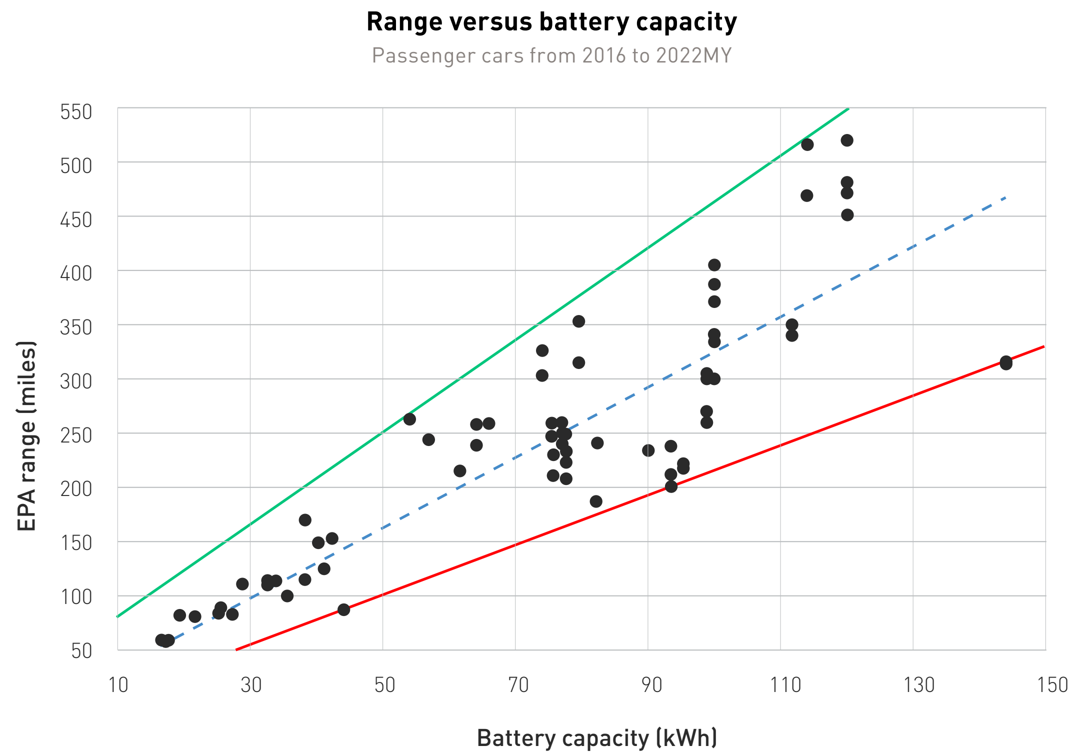
Battery size (the most expensive component of an EV), its energy density and life can contribute to cost reduction and, therefore, profitability. But this requires adopting new technologies that allow for either smaller battery packs for the same range or an extended driving range with the same battery size. Smaller batteries—achieved through technologies such as eDTS—would be less costly, making EVs more affordable and profitable, while also being better for the environment.

Vehicle performance

Comparing EVs to ICE vehicles can make some of us feel a little self-satisfied. But, when the situation is considered honestly, we need to make the EVs greener, not just cheaper and more consumer-friendly. It is necessary for us to beat the existing EVs in efficiency and performance, not just the ICE cars. As mentioned above, new technologies that improve vehicle efficiency and extend battery life have to be developed and used in all EVs.

The graph below shows a number of EVs currently on the market and the diversity of efficiency among these vehicles.

17 *An Electric-car Battery That Can Be Charged as Fast as Filling Up Your Gas Tank Was Just Shown Off by a Startup*, Grace Kay, Business Insider, 2021
18 *Product Overview: Dynamic Torque Switching*, ePropelled, 2021
19 *Electrifying the Bottom Line*, McKinsey and Company, 2021
20 *Driving EVs to Profitability*, 2021, ePropelled, 2021



Data from U.S. EPA website www.fueleconomy.gov

The EVs cluster together on the graph either within the 80-180 miles for a 20-40 kWh battery capacity (these, often early models, are sometimes referred to as "compliance cars" built to "test the market" or simply fulfill compliance regulations) or within the 200-350 miles range for 60-100 kWh battery capacity (most of the modern cars fall into this category).

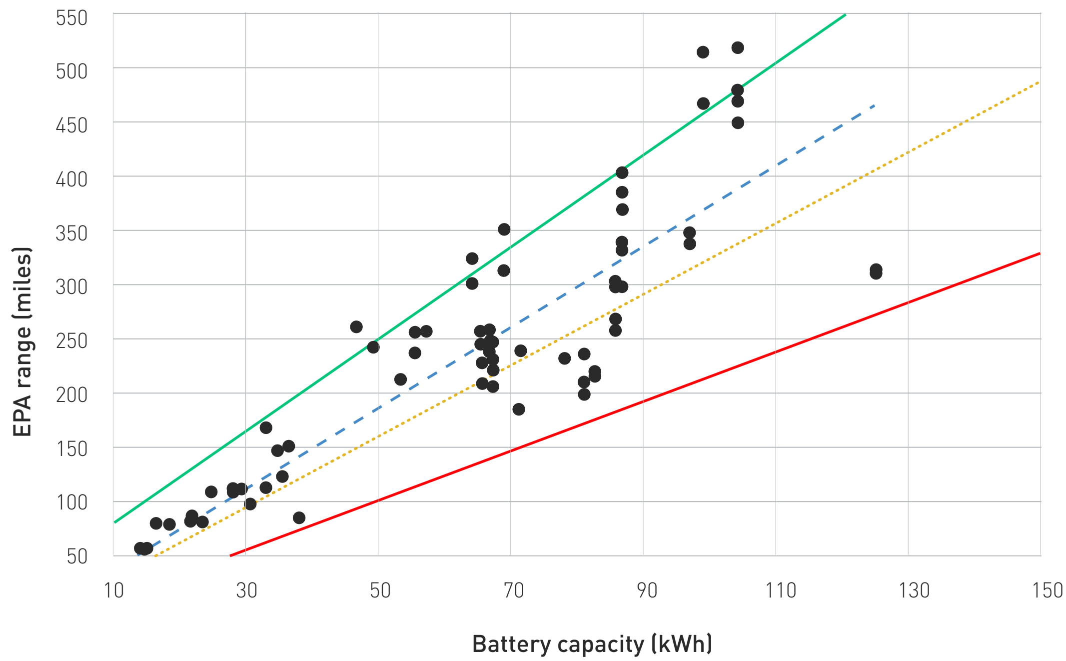
What's interesting about the current EV designs is that a larger battery simply means a longer range but not necessarily better efficiency (with only a few exceptions to date, as seen on the graph). As a result, a longer range that comes with the expense of a larger battery increases the overall weight of the car, costs to manufacturers and consumers, and environmental costs involved in additional battery cells and more electricity consumed by the vehicle. A large battery capacity quite simply only translates to a more costly (monetarily and environmentally) vehicle.

The "average" line marked on the graph is dragged down mostly by less efficient large vehicles with big batteries. That's because larger batteries unfortunately tend to go in tandem with markedly poorer system efficiencies. Engineers and manufacturers who work with small batteries have to find ways to make them last longer and, therefore, look for solutions that make their cars more efficient. But makers of vehicles with larger batteries that already reach a certain range have less pressure or interest in investing in research and innovation that would make them more efficient since their costs are already very high.

In the end, what the industry really needs is increased efficiency. If we can make EVs at least 15% more efficient, it would allow for a smaller battery to offer the same range or for the same size battery to offer a greater range. As the two graphs below show, this improvement would elevate the "average" vehicle to an efficiency level that's only achieved by today's "best" vehicles (the new average is marked in blue while the old average is now yellow) and the "best" vehicles could be even better than they are now. This could be achieved without any increase in cost or additional damage to the natural environment (ensuring that the EVs consume less energy from the grid and reach their "break even" point sooner).

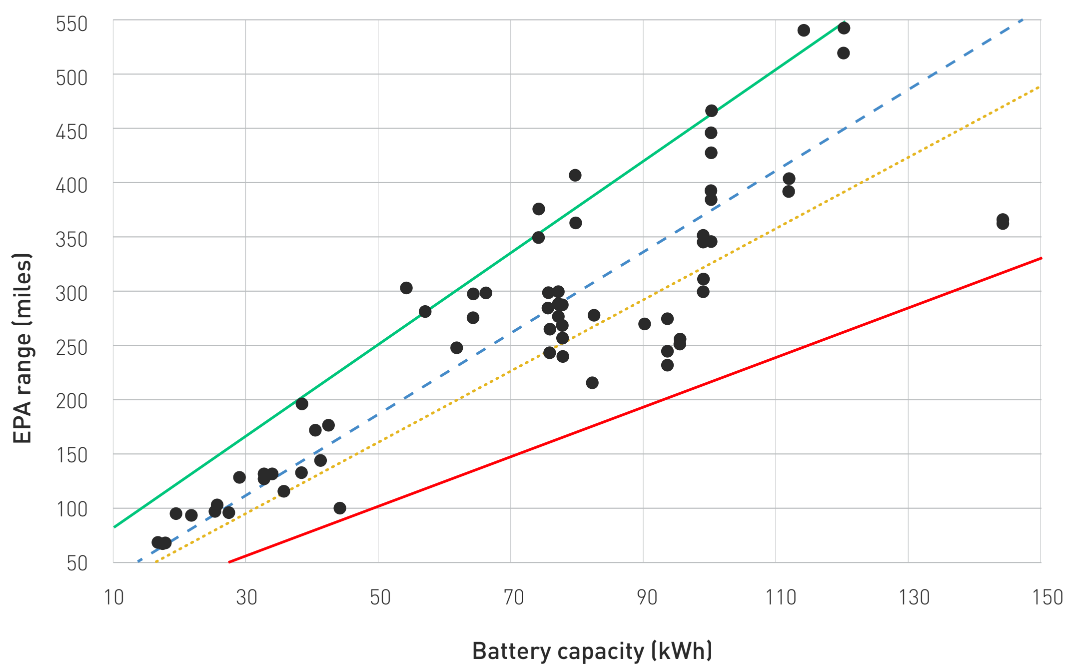
Battery capacity reduction of 15% for the same range

Passenger cars from 2016 to 2022MY



Range increase of 15% for same battery capacity

Passenger cars from 2016 to 2022MY



It's important to note that increasing efficiency by 15% will save, on average, 10 kWh in battery capacity (from 4 kWh for the smallest cars on the graph to 20 kWh for the biggest vehicles), which would translate to savings of roughly $400-$2000. But that's only the financial effect of improved efficiency.

According to ICCT, "battery production is associated with 56 to 494 kilograms of carbon dioxide per kilowatt-hour of battery capacity (kg CO_2/kWh) for electric vehicles."[21] This wide range depends on many factors specific to battery type and manufacturing location, so if we take a specific example of **Polestar 2**[22], whose battery modules (77kWh) account for 7 out of 26.2 tonnes of CO_2e from the manufacturing process, a reduction of 15% would mean that roughly 1 tonne of embedded CO_2e could be avoided.

ICCT also provide estimates for the equivalent amount of emissions per kilometer driven over the vehicle lifetime, stating that studies "generally find 1–2 g CO_2 per kilometer per kWh of battery capacity." Over a lifetime of use (assuming 160,000 km), an average of 10 kWh reduced battery would save a further 1.6 to 3 tonnes of "hidden" CO_2. This is, of course, in addition to the energy saved by the improved propulsion efficiency alone.

By improving system efficiencies that allow for smaller batteries (or for the same size batteries to provide a longer range), we make room for EVs to:

1. BE CHEAPER TO BUILD
2. BE CHEAPER TO RUN
3. REDUCE THEIR ENVIRONMENTAL IMPACT

As an industry, simply moving to EVs and away from ICE is not enough. We need to constantly improve and compare EVs to other EVs. They have to continue getting more efficient and, therefore, greener.

21 *Effects of Battery Manufacturing on Electric Vehicle Life-cycle Greenhouse Gas Emissions*, Dale Hall and Nic Lutsey, International Council of Clean Transportation, 2018
22 *Life cycle assessment — Carbon footprint of Polestar 2*, Lisa Bolin, Polestar

Summary

Smaller batteries with the same range benefit manufacturers, customers, and the environment.

A reduction in electricity used from the grid by at least 15% is especially beneficial in areas where the grid is not as clean as it could be or has restricted power capacity.

Smaller batteries mean less environmental strain and a faster charge, benefitting the customers.

Batteries that last longer take the pressure off raw materials, manufacturing, and recycling.

There are currently 4 billion tonnes of **energy-related CO_2 emissions** coming from ICE passenger cars.[23] EVs are already showing signs of lowering this number but that's not a reason to rest on our laurels. There is still a lot to achieve. More environmentally friendly doesn't equal zero emissions. It doesn't equal reaching global temperature limit goals. It doesn't get us to where we, as a species, need to be. We need to do better.

We have to work together as an industry, do what we can to embrace efficiency, keep creating better EVs and continually improve them. What's more, the better the EV, the more likely it is that it will be embraced by the buyers. Looking after the planet doesn't exclude creating cars that customers will want. Both can be achieved at the same time.

Making better EVs means building motors that are more efficient and batteries that last longer. This benefits the manufacturers, the customers, AND the environment. According to our in-house calculations, if we make EVs at least 15% more efficient, the environmental impact could be significant. If we take the example of the total BEV fleet in the U.K. alone (300,000 cars at the time of writing), we will assume:

- an average energy efficiency of 300 Wh/mile,
- an average annual distance driven of 7,000 miles, and
- carbon intensity of the grid set at 250 g CO_2eq/kWh.[24]

With the total energy consumed by the fleet per year adding up to 630,000 MWh, the total CO_2 (in-use only) will be 157,500 tonnes. With EV efficiency improvements of only 15%, we can save 23,625 tonnes of CO_2 per year.

This is in the U.K. alone and based on the current size of the EV fleet. This number will keep growing and so will the global savings that will be achieved by more efficient motors. In the end, if efficiency is improved in all EVs, that would allow the industry to finally and, in all honesty, call itself "green".

23 *Cars, Planes, Trains: Where Do CO_2 Emissions from Transport Come from?,* Hannah Ritchie, Our World in Data, 2020
24 The live updates of the *electricityMap* show that the carbon intensity of the grid varies not only daily but hourly. Our calculations were based on the higher spectrum of the daily use. https://app.electricitymap.