THE OXFORD INSTITUTE FOR ENERGY STUDIES

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Disruptive Change in the Transport Sector:

Eight Key Takeaways

The Oxford Institute for Energy Studies held a Workshop – the first of a series – on 'Disruptive Change in the Transport Sector' in relation to its impact on energy use in private transport. Participants included experts from the energy, auto, mobility, and technology sectors.[1]

The workshop resulted in eight key takeaways:

1. ***Despite many government announcements and strong press coverage regarding vehicle electrification, there are alternative technologies which are also important for future mobility.***
2. ***Level 5 Autonomous Vehicles are still some years away, and will be context-specific.***
3. ***Cost is one among multiple factors in the scaling up of batteries.***
4. ***Grid management is critical to electric vehicle (EV) adoption.***
5. ***Automobile manufacturers will need to restructure their business models around value creation.***
6. ***Technology diffusion goes beyond cost-competitiveness.***
7. ***Emerging markets will also adopt EVs, driven primarily by government policy – but outcomes will differ.***
8. ***Automation, electrification and shared mobility imply very different types of impacts in different combinations.***

The following summarises the key takeaways from the Workshop discussions.

[1] ***OIES is grateful to the speakers and participants for bringing valuable insights to the debate.***

1. Despite many government announcements and strong press coverage regarding vehicle electrification, there are alternative technologies which are also important for future mobility.

There are many technological pathways currently being explored with the aim of minimising carbon emissions in transport (see Figure 1), although electrification is the one attracting the greatest attention at present. While vehicle electrification is being driven primarily by government policy around the world, many other technologies are being developed through private investment, including the use of venture capital.

Many of these technologies target improvements to passenger vehicle fuel economy through **advances in the efficiency of the Internal Combustion Engine (ICE)**.

- Homogenous charge compression ignition, and spark-controlled compression ignition, are ICE technologies that could reportedly improve engine efficiency by 20 to 30 per cent, alongside lower emissions of NO_x and soot.
- Another ICE innovation that is being looked at is 'octane-on-demand' – the utilisation of high-octane fuel in the engine only at moments when it is needed, improving the efficiency of fuel use. Two approaches have been proposed to enable this: first, the use of dual fuel tanks – namely separate tanks of regular gasoline and high-octane fuel – with controlled use of the latter only when more power is needed to handle the load. And second, the enabling of onboard separation; this entails extra equipment and higher energy consumption, but is an option for consumers who do not want to deal with dual fuel tanks.
- Another approach to improving ICE efficiency is to move from the 'Anti-Knock Index' (AKI) octane rating (this is the average of the motor octane number and the research octane number) to a pure research octane number. This would catalyse a shift towards the refining of higher octane fuels that could be utilised by vehicles with a higher compression ratio, enabling the CO_2 footprint of each mile travelled to be reduced.

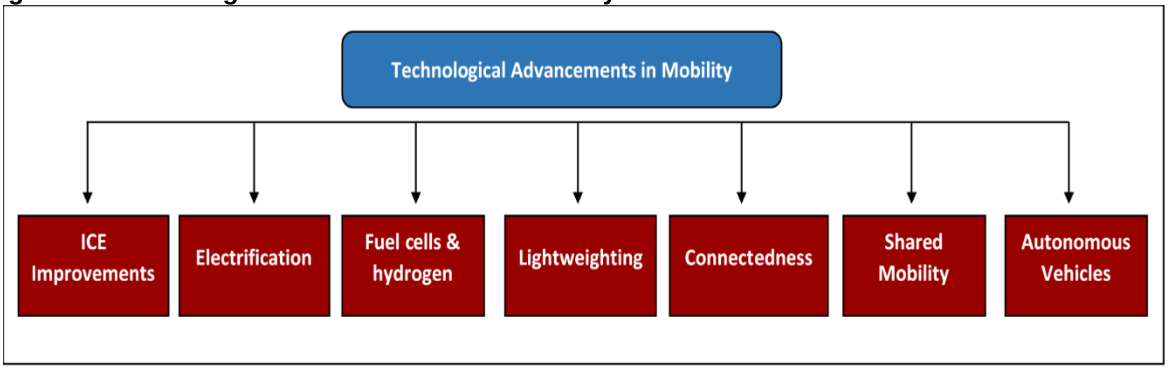
While the potential for these technologies is well known, the key issue lies in aligning the standards of auto companies, regulators, and oil companies, in order to catalyse the shift to higher ICE efficiency.

The use of alternative fuels to enable low-emission transport is another area under consideration. **E-fuels** are one such type of fuel; these involve taking negatively priced electricity (electricity produced during periods of very high renewable penetration, as seen in the USA and Europe) and converting it into some other valuable form of stored energy, such as hydrogen. Another approach is to enhance biofuels with hydrogen (generated via electrolysis or other methods) to sharply increase carbon utilisation in biofuel production.

Yet another technology being considered is the **onboard capture of CO_2 emissions**, with the option of capturing 30–50 per cent of CO_2 before it leaves the tailpipe of the car. However, the economics of capturing carbon at a small scale are less favourable than capturing it at large stationary point-source locations (such as coal-fired power plants). An added complexity is the onboard storage of CO_2, which has to eventually be removed from the car.

Fuel cells and hydrogen are actively being considered in the transportation systems of some countries (such as Japan). The main challenges to this technology include cost, infrastructure, and onboard hydrogen storage. Although hydrogen is superior to most fuels when it comes to megajoules of energy produced per kilogram, the systems to contain it have not yet matured or been developed at scale. For instance in some hydrogen vehicles, tanks weigh around 90 kilograms but are only able to contain around 5 kilograms of hydrogen. Hydrogen pathways being considered include methane-to-hydrogen (with or without carbon capture), heat-to-hydrogen, electricity-to-hydrogen, and solar-to-hydrogen. An alternative approach being considered by researchers is the onboard reforming of hydrocarbons to produce hydrogen within the vehicle – a process that would still use fossil fuels but with greater efficiency than an internal combustion engine.

Figure 1: Technological advancements in mobility



Source: Workshop Proceedings, Session I.

'**Light-weighting'** – the building of vehicles that are less heavy, to achieve better fuel efficiency – is another technological innovation being actively considered in transport. In particular, **composites** have a significantly lower carbon footprint and also present a new market for hydrocarbons.

Technologies to enable **connectedness** are also being developed; these include vehicle-to-vehicle, vehicle-to-infrastructure, and people-to-mobility connectivity. Along with **shared mobility** (ride-sharing, ride-hailing, and car-sharing), this could have a significant disruptive impact on vehicle ownership and energy use in transport. An enormous amount of technology is also going into developing **Autonomous Vehicles**, in terms of building algorithms for robust navigation and advanced control systems.

2. Level 5 Autonomous Vehicles are still some years away, and will be context-specific.

Full automation (also known as **'Level 5'** automation, see Figure 2) which completely dispenses with the need for a human driver, leads to cost savings (for freight/commercial vehicles, cost savings would occur by removing the driver and hence reducing salary costs; for private transport, cost savings would occur by ride sharing and/or improvements in the productivity of travel time). The development of Level 5 automation technologies entails solving two key machine-learning problems:

- First, the building of a very accurate model or **reconstruction of the world** around us that we see at any given moment.
- Second, using the model to **make predictions** for a specific urban environment. Robotic systems are efficient at collecting data about the environment, but making sense of that data remains very challenging.
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It is likely that Autonomous Vehicle (AV) technologies will need to be developed on a **city-by-city** basis and perhaps even on a **road-by-road** basis. For instance, an AV developed to operate within a major western city cannot be transferred directly to a city in developing Asia; **driving is a form of negotiation** based on the motorist's idea of the behaviour of other motorists, following which the motorist then takes certain actions on the road which confirm those beliefs. It is currently implausible, for instance, to deploy the same Level 5 AV in both a major western city and a city in the developing world (where not just urban planning but also traffic patterns, rule compliance, and driver behaviour are fundamentally different). Generally, cities where roads form a grid pattern are likely to be easier to adapt to AV technologies than those with a more irregular layout, as are cities with fewer cyclists, and cities with more compliant driver behaviours.

Although the technologies to deploy Level 5 automation may exist five to ten years from now, its deployment will be contingent upon other factors such as public opinion, politics, and regulatory and licensing frameworks. Level 5 automation, when first implemented, is therefore more likely to be limited to certain environments in Western cities. Fully autonomous vehicles will need the requisite supporting infrastructure (for example, AVs need to be able to communicate with designated charging points) and the remote operation of Level 5 AVs will entail detailed regulations around safety and privacy.

On the other hand, Level 3 automation (where a human driver is able to take back control of the vehicle at a moment's notice) is more likely to be seen within the next two to three years, in highway environments.

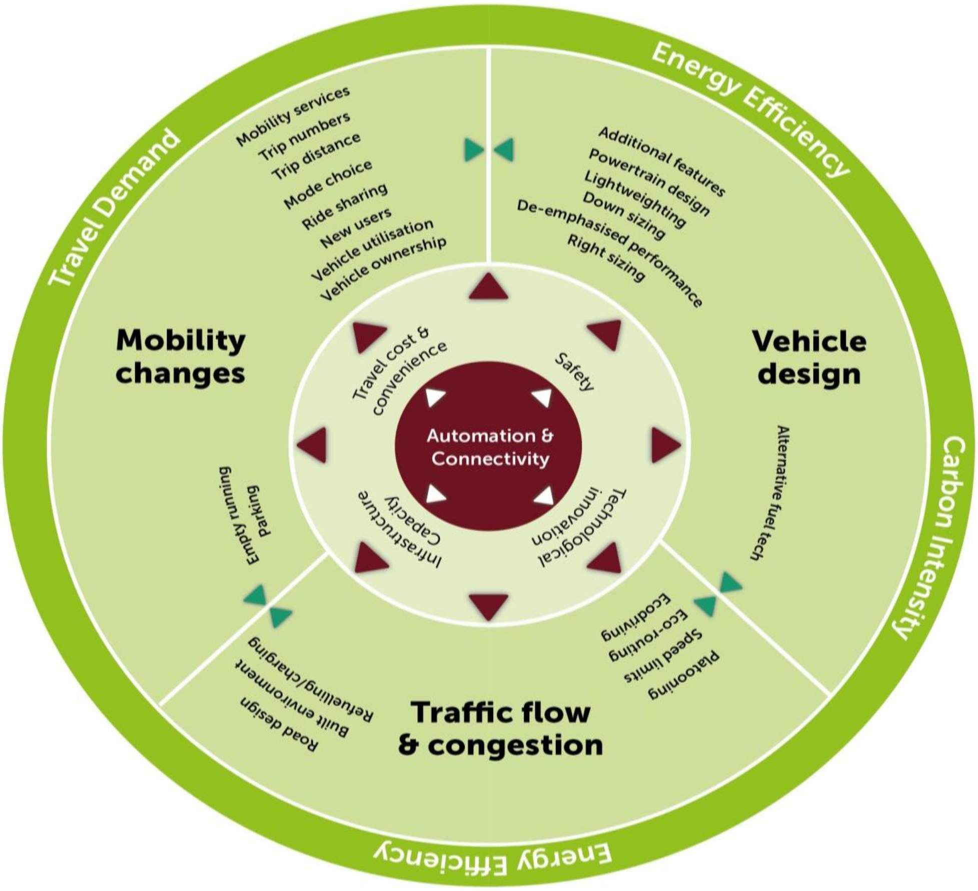
Figure 2: Levels 1–5 of automation in transport

1	Driver assistance	Individual activities which assist steering or acceleration/deceleration are partially automated
2	Partial automation	Several simultaneous activities which assist steering or acceleration/deceleration are partially automated
3	Conditional automation	In certain driving scenarios, all dynamic, non-strategic driving activities (e.g. vehicle control but not route choice) are automated but human is expected to intervene when requested
4	High automation	In certain driving scenarios, all dynamic driving activities are automated and vehicle can cope with human not intervening if and when requested; key to Transport-as-a-Service (TaaS)
5	Full automation	Always and everywhere, all dynamic activities are automated with no need for human intervention

Source: 'Connected and Autonomous Vehicles', UK House of Commons Briefing Paper No. CBP7965, June 2017.

The **impact of Level 5 AVs on energy use is not clear** and may not necessarily change energy consumption, but it may enable other changes such as reduction in costs, new mobility types/sharing, and electrification that would affect energy consumption (see Figure 3). Also the uptake of Level 5 AVs is likely to differ by consumer income groups. Research suggests that business travellers are most likely to be early adopters, due to benefits associated with the **productive use of travel time**. Fully automated vehicles can offer a similar environment to the traveller as that on public transportation. If Level 5 AVs therefore induce a switch from public transport to private transport (given associated cost reductions), the **number of vehicle kilometres travelled** could increase. Similarly, if Level 5 AVs remove the incentive for ride-sharing (which is primarily cost-driven) due to the associated cost savings, this could also increase energy use. At the same time, if Level 5 autonomy enables **mobility-on-demand** (namely the matching of on-demand mobility to the right vehicle size), there are likely to be substantial energy savings and the combination of automation with mobility-on-demand offers a good business case. Automation by itself without a change in travel behaviour will likely push up vehicle miles travelled, but the extent to which this is allowed to increase is contingent on government policies. Level 5 AVs, in combination with electrification and ride-sharing, could bring about significant disruptions in transport.

Figure 3: Ripple energy and carbon effects of automation and connectivity



Source: Zia Wadud and Jilian Anable (2016) Automated vehicles – automatically low carbon? Report by the Institute for Transport Studies (University of Leeds)

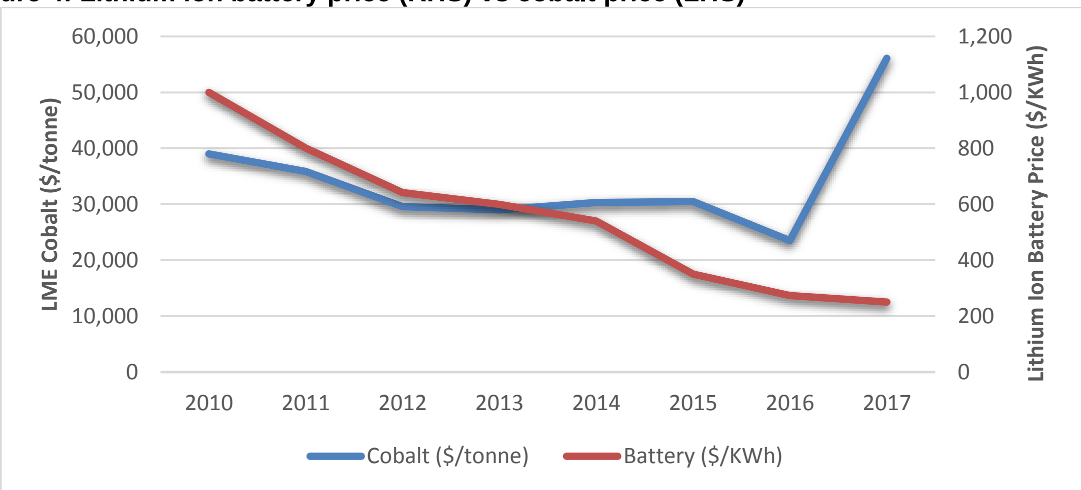
3. Cost is one among multiple factors in the scaling up of batteries.

Much of the popular debate has focused around cost reductions in battery technologies that could enable Electric Vehicles (EVs) to compete with ICE vehicles. Battery costs **declined by 12 to 14 per cent on average per year** from 2000 to 2015, and costs in 2016 stood at a low-to-high range of roughly \$200–\$300/Kilowatt-hour (KWh). The US Department of Energy is targeting a cost figure of **\$125/KWh by 2022**, which many argue could bring battery and EV technologies within the ballpark of **cost competitiveness with ICE** vehicles. This, however, depends on other factors that affect costs and payback periods, such as fuel taxes, EV purchase subsidies, annual kilometres driven, *inter alia* (and ignoring uncertainties around non-cost factors, such as technology diffusion and consumer preference).

There are **two narratives within the popular debate** on battery costs and EV uptake: the first states that continued R&D and policy support will be needed to scale up batteries within the vehicle fleet, despite auto companies committing to EVs in principle. The second argues that improvements in battery chemistries and higher volumes will cause costs to plummet further, precluding the need for subsidies. The two narratives can be evaluated against the following key features of the battery industry:

- Advanced battery technologies have been around for four decades, but their recent rise to prominence is partly because the current status represents a **convergence of several multi-billion dollar industries** including auto, technology, and energy.
- Evidence shows that the battery industry has been fairly accurate in predicting engineering advancements in technologies. **Current battery chemistries will be difficult to beat**, although there is ongoing research to find alternatives that enable a higher capacity or voltage.
- Batteries have **multidimensional** features in relation to their performance. They need to be durable, have high energy and power density (primarily gravimetric, but also volumetric), conform to safety standards, and be recyclable. All of these features must be balanced against cost considerations.
- **Multiple factors impact battery supply chain operations and costs**. Analyses of scale should therefore consider not just battery chemistries but also material supply chains, manufacturing processes, location to market (for example, the co-location of battery plants and EVs, as batteries are more safely transported within EVs), and recycling. Each of these has associated opportunities and challenges. For instance, current recycling uses 'open loop' processes, implying that recycled materials cannot be re-used in the battery industry but will have to be used in other industrial uses (such as cement); the battery industry will likely need to move into 'closed loop recycling' to make production sustainable.

Figure 4: Lithium ion battery price (RHS) vs cobalt price (LHS)



Source: Bloomberg New Energy Finance; London Metals Exchange (LME).

An interesting dynamic also playing out at present (see Figure 3) is the fact that **battery prices are continuing to decline** (points 1 and 2), **even though raw material prices are beginning to increase** (point 3). The potential reasons for this include:

1. **Strategic market behaviour**: There are indications that some battery manufacturers (for example those in Asia) may be sacrificing margins in order to capture market share, lock in contracts, and attempt to secure a significant market share five to ten years in the future. However, further reductions in battery costs could result in manufacturers adopting one of two potential strategies: first, passing on the reductions to their customers through lower prices, or second, utilising part, or all, of the margin to increase the battery size (which could enable greater ranges on a single charge).
2. **Global overcapacity**: Global lithium ion battery production capacity is around 116 Gigawatt hours (GWh) per year, and could reach 290 GWh a year by 2021, based on plants that are under construction or have been announced. However, passenger EV sales have not kept up with this growth – total passenger EV battery demand last year was

estimated at around 21 GWh. This has accounted for some of the fierce competition for market share between battery manufacturers. Low demand has not stopped plans for the building of several lithium ion mega-factories in the next few years – in anticipation of large increases in battery demand as governments' EV policies begin to take root. Over 60 per cent of this new capacity will be located in China.

3. **Supply chain bottlenecks**: The main materials for battery manufacturing include lithium, cobalt, graphite, nickel, aluminium, copper, and manganese. As EVs are scaled up worldwide, associated supply chains for these materials could come under pressure. **Resources are concentrated** in a few countries and production is subject to their regulatory frameworks and operating environments. According to the US Geological Survey, roughly 65 per cent of world lithium resources are concentrated in three countries (Argentina, Chile, and Bolivia). Similarly, around 65 per cent of cobalt production comes out of the Democratic Republic of Congo. Concerns over rising prices of cobalt have recently led some EV manufacturers to seek long-term materials supply contracts. Although these supply chain bottlenecks can be resolved by substituting away from these materials and developing other types of battery chemistries that use lower ratios of cobalt and manganese, short-term **price volatility** in raw materials cannot be entirely discounted.

There are around 1 billion cars on the planet, of which just over 2 million are estimated to be EVs. A back-of-the-envelope calculation suggests that the amount of lithium resources required for about 1 billion EVs could be close to 7 million tonnes of lithium carbonate (LCE) – equating to 50 per cent of reserves but only 3 per cent of global resources. Current production remains in the tens of thousands of tonnes. **Large investments running into the billions of dollars** will be needed over the next few years for mines to ramp up the production of battery raw materials.

4. Grid management is critical to EV adoption.

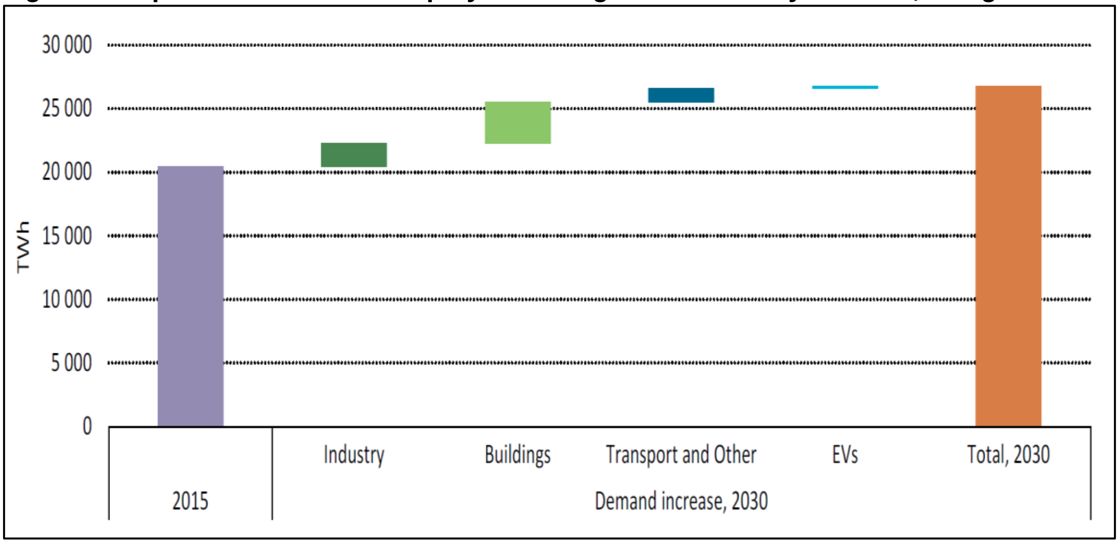
Research suggests that the electrical installed capacity required to meet additional demand from EVs by 2030 will be not be a major constraint. The International Energy Agency, for instance, estimates that the additional generation needed to meet EV demand in the two degree scenario will represent only 1.5 per cent of total electricity demand by 2030 (see Figure 4). Rather than considering the levels of absolute capacity, it is the management of the grid which will be critical to EV adoption. In the power sector, **EVs are just one component of an ongoing transformation** in which consumers are becoming 'prosumers'. The development of electric mobility is therefore compatible with the current power system **so long as it can be anticipated and the infrastructure adapted to it in advance**.

- Successful grid management entails the **optimisation of the plant fleet**. If this is absent, peak loads in countries where EVs are adopted on a large scale could increase significantly.
- Optimisation also involves **predicting 'charging hotspots'** and planning load management and infrastructure around them. The power industry needs to work out how to manage the uncertainties around EVs – such as in which regions/cities they are most likely to be developed.
- Solutions being proposed to reduce these uncertainties involve 'controlled charging' and 'smart charging'. These could be enabled in two ways: first, they may require the **development of incentives to influence consumer behaviour** and reduce uncertainties around grid charging. And second, there may be a role for **'integrators'** or agents in the power industry whose role it would be to gather information from various entities and to manage demand.

Grid management implies some unique challenges – but also opportunities – when technological advancements in battery charging are discussed in greater depth. **Fast charging** (to address range anxiety held by consumers) is one such technology being discussed, and this could enable quicker EV adoption. But given that the quickest way to 'kill' a battery is to charge it at high temperatures and/or operate it outside its voltage stability windows, charging in seconds is unrealistic. Charging times can be brought down considerably from the current figure of six to eight hours, but the infrastructure required to bring it down to minutes (in other words, under an hour) is as yet undeveloped at scale.

Wireless charging is based on magnetic resonance technology and avoids the need to plug in the vehicle. This energy transfer mechanism requires a charging coil in the ground and a coil on the bottom of a vehicle. Wireless charging has two main categories: stationary (allowing parked vehicles to charge) and dynamic (allowing moving vehicles to charge). **Stationary wireless charging** is currently being deployed for a limited number of EV car models. **Dynamic wireless charging** has future potential for deployment on fixed bus routes as a means to reduce the required battery size and costs. However, the associated infrastructure requirements for these technologies, together with their implications for grid management, would need to be carefully taken into account. **Interoperability** will be necessary to optimise grid management.

Figure 5: Impact of electric car deployment on global electricity demand, 2 degree scenario



Source: Global EV Outlook, International Energy Agency, 2017:47.

5. Automobile manufacturers will need to restructure their business models around value creation.

Global sales of EVs have increased over the period 2010–16 (see Figure 5), but the auto industry faces a unique set of challenges emerging from a **radical disruption in their business models**. The main uncertainties faced by the auto industry around EV adoption include: which consumers will adopt EVs, how fast, and where? And, what will the effects of EV adoption be alongside automation and mobility – will this, for instance, lead to higher or lower car ownership and sales? At the same time, governments around the world are currently implementing regulations which mandate auto manufacturers to increase their EV production in the near future. There are several implications of these trends for the auto industry.

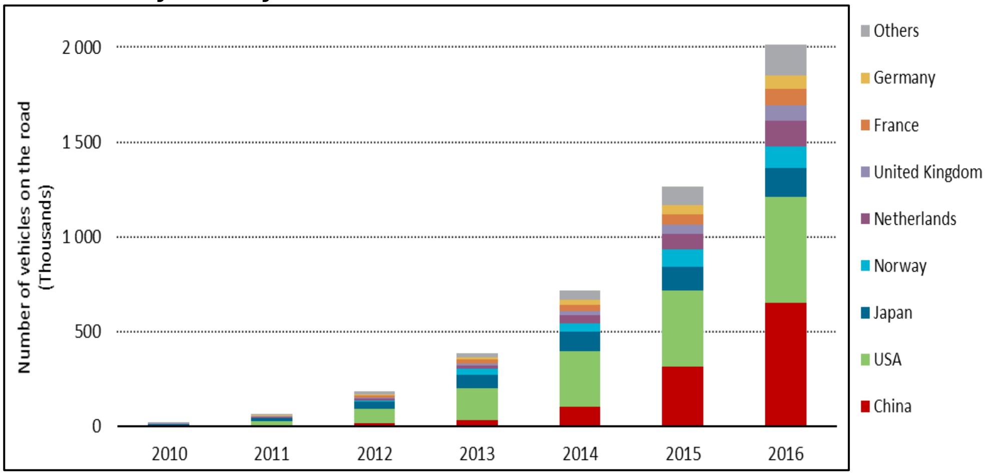
- Auto companies **need to allocate investments now, but face uncertainty over the future demand for EVs**. One way to hedge against this future risk has been for auto companies to announce EV models in nearly every consumer segment, with a view to ascertaining the models which are most likely to take off. Consequently, the EV businesses of many auto companies are not profitable, as the consumer uptake of EVs has been slow relative to the production of EV models.
- Another key disruption to auto companies' business models is the fact that **profitability** at present comes almost entirely from the sale of vehicle units. If automation, electrification,

and mobility lead to a net drop in sales, auto companies will have to reorient their business models in order to seek profitability elsewhere. Companies will have to move from relying on individual sales to **continuous customer engagement** throughout the life of the product – not just at the point of sale. This implies that auto companies could increasingly move towards being more **service-oriented businesses**, and in the future we could see more alliances between auto companies and mobility services.

- An important aspect of EV manufacturing is that EVs have far fewer parts than ICE vehicles – one estimate puts EV parts at around 18,000 compared with 30,000 for a conventional vehicle. This translates into a smaller number of jobs in EV production. Auto companies will face pressure to **preserve as many jobs as possible while making the transition to EV manufacturing**. Companies will need to negotiate the balance of lower profitability from manufacturing vehicles, with the opening up of new business areas (associated with a more service and customer engagement-oriented business model).

The majority of value creation in the auto industry today lies in house, in the development of the ICE engine. However, as EV motors are scaled up, **value creation is likely to move further up the supply chain**, so the industry structure, as well as the structure of jobs, will have to be reorganised accordingly. There is a risk that if governments ramp up EV regulation prematurely, this could lead to short-term disruptions in jobs being reorganised along the supply chain. Therefore, the auto industry is likely to move from a period of 'fragmentation' and the development of varied EV models, to one of **consolidation and alliances with service and mobility business**, as the EV models most preferred by consumers are determined and begin to scale up in the vehicle fleet.

Figure 6: Global EV sales by country



Source: Global EV Outlook, International Energy Agency, 2017.

6. Technology diffusion goes beyond cost-competitiveness.

Many of the arguments around EV adoption focus on cost (or price) as the key variable influencing consumer preference in the uptake of new technologies; however, this is not the only variable, particularly in countries where markets are not fully developed. EV adoption by a consumer effectively involves 'fighting' against an entire **existing ecosystem** that is built around the internal combustion engine (ICE). A focus on the economic (cost) element risks entirely dismissing the **political and cultural factors** involved in EV adoption and the diffusion of new technologies in general.

In this context, '**hype–disappointment cycles'** – which are commonly seen in new technology diffusion (see Figure 6) – are a useful way to understand consumer behaviour in relation to EV and AV penetration. A hype cycle is described as occurring in societies when there is a rapid increase in the attention being paid to a particular technology, with expectations ratcheted up very quickly to a point, following which, expectations are adjusted downwards, and attention begins to taper down. Subsequently, the technology is sometimes adopted successfully on a widespread basis, whereas at other times it is not (the use of alternative fuels – such as ethanol and natural gas in the USA – in transport provides a good example of hype cycles).

The diffusion of new technologies can be understood through multiple perspectives:

- The one which dominates much of the current thinking around EV adoption is **'stimulus–response'** or the idea that if a technology is 'simply put out there' people will adopt it.

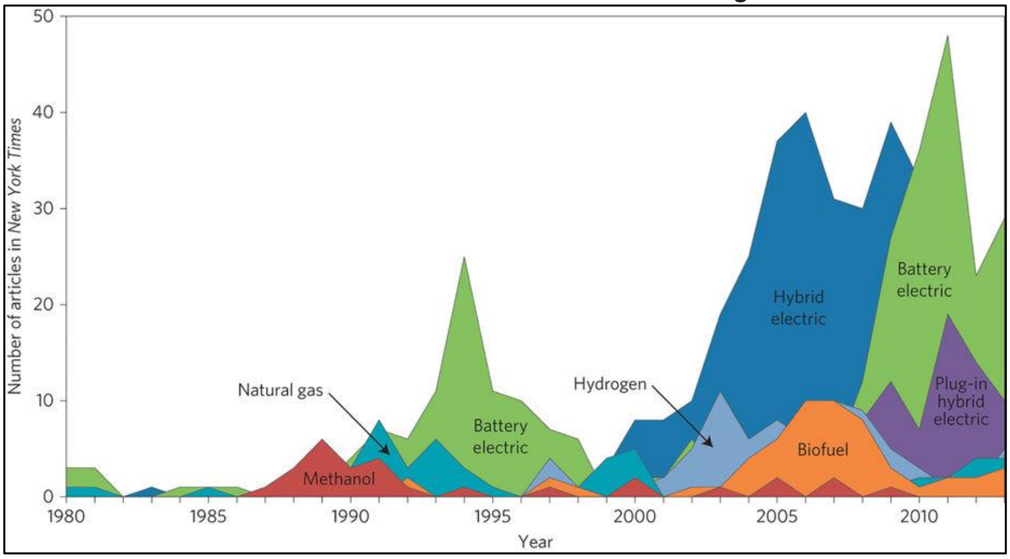
- Another perspective relates to the **dissemination of information** – in other words, if consumers are given complete information about the benefits of the technology, they will buy more EVs.

Both these perspectives can be challenged. For example, there is evidence that many consumers do not seek complete information on which to base their decisions, but simply look for information that is 'good enough'.

- Sociologists and geographers study EV adoption not just in relation to the purchase of EVs, but also the way in which **EVs become embedded within everyday practices**. The 'domestication approach', which was developed originally to describe the adoption of mobile technology, sets out three types of 'work' involved in technology adoption on the part of the adopter: first, cognitive work involves learning about the new technology and what it does; second, symbolic work involves developing a set of cultural categories to make sense of the technology; and finally, practical work involves embedding the technology in everyday activities.

At the same time, no single approach can be generalised to **understand the diffusion** of different technologies. The factors underpinning **household adoption of EVs** are also different from those affecting the **commercial adoption of EVs**. In the latter, the overriding factor is cost. But in the former, the relevant factors are not just linked to economics but also to **societal preferences and cultural shifts** – for example, research shows that millennials tend to drive less and own fewer cars. But it is as yet unclear whether this is due to short-term factors such as lower earnings and job insecurity, or to a longer-term shift in cultural preferences over mobility.

Figure 7: Media attention for all alternative fuel vehicle technologies for 1980–2013



Source: Melton, N., Axen, J., and Sperling, D. (2016) 'Moving beyond alternative fuel hype to decarbonize transportation', *Nature Energy* 1, 16013 (2016). Doi:10.1038/nenergy.2016.13. (Reused with permission).

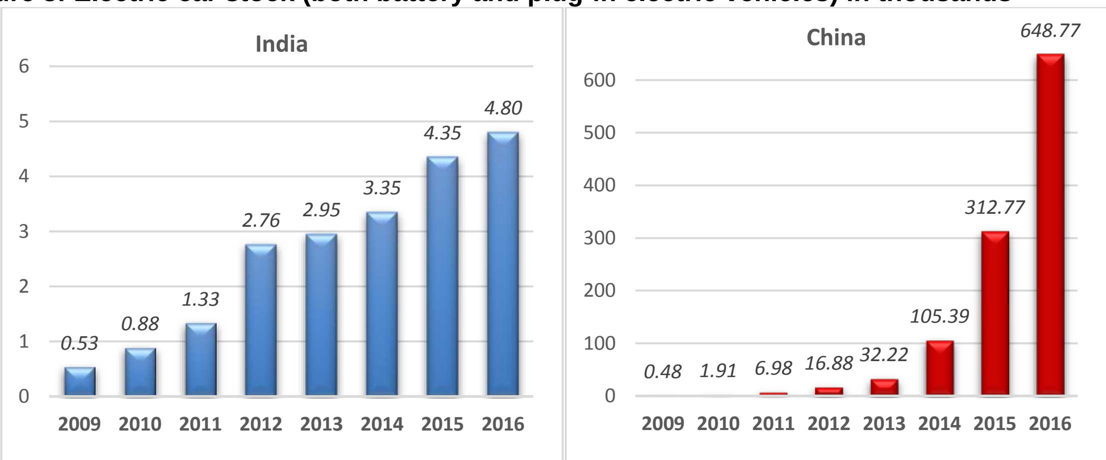
7. Emerging markets will also adopt EVs, driven primarily by government policy – but outcomes will differ.

China and India – the world's largest and fifth largest automobile markets, respectively – are together expected to account for over 50 per cent of the increase in global oil demand to 2035. Transportation forms the largest single proportion of oil demand in each country (around 55 per cent in China and 40 per cent in India). As their **per capita incomes exceed a threshold level**, historical data shows that vehicle ownership in these countries will grow exponentially in the absence of policy measures to alter this expected trajectory. However, both emerging markets have **three characteristics** which imply that 'lock-in' of ICE-oriented transportation systems has yet to set in: **low levels of vehicle ownership**, **low motorisation**, and an already **high proportion of shared trips** taken on public transport. These characteristics should enable these countries to 'leapfrog' to electric mobility. Figure 7 illustrates the take up of electric cars during the period 2009–16.

Fundamentally, both countries are aiming to use the switch to EVs as a way of improving their energy security, by **reducing long-term oil import dependency**; in 2016 this stood at around 66 per cent (of crude oil consumption) in China and 80 per cent in India. Another key driver has been the regional move (provincial in China and state-level in India) to regulate and **improve rapidly worsening urban air quality.**

Consequently, India's government has expressed a policy aspiration to move to a completely electrified vehicle fleet by 2030, and China's government anticipates that sales of 'New Energy Vehicles' (NEVs) will reach 5 per cent of total vehicle market demand by 2020 and 20 per cent by 2025. In other words, India aims to have six to seven million EVs on the roads by 2020, whereas China plans to have 5 million NEVs by 2020. This implies a much higher level of EV ambition for India, than for China – yet China has a long-term policy plan in place to catalyse its goals, whereas India has yet to announce one.

Figure 8: Electric car stock (both battery and plug-in electric vehicles) in thousands



Source: Global EV Outlook, International Energy Agency, 2017: 49.

Both countries will **face similar challenges** in the scaling up of electric mobility if they are to completely replace conventional vehicles. However, governments will respond to these challenges differently given their different governance structures (policy in China will be centralised, whereas in India it will require buy-in from state governments) and the **outcomes will accordingly differ**.

- **Trade policy** and **employment** opportunities will be central to the adoption of EVs by China and India. China's EV policy forms a part of its overall industrial strategy, and has been based entirely on **promoting domestic manufacturing**. From 2019, all auto companies will be required to manufacture a certain number of EVs as a percentage of their total production, and this figure will be adjusted upwards going forward. In India, the supply chains to support domestic EV manufacturing are currently weak. At the same time, India will want to avoid repeating its experience with solar panels, where despite massive increases in contracted solar capacity, 80 per cent of the solar panel market was dominated by Chinese imports. India may adopt a mixed strategy involving partnerships with foreign companies.

- Another challenge faced by both countries is the **promotion of consumer uptake of EVs**, especially around the **targeting of subsidies**. Central government subsidies in China have been matched with local government subsidies, and government spending on subsidies to promote EVs has been estimated at around $3 bn. Automakers have utilised subsidies without complying with their terms – thus there have been significant leakages, and the penalties for non-compliance are unclear. It is likely that **subsidies will continue to drive industrial policy** around EVs until they are scaled up to meet government targets. India has attempted consumer subsidies for EVs in the past, but at much lower levels of funding relative to those in China. These, however, largely benefitted hybrids over EVs, whereas going forward hybrids are likely to be discouraged. Subsidies are likely to be utilised for a time-limited period, and **leakages could be curbed** using the country's system of biometric identification numbers. The battery-swapping model – making EVs more affordable by allowing consumers to lease batteries – is one proposed business model being developed that will need to be tested, as this will essentially entail removing the most expensive/valuable part of the vehicle.
- The **pace of EV uptake is likely to differ across different regions**, provinces, and states in both countries. In China, provinces use a lottery system administered at the city level for vehicle sales, but until recently, EVs were largely exempted from this. However, this has resulted in the demand for EVs soaring in some cities, causing administrative authorities to regulate their sales as well. Similarly, cities administer and manage prohibitions on ICE vehicles, in relation to congestion and pollution control. Indian states have similarly had to impose bans on older diesel vehicles, but as these bans originate in and are mandated by the courts, and have also been later challenged in the courts by state public transport corporations which rely on such vehicles, permanent bans are difficult to administer. In India, it may also be difficult to commit a future government to a permanent ban.
- Both countries will need to **institute regulations and quality standards** to clarify 'grey areas' – such as the use of millions of low-speed, lead acid battery EVs, for which parallel unlicensed markets have emerged. As the mainstream EV market is scaled up, both countries could see some consolidation in the market.
- Emerging markets will need to account for **social equity issues** in their EV targets. In developed countries, EVs are often purchased by richer consumers, and often as a second vehicle. In emerging markets, tax revenues from transport fuels make up a large proportion of government finances. Similar social equity issues will need to be addressed with regards to restrictions on ICE vehicles – for example, ICE bans on older vehicles tend to impact poorer consumers who purchase second hand cars. The solutions to these issues lie in emerging markets proactively adopting industrial policy as the key driver of EV targets, as opposed to solely as a reaction to environmental pressures. While China has explicitly adopted EVs as part of its industrial strategy, in India there may be delays in achieving targets as its EV policies involve coordination among several different ministries and government agencies.

8. Automation, electrification and shared mobility imply very different types of impacts in different combinations.

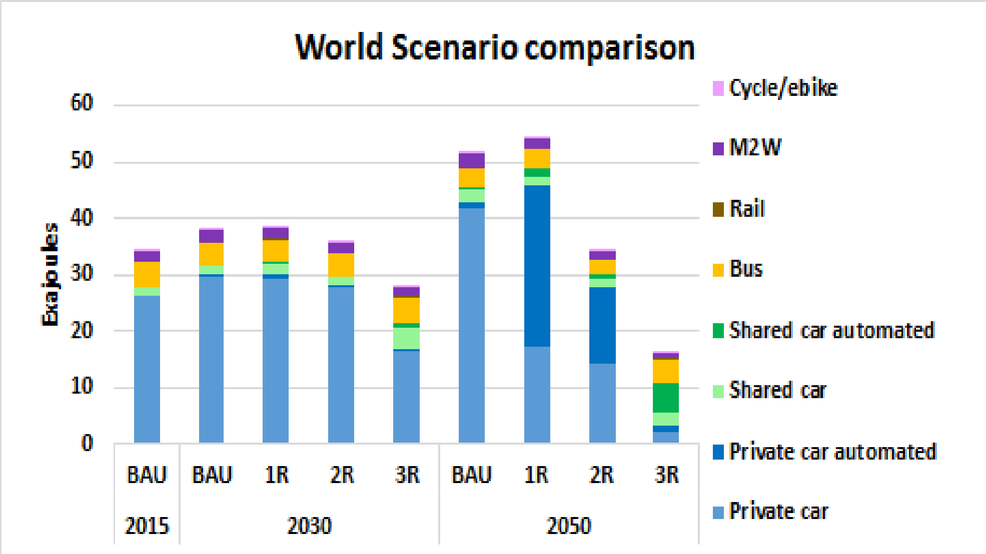
The **net impact – on energy use and on oil demand** – of disruptive change in transport will come from a combination of automation, electrification, and shared mobility (ride-hailing, ride sharing, and car-sharing).

Some of the projections made by oil companies of the impact of electrification alone on oil demand suggest that these will **dent rather than destroy** demand – for instance, one such projection based on a simple arithmetic calculation estimates that 100 million EVs by 2035 would displace 1.5 mb/d of oil demand.

The confidence intervals around this projection are, however, large as they depend on questions such as: what will the regulatory environment be; what sort of governmental push will we get towards EVs; what are the fiscal implications of that; and, how will social preferences evolve. Similarly, all such projections basically boil down to the assumptions which go into the scenarios, and whether it can be said with certainty which of these will play out.

The **interactions between automation, electrification, and shared mobility** are not clearly understood, which accounts for these low projections. It is, however, clear that the metric that will determine the net impact on energy is not the absolute number of EVs, but Vehicle Kilometres Travelled (VKT; also Vehicle Miles Travelled or VMT) as the three disruptions will manifest in the ways in which they change peoples' travel behaviour. **Automation** on its own is likely to **massively reduce the cost of travel**, but there is likely to be a **'rebound effect'**; in other words, if automated travel becomes so cheap that there is no longer any incentive to ride-share, this could lead to an increase in VKT and consequently in energy use and emissions.

Figure 9: Energy use by scenario and mode



Source: Fulton, L, Mason, J., and Meroux, D. (2017) 'Three Revolutions in Urban Transportation', UC Davis Sustainable Transportation Energy Pathways of the Institute of Transportation Studies.
Note: 1R-automation; 2R-automation and electrification; 3R-automation, electrification, and shared mobility.

Vehicle electrification in addition to automation would, on the other hand, result in **lower energy use**, as oil is substituted away in transport (the emissions implications of this scenario would depend on the source of electricity). **Shared mobility**, in addition to automation and electrification, could result in a drop in vehicle ownership and in the figure for VKT, bringing about a **massive reduction in**

energy use – the literature estimates a 50 per cent reduction over the automation plus electrification scenario by 2050 (see Figure 8).

The big questions lie around how quickly the world can get to a ‘three revolutions’ scenario, whether the three disruptors will occur in combination, and what implications the interaction between automation and shared mobility in exclusion, or between electrification and shared mobility in exclusion, will be.