Electric vehicles:
driving innovation

3

The drive to bring **electric vehicles into the mainstream** is picking up speed. Entrepreneurs are jostling for position to produce this generation's Model-T. **Major car manufacturers have entered the arena** and are gearing up for **mass production of plug-in vehicles**, and electric cars – actually on the road – are appearing.

Part of a series of papers on IBM Smarter Energy

Governments are providing incentives to drivers to choose cars with demonstrably **lower carbon emissions.**

These range from purchase incentives provided by Central Government to usage incentives offered by local authorities. Exemption from London's Congestion Charge represents potential savings of over £1,600 per year. Despite drastic spending cuts across the board, the UK Treasury has ring-fenced funding for a 25 per cent purchase subsidy up to £5,000 per vehicle and the UK Central Government is spending £30m on the roll-out of electric vehicle charging infrastructure in three areas of the UK. In the nascent world of electric vehicles things are starting to move quickly. But many questions remain unanswered

If half the UK's car fleet were to go electric, demand for electricity could rise by as much as 25 per cent[1] – how will this demand be met? How do you charge your car if you don't have off-street parking? Will electric vehicles manufactured in the UK charge in the same way as those built elsewhere in the EU or the rest of the world?

Electric vehicles may be arriving, but if the infrastructure is not in place, consumer acceptance could crumble – even if the evidence suggests that most will charge their cars at home if they can. What infrastructure will allow electric vehicles to flourish? Are the CO_2 emissions of the traditional internal combustion engine simply being replaced by increased emissions from electricity generation? And indeed, would increased fuel efficiency from these traditional vehicles offer a surer, less expensive and less disruptive path to a low emissions future?

WHY ELECTRIC VEHICLES?

The arguments for going electric are becoming more widely understood and accepted. First and foremost, adoption of electric vehicles (EVs) has the potential to reduce greenhouse gas emission arising from conventionally-fuelled personal transportation. This reduction extends to other pollutants, including particulates from diesel smoke and brake dust from friction braking (as EVs usually replace traditional braking systems with regenerative braking). EVs are also known to be quieter than traditionally powered vehicles (although, somewhat ironically, this has raised pedestrian safety issues resulting in plans for artificial engine noise). Adoption of EVs, especially in densely populated urban areas, provides a real opportunity for an improved environment.

Energy security, reducing dependence on fossil fuels – oil in particular – and the increasing cost, both financial and environmental, of developing new sources of fuel supply are all key concerns for nation states around the world. The adoption of electric vehicles could make a major contribution in addressing these concerns by reducing the demand for fossil fuels for transportation.

It can be argued that EV's simply shift the emissions from the road to the power station and that energy losses in electricity generation and transmission offset any benefits. The UK Department for Transport argues otherwise, stating that "Research suggests, using the current UK power mix, EVs could realise up to a 40 per cent benefit in CO_2 savings compared with a typical petrol family car in the UK over the full life cycle. Larger emission reductions can be realised over time if the UK moves to lower carbon sources of power generation".[2]

EVs could minimise the financial impact of rising car ownership on emerging economies that are struggling to manage soaring population growth and massive urbanisation. For nation states with no, or in the case of the UK, dwindling indigenous hydrocarbon resources, EVs offer the prospect of expanding personal mobility without increasing their exposure to volatile global oil markets. Of course, this is dependent on these economies securing their electricity supply without recourse to those same oil markets. And the emissions benefits, in the short term at least, will rely on them doing so without relying heavily on coal, which could be problematic for some.

EVs are seen as a key building block in stimulating low carbon economic growth, with the promise of new jobs in the expanding electric vehicle sector and the prospect of a competitive advantage for businesses and nations that get it right. The manufacture and after sales service of an EV could bring benefits to the wider environment when compared to traditionally powered vehicles – EVs have fewer components bringing manufacturing efficiencies and lower waste, and longer intervals between servicing.

£30m

is being spent in the UK on the roll-out of EV charging infrastructure

In the wider context, battery-powered electric vehicles are widely seen to represent a far more promising immediate prospect than the alternatives. Cars fuelled by hydrogen, for example, have significant safety implications and infrastructure requirements, while for bio-fuels, there's simply not enough agricultural land available to fill both our plates and our fuel tanks and they pose other land use and bio-diversity issues where they are grown on non-agricultural land.

As with any new technology that offers potential environmental benefits, the advantages of going electric are cast against a background of limitations which it is still striving to overcome – key amongst these are the current price of an EV when compared to conventional vehicles, the range an EV is able to travel before having to refuel, the availability of infrastructure to undertake that refuelling and the features an EV manufacturer is able to offer when compared to existing conventional models. However its not all sandals and sackcloth – there are real demand-side drivers too. The kerb appeal and performance of certain electric models is undeniable, with vehicles such as the Tesla Roadster offering a top speed of 125mph and eye-watering acceleration – 0 to 60 mph in 3.7 seconds – for those who want it.

Ultimately though, the arguments in favour of electric vehicles are underpinned by an important realisation. And it's this. The geography of Britain – and that of most of the developed world – is now the geography of the car. Personal mobility is the glue that binds that world together. Take away or restrict access to cars and that model could start to crumble, with the potential for huge social, economic and political repercussions.

ELECTRIC IDENTITY

What about the vehicles themselves? **Today's EVs come in three basic but related forms.** Fully-electric vehicles (FEVs), such as the Tesla Roadster, depend entirely upon battery power and external recharging: there's no back-up from an internal combustion engine. High battery costs mean that FEVs are still relatively scarce.

Plug-in hybrid electric vehicles (PHEVs) are a halfway house. These have a battery that can be recharged via an external charging point, as well as a conventional onboard internal combustion engine.

Hybrid electric vehicles (HEVs) – the most common electrically-enabled vehicles – cannot be externally charged. These use a combination of battery and internal combustion engine power; the car's battery is charged by the engine and in some vehicles by regenerative braking.

Fully-electric vehicles are often presented as the "gold standard" in emissions reduction, as they produce no emissions at all at the point of use. But the energy needed to recharge their batteries has to come from somewhere, so the extent to which such vehicles are responsible for indirect emissions depends on how electricity is generated. There are wider cradle-to-grave environmental concerns too, especially concerning the minerals and chemicals required for manufacture.

In the UK, fully-electric vehicles produce lower per-kilometre emissions than vehicles burning petrol or diesel. That's because around a quarter of UK electricity generation comes from low-carbon or zero-carbon sources, such as renewables and nuclear. UK per-kilometre emissions are likely to fall further as carbon-dependent generation is stripped out of the mix.

The environmental arguments for fully-electric vehicles do not – yet – stack up in countries such as India and China, both of which depend heavily on coal-generated electricity. Those countries could see indirect emissions rise quickly if EV ownership takes off. But the political arguments for EV adoption are potentially unassailable – coal-fired energy for EVs at least holds out the promise of increased personal mobility without the supply risks associated with imported oil and the emissions from coal generation will be and are being gradually addressed through cleaner combustion technologies and carbon capture.

What's clear is that it is not environmental arguments alone, but also pragmatic considerations that will influence the uptake of electric personal mobility. It's also clear that the electric vehicle sector is being strongly shaped by government interventions at national, regional and local levels.

These include everything from loan packages aimed at the vehicle industry in the US, worth in excess of $27 billion, to proposed subsidies, due next year, for British motorists choosing electric vehicles. Canada and Japan are amongst the growing number of nations offering subsidies for EV ownership.

But providing incentives for change is not all about cash handouts: governments around the world are also seeking to nurture consumer enthusiasm for electric vehicles with non-fiscal stimuli. These range from discounted parking to road-user charging exemptions and access to dedicated lanes on busy urban roads.

GAINING TRACTION

Given that low or zero carbon personal transport is likely to become essential, rather than desirable, what happens next?

Two things are clear. First, the success or failure of electric personal mobility is likely to depend on radical changes and improvements to existing energy infrastructure – generation as well as distribution. The ability to scale-up new infrastructure as vehicle numbers increase, and to ensure consistency and security of supply, is likely to be of critical importance.

Second, if electric cars are to become part of our daily lives, it must be possible to charge them – and to pay for charging – as easily as we pay for

petrol today. That means massive, nationwide, distribution of charging services capable of providing universal service. And batteries that last long enough to make recharging an occasional – instead of constant – concern.

Compatibility here is essential. Format issues have marred every industry from railways in the 19th century (different gauges) to video in the 20th (VHS versus Betamax) and mobile phones in the 21st (non-interoperable chargers). Fail to sort out a standard early enough, allow equipment to proliferate and it can take anything from 20 to 50 years to get it nailed down. It's taken more than 20 years to settle on a universal mobile phone charger standard. When it comes to electric vehicles, we simply may not have that long.

No-one can be sure how quickly the vehicles themselves will be developed, how readily consumers will buy into the idea and how they will go about using and charging electric vehicles if they do. But it is clear that we have reached the point where electric vehicles are a reality. What advances are needed in battery technology to win consumer acceptance? What are the implications for our power grid and energy infrastructure? And what does it require in the way of an intelligent architecture?

0.3%
of the cars in the UK roads today are electric – these are still early days

REINVENTING THE CAR

The shift to electric vehicles has massive implications, but it's early days. Today, there are over 29 million cars on the road in the UK and only around 8,000 of them are electric. We're still a long way from achieving critical mass and the likely direction the technology will take is still, largely, a matter of guesswork.

Fully-electric vehicles require a more intelligent, interconnected and instrumented relationship with their energy supply than conventionally fuelled cars. They're less like combustion engines on wheels and more like large electrical appliances. And that means changing our preconceived notions of what a car is and the infrastructure needed to keep it moving.

There is still a considerable distance to travel in terms of the cars themselves and in breaking the petrol-pump era habits that could go with them. Conventional vehicles are fuel-and-forget – a tank full of diesel might last 500 miles. But the world of fully-electric vehicles is quite a different one, and it's a world of trade-offs and compromises because the energy density of batteries – the amount of energy it's possible to store in them per unit of weight – is at present far less than that of petrol or diesel. The best commercially available battery technology has an energy density one sixth that of diesel fuel. Battery weight is a determinant in a way that fuel weight simply isn't in conventional cars. Current technology imposes limitations on the range of fully-electric vehicles, typically about 100 miles, as well as the speeds that are possible.

Battery price continues to stifle demand for electric vehicles. Nickel-metal hydride batteries currently dominate the hybrid sector, but their limited power-to-weight ratio means they are not ideally suited for deployment in fully-electric vehicles.

Lithium-ion batteries – a scaled-up version of those used in today's mobile phones and laptops – have much greater potential, providing about twice as much energy storage as nickel-metal hydride batteries on a weight-for-weight basis. Lithium-ion technology in its current form is not – quite – a magic bullet solution.

Safety and performance durability concerns have still to be fully addressed and they're extremely expensive, representing around 40 per cent of total vehicle cost – more in some cases. At current prices, a 20 kWh battery pack capable of providing energy for a 60-mile journey would cost around £12,000.

It's forecast that technological improvements, process enhancements and scale purchasing could drive battery costs down considerably over the next five years. Standardisation and rules for battery interoperability would also help, although given the car industry's traditional reluctance to engage in collaborative actions, this seems unlikely in the short term.

Next generation technologies are being investigated in research projects such as IBM's Almaden Research Lab where a consortium is involved in the "Battery 500 Project". Its goal is to power a typical familay car for 500 miles on a single charge at levels of performance comparable or even superior to those achieved from internal combustion engines. Lithium-Air offers this potential and more, offering potential energy densities (watt-hours / kilogram) of over six times that of current Lithium-Ion and almost that of gasoline. With anticipated 88 per cent battery-to-wheel efficiency compared with 13 per cent[3] tank-to-wheel for gasoline, this technology promises usable energy content in excess of gasoline. Combined with the generally lighter EV power trains, the potential is exciting and perhaps beyond the magic "500". But it is early days and some years before this next generation of batteries could be powering your car.

In the meantime, the US government has set a target of $250 per kWh for lithium-ion battery technology – a quarter of the current price. This is the level at which electric vehicles become competitive with conventional internal combustion engine drive trains.

Goals of this sort are not just political hot air: governments are, increasingly, lining up behind manufacturers with real support for research and development. The US government's $25 billion Advanced Technology Vehicles Manufacturing Loan Program is a case in point, with funding intended to enhance the efficiency of both electric and conventionally-fuelled vehicles.

A further $2.4 billion in grants is being directed towards research and development of advanced battery manufacturing.

In the long term, lithium technology is likely to win out. But “range anxiety” – the fear of a running out of power while travelling – remains a very real concern for electric vehicle owners, as indeed is the perception that if the battery runs flat, there’s no jerrycan solution – recharging takes time, whichever battery technology comes out on top.

Interestingly, whilst the anxiety is real, it is not necessarily based on real issues. UK DfT figures[4] for leisure, shopping, commuting and education “school runs” suggest an average journey distance of less than 10 miles – well within the range of current EVs and certainly not requiring a fuel fill if undertaken by a conventional vehicle.

Of course, the EV solution does require both planning and the ability to recharge daily, and consumers don’t buy their cars simply for the “average” journey – suggesting a shift in behaviour and perhaps also a shift in car-ownership paradigms are needed.

Vehicle telematics – which warn of an impending flat battery and provide guidance to the location of the nearest recharging point – could help to assuage those concerns. And re-charging an electric vehicle battery takes rather less time than is sometimes believed. Nissan estimates that it will take around 30 minutes to deliver an 80 per cent battery charge to its new all-electric Leaf model due to go into production in 2013, giving a range of around 80 miles, although the 30-minute refill is only possible with high-voltage charging equipment. Recharging at home is likely to take around eight hours – assuming the battery is charged from flat which is unlikely.

Some business models – which envisage batteries being leased rather than owned – could allow for battery “swap outs”, changing a flat battery for a freshly charged one, rather than time spent plugged in. These models are highly dependent on standards being adopted by the vehicle manufacturers which may not happen easily. The point of ownership of the “customer relationship” shifts to the battery leas≠e company, which is likely to face resistance from both auto makers and electricity supply companies. And while the model will deal well with changing battery technologies, there will be a net increase in the capital tied up in batteries across the overall system, raising the cost to the consumer. Alternatively, the breakdown trucks of the future could carry either fast-charge generating sets or ‘get me home’ battery packs – if the technology can be standardised.

HOOKING UP

Seamless acceptance of electric vehicles requires a charging infrastructure that is as intelligent, interconnected and instrumented as the cars themselves. That is likely to mean public charging points – everywhere – that are smart enough to measure how much electricity they’re delivering, what they are delivering it to, and – most important of all – the ability to charge an account, or take a payment, for the electricity provided.

Plugging-in like this implies an exchange of data as well as a power download. Public charging points will not only be connected to the electricity network, they

China: driving towards the future

China has made its intentions clear with regards to electric vehicles (EVs), paving the way for them to play a big part in the country’s efforts to lower emissions in the very near future.

For example, the State Grid Corporation of China, the country’s leading power grid operator, has already announced plans to dedicate 10 per cent of this year’s State Grid asset investment plan to building 75 plug-in electric car charging stations, 6,200 charging poles and other Smart Grid pilot projects.[7]

The country’s forthcoming “Emerging Energy Industries Development Plan” is also reported to cover the development of wind, water, solar, bio-material and nuclear power, as well as “new energy for cars”.[8] In June 2010, the Chinese government launched a pilot programme in five cities, subsidising the private purchase of new energy cars. In Shenzhen, additional subsidies were announced by local government. In both cases, the focus is on plug-in hybrid EVs and plug-in EVs.

As for the vehicles themselves, the first “purely electric car” to be bought by a private individual in China took place in late July 2010, in Hangzou.[9] The 5008EV, manufactured by Zotye Auto, was one of 100 EVs the company had made available for lease earlier in the year. In addition, a taxi fleet of 40 EVs manufactured by BYD Co is already operating in Shenzhen, with plans to make the model available to the public in the near future.

will, almost certainly, have to be connected to data networks too, with a robust customer facing front-end to support transactions.

Get this bit right, and the lack of access to domestic off-street parking may not be a deal breaker. Businesses may begin to subsidise or offer free charging to win and retain customers. A trip to the supermarket could include hooking-up to parking lot charging posts to top-up batteries while customers do their shopping.

In this context, electricity as a fuel would be a bargaining chip, rather than a commodity. At current electricity prices, it costs between £4 and £51 to fully charge an EV battery – a fraction of the average family's £100 weekly shop. Major retailers might consider that a relatively small price to pay for customer loyalty, providing it is cost effective to provide high-voltage fast charging points.

Railway stations, airports, office or public car parks offer similar opportunities for targeted re-charging facilities either as incentives or as new revenue streams.

Critically, recharging of this sort would not require huge behaviour changes. Trips to the filling station might soon be a thing of the past. It's easy to envisage how quickly the public would adapt to a "park-up, plug-in" mantra. Because it takes time to recharge a vehicle – currently around 30 minutes under rapid charging – it's increasingly clear that the car parks of tomorrow could also be filling stations.

Much of the debate around charging is focused on miles-per-charge: how far should consumers expect to travel in their electric vehicles? Not far, probably, at least not to start with. Current ranges are limited by battery capacity. Top speeds are limited as well, to preserve battery life: energy consumption increases dramatically with speed.

Does that matter? It certainly challenges conventional notions of what a car should be. First and second generation mass-produced electric cars are unlikely to be sleek motorway cruisers and they are not intended to be. But they reflect the reality of most day-to-day motoring.

In London, for example, 90 per cent of car journeys are less than ten miles: to get to work, to school, to the shops. Electric vehicles are well-suited for these city journeys and 80 per cent of the UK population lives in urban areas.

The reality – for now – is that many of us deliberately choose and own motor vehicles with capacity, both in terms of power and size, that vastly exceeds our daily needs. And that's likely to be a tough habit to break, especially in free-market economies where the car, for many, is inextricably linked with notions of social status and freedom – the potential to drive for 200 miles without a refill. Cheaper high-capacity batteries cannot come soon enough.

SMARTER INFRASTRUCTURE: POWER TO THE PEOPLE?

Getting the vehicles right is only one part of the equation. How will the energy industry cope with the rising demand for electricity that would accompany even a relatively modest uptake of electric vehicles? And how will consumers pay for the power used?

IBM is studying the question. It is working with the UK energy efficiency specialist Energy Technologies Institute (ETI) and companies such as E.ON and EDF Energy to study how the UK's power grid will need to be updated to accommodate an increase in electric vehicle use.

At the moment, the proportion of fully-electric vehicles in Europe is only expected to reach nine per cent by 2020 and even when plug-in hybrids are included, it's still no more than 20 per cent[5]. But even those numbers could present problems for existing local electricity distribution networks – the "last-mile" cable systems that link our homes to the grid.

Local cable networks are configured to meet current needs – average consumption of electricity for a family household in the UK is around 14 kWh each day. If that household has two cars, the second car will clock up an average of 6,000 miles each year – say 16 miles every day. And let's assume that only the second car is replaced with an electric one, doing the same mileage. Using today's battery technology, an electric vehicle will squeeze about four miles out of a kilowatt-hour. That's an average of about four kWh per day.

This presents two different sets of potential problems. The first of these relates to power – the rate at which electrical energy is delivered. The risk of

First and second generation **mass-produced electric cars** will not be sleek motorway cruisers overloading local distribution networks is very real if everyone decides to charge their cars electric car batteries at more or less the same time during peak hours. This risk is exacerbated by the likely "clustering" of EV ownership due to demographics, infrastructure availability, local incentives and "follow me" behaviours. This challenge is already acknowledged by the energy industry.[6]

The other challenge is, quite simply, the need to provide additional generation capacity.

Smart power management – and smart tariffs to drive demand into shorter periods – will be critical to support the shift to electric vehicles, if only to avoid the need to tear up countless streets in the UK to provide higher-capacity cables. Deliberate forward planning is essential. And it goes beyond current notions of smart metering – the system needs to be dynamic, with the intelligence to switch out non-core demand, such as overnight car battery charging, as network loads change from minute to minute.

Electric vehicles offer an unprecedented opportunity to make sense of renewable energy, especially wind power, which by its very nature is more variable than other forms of renewable generation. Today, some renewable energy suppliers have to pay to dump surplus wind-generated power, which is costly to store.

Electric vehicles could change that dynamic. Hooked up to a smart grid, they could become a vast, ready-made repository for energy – a mobile storage facility. With a typical battery capacity today of around 24 kWh – more than a day's worth of average domestic energy use – the scope for distributed storage is considerable. And as well as allowing a degree of electricity stockpiling – charging now to use later – in theory smart grids can draw on stored vehicle energy to meet supply shortfalls at times of peak demand, though there are many issues, both technical and commercial, to be worked through before this becomes a reality.

EVs are certainly a challenge for the utilities industry. But the opportunities are also clear. Grid interaction means better use of intermittent supplies, with vehicle-to-home (V2H) discharging to reduce loading on local distribution networks. And vehicle-to-grid (V2G) interaction could support a whole new set of relationships, with customers and suppliers trading energy stored in vehicle batteries – a relationship in which the customer could potentially make money when the vehicle was not in use.

With potentially dozens of stakeholders in the energy distribution and management process – from electricity suppliers to supermarkets offering customer incentives, from vehicle manufactures to car park owners and local government agencies – it's clear that electric vehicles demand a totally new sort of infrastructure, capable of monitoring and managing data on a huge scale.

90%

of London's car journeys are less that 10 miles – 80% of people in the UK live in urban settings

What's equally clear is that the technology that will make this possible will be distributed rather than centralised – intelligence will reside in vehicles, back office systems, charging point RFID devices, smartcards and in mobile phones needed to authorise payments. Overall systems integration is critical.

NEXT STEPS

The challenge of delivering the electric future is all about creating the right architecture – along with the ability to deliver massive systems integration on a scale that has not been seen before.

That integration includes the development of smart grids, the roll-out of smart metering and the ability to manage tens of thousands and, within perhaps 15 years, tens of millions of individual payment transactions every day.

IBM's expertise in creating and managing large, complex systems can make a significant contribution to turning mass electric car ownership into a practical, secure and environmentally friendly reality. That includes a unique ability to create interoperable solutions to support highly plural markets and supply chains as they emerge.

Working with the Energy Technologies Institute, partner companies EDF and E.On, and academic expertise from Imperial College, IBM is investigating the implications of future EV take-up and usage on the electricity distribution network. It is examining the role that intelligent architectures will play in mitigating problems and mediating between vehicles, drivers, the grid, charge points, electricity supply companies and EV service providers.

Other closely related ETI projects are looking at the future vehicle capabilities and consumer behaviours and the net economic and carbon benefits to the UK of an EV future.

The company's expertise in systems architecture, communications and high-performance computing are likely to prove decisive in the quest to dynamically manage grid-to-vehicle and vehicle-to-grid interactions. Working with the EDISON research consortium in Denmark, IBM has already established the viability of smart technologies that synchronise the charging of electric vehicles with the availability of wind energy in the grid.

And from innovative research projects to full-scale deployment and software solutions – including SAFE, the new Solution Architecture for Energy and Utilities Framework – IBM has participated in more than 60 smart grid projects around the world.

Getting electric vehicles right has huge implications for the UK – not only for the environment, but for the economy and society as a whole. What's emerging now is a tantalising glimpse of the post carbon world. The ability to respond, now, at speed and at scale, may prove critical in turning that vision into reality.

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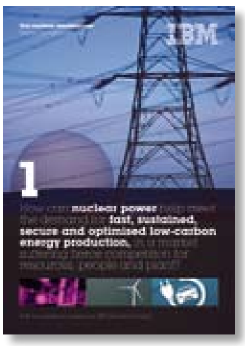

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