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Smart Grids and Electric Vehicles: Made for Each Other?

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Smart grids and electric vehicles: *Made for each other?*

SUMMARY

Electric vehicles[1] (EVs) could play a central role in decarbonising road transport. But this new type of electricity load will need careful management. Although electricity needs for EVs are likely to remain small relative to overall load in most regions for many years to come, they could have a much bigger impact on peak load as motorists seek to recharge their batteries during the evening. Electricity suppliers will need to anticipate the long-term investments that will be needed to respond to this emerging trend.

Recent technological advances in electricity distribution and load management that make use of information and communications technologies, referred to as "smart grids", promise to facilitate the integration of EVs into electricity load and to lower costs. Smart-grid technology can enable EV-charging (grid-to-vehicle, or G2V) load to be shifted to off-peak periods, thereby flattening the daily load curve and significantly reducing both generation and network investment needs. Advanced metering equipment is an essential component, enabling a two-way flow of information and providing customers and utilities with real-time data and enabling customers to schedule charging intelligently.

In the longer term, there may be potential for smart-grid technology to enable EVs to be used as distributed storage devices, feeding electricity stored in their batteries back into the system when needed (vehicle-to-grid, or V2G, supply). This can help to reduce electricity system costs by providing a cost-effective means of providing regulation services, spinning reserves and peak-shaving capacity. In this way, EVs could both benefit from and drive forward investment in smart grids. However, there are a number of technical, practical and economic barriers to such a development, including low battery discharge rates and storage capacity. Developments in battery technology will be critical to the future of V2G supply.

Electricity market structures and regulatory frameworks will need to adapt to facilitate the demonstration and commercial deployment of smart grids, including the specific technologies needed to make G2V and V2G technically and commercially viable. It is vital that regulatory frameworks be adapted to allow tariffs to be set to provide incentives for electricity transmission and distribution companies to invest in appropriate smart-grid technologies, for system operators to take decisions that ensure economically efficient operation of the entire system and for EV owners to optimise G2V and V2G load.

[1] An electric vehicle is defined in this paper as a vehicle with an electric battery than that can be charged from the network, i.e. plug-in hybrids and battery electric vehicles.

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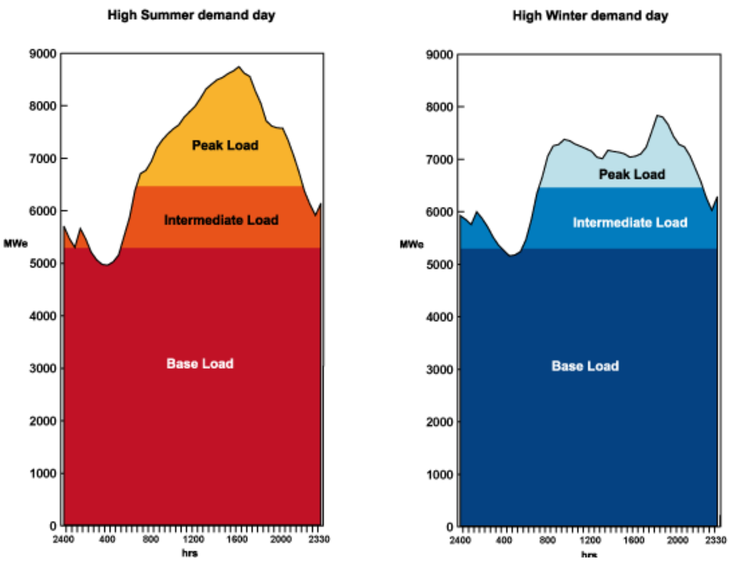
Introduction

Electrification is a potentially significant route towards decarbonising road transportation. It would require major investments, both in developing vehicles, the electricity network and associated charging infrastructure. As the use of electric vehicles (EVs) grows, this new type of electricity load will need careful management in order to minimise the impact on peak electricity demand and, therefore, the cost of supply, given the likelihood that a large proportion of motorists would seek to recharge their vehicle batteries during the evening. The evening is typically a period of high demand as people return from work and school, switching on home appliances, lighting and heating/cooling while much office and industrial equipment is still running. But recent technological advances in electricity distribution and load management, referred to as "smart grids", promise to facilitate the integration of EVs into electricity load and to lower costs.

Electric utilities have already begun to deploy smart-grid technologies to better manage commercial and household load using intelligent metering and communication systems in order to save energy, cut emissions and reduce peak loads. More widespread deployment would enable EV charging to be scheduled intelligently. In addition, it could – at least in principle – enable the storage capacity of the batteries in EVs to be used as a supplementary source of power at times of peak load; the residual charge in those batteries could be fed back into the network during the evening peak and the battery recharged at night. There may also be scope for exploiting this storage potential to compensate for the variability of electricity supply from variable renewable energy sources such as wind and solar. In this way, smart girds and EVs could be mutually beneficial: EVs could both benefit from and help to drive forward investment in smart grids.

Figure 1: **Peak electricity demand: Load curves for a typical electricity grid in a warm temperate climate**



Source: World Nuclear Association.

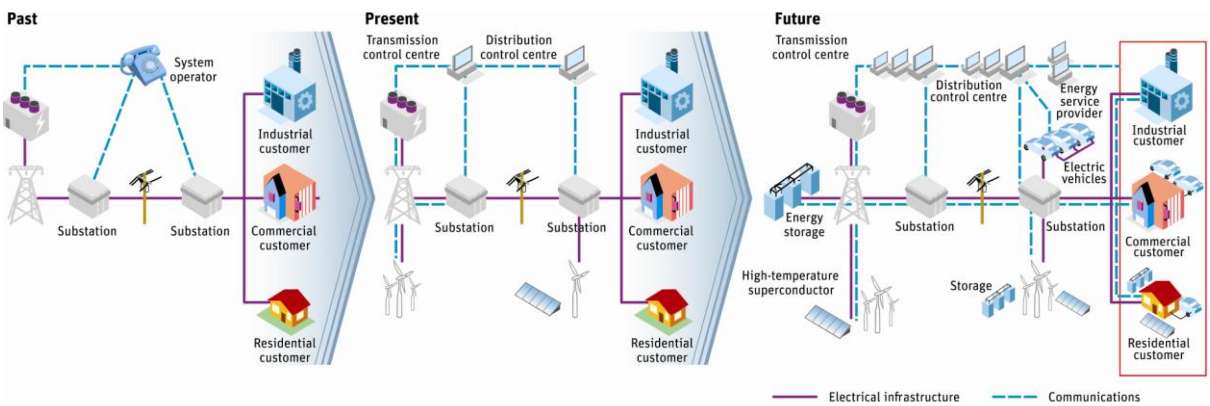
This background paper explores the implications for the electricity network of a potential increase in the use of light-duty EVs for private and commercial purposes, the role that smart-grid technologies could play in encouraging the take-off of EVs and the extent to which EVs could reinforce the benefits of smart grids. It also considers how these developments might affect the electricity utility business model and reviews the current status of research and development of smart-grid technologies worldwide related to the integration of EVs into electricity supply.

Smart-grid technology

What is a "smart grid"?

A smart grid is an electricity network that incorporates a suite of information, communication and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users.[2] Smart grids allow for better co-ordination of the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders in operating all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability (IEA, 2011a). The process of "smartening" the electricity grid, which has already begun in many regions, involves significant additional upfront investment, though this is expected to reduce the overall cost of electricity supply to end users over the long term. Smart-grid technologies are evolving rapidly and will be deployed at different rates around the world, depending on local commercial attractiveness, compatibility with existing technologies, regulatory developments and investment frameworks. The evolutionary nature of this process is illustrated stylistically in Figure 2.

Figure 2: **Smartening the electricity grid**



Source: IEA (2011a).

[2] Smart grid concepts can be applied to a range of commodity infrastructures, including water, gas, electricity and hydrogen.

Why do we need to smarten electricity grids?

Electricity systems worldwide face a number of challenges, including ageing infrastructure, continued growth in demand, shifting load patterns (including changes resulting from the increased use of EVs), the need to integrate new sources of supply and the variability of some sources of renewables-based supply. Smart-grid technologies offer a cost-effective means of helping to meet these challenges and, in so doing, contribute to the establishment of an energy system that is more energy efficient, more secure and more sustainable. They do this by:

- Enabling and incentivising customers to adjust their demand in real time to changing market and network conditions.
- Accommodating all generation sources and storage options.
- Tailoring power quality to customer needs.
- Optimising the utilisation and operating efficiency of generation, transmission and distribution assets.
- Providing resiliency to unplanned supply disruptions and outages.

Accommodating variable generation technologies such as wind and solar power is a major driver of smart-grid investment. The importance of such technologies is growing rapidly in many regions in response to the need to reduce greenhouse-gas emissions and reliance on imports of fossil fuels. According to the International Energy Agency's latest *World Energy Outlook*, they will account for 37% of the net increase in generating capacity worldwide between 2009 and 2035 on planned policies (IEA, 2011b). As the share of variable generation increases, it becomes increasingly difficult to ensure the reliable and stable management of the electricity system where it relies solely on conventional grid architecture and technology. Smart grids can support greater deployment of variable generation technologies by providing operators with real-time system information that enables them to manage generation, load and power quality, thus increasing system flexibility and maintaining stability and balance.

Smart-grid technologies could also facilitate the integration of electricity networks over larger geographic areas, creating "super grids". Such a development can bring benefits in the form of more efficient use of generating plant and improved system adequacy, as a bigger grid increases the flexibility of generating options and reduces the overall variability of output from renewables-based plant (as the strength of sunshine or wind speed is less correlated across a wider geographic area).

What are the main smart-grid technologies?

There are a number of different types of smart-grid technology, all of which make use of information and communication technology (hardware and software) such as internet and radio, cellular and cable networks (Table 1). Smart grids involve the gathering, by means of sophisticated metering systems, and exchange of large amounts of information in real time at different levels of the supply chain. Sensors can be installed on each device on the network (such as power meters, voltage sensors and fault detectors) to gather and transmit data, while two-way digital communication between the device in the field and the utility's network operations centre, which enables the utility to adjust and control each individual device remotely. A key feature of the smart grid is automation technology, which lowers the cost and increases the efficiency of load-management operations (for example, automatic adjustments to the operation of the power system in response to a sudden breakdown of one component). Importantly, information flows between suppliers and end users can also be bi-directional, allowing both parties to adjust their behaviour in response to changes in pricing at short notice.

Table 1: **Principal smart grid technologies**

Technology area (level of maturity)	Hardware	Systems and software
Wide-area monitoring and control (developing)	Phasor measurement units (PMU) and other sensor equipment	Supervisory control and data acquisition (SCADA), wide-area monitoring systems (WAMS), wide-area adaptive protection, control and automation (WAAPCA), wide-area situational awareness (WASA)
Information and communication technology integration (mature)	Communication equipment (Power line carrier, WIMAX, LTE, RF mesh network, cellular), routers, relays, switches, gateway, computers (servers)	Enterprise resource planning software (ERP), customer information system (CIS)
Renewable and distributed generation integration (developing)	Power conditioning equipment for bulk power and grid support, communication and control hardware for generation and enabling storage technology	Energy management system (EMS), distribution management system (DMS), SCADA, geographic Information system (GIS)
Transmission enhancement (mature)	Superconductors, FACTS, HVDC	Network stability analysis, automatic recovery systems
Distribution grid management (developing)	Automated re-closers, switches and capacitors, remote controlled distributed generation and storage, transformer sensors, wire and cable sensors	Geographic information system (GIS), distribution management system (DMS), outage management system (OMS), workforce management system (WMS)
Advanced metering infrastructure (mature)	Smart meters, in-home displays, servers, relays	Meter data management system (MDMS)
EV battery charging infrastructure (developing)	Charging equipment (public and private), batteries, inverters	Energy billing, smart grid-to-vehicle charging (G2V) and discharging vehicle-to-grid (V2G) methodologies
Customer-side systems (developing)	Smart appliances, routers, in-home display, building automation systems, thermal accumulators, smart thermostat	Energy dashboards, energy management systems, energy applications for smart phones and tablets

Sources: Based on IEA (2011a).

The various smart-grid technology areas – each consisting of sets of individual technologies – span the entire grid, from generation through transmission and distribution to the different categories of electricity consumer. Not all the different technology areas need to be installed to increase the "smartness" of the grid, which can be accomplished incrementally over time. Companies manufacturing smart-grid equipment or developing software include technology giants, established communication firms and new start-ups.

EV-charging infrastructure could form an important part of the smart grid of the future. This includes physical charging facilities (connectors and meters), as well as billing, scheduling and other intelligent features for smart charging during off-peak periods. As the share of EV charging in overall electricity load increases, the grid would need to incorporate other assets in order to enhance the capacity to provide power-system ancillary services (reserve generating capacity and peak-shaving facilities), and, potentially, power discharging hardware and software to enable EV batteries to be used as storage devices (see below).

How is the deployment of smart-grid technologies progressing?

Smart-grid technologies are at varying levels of maturity. Some of the technologies are considered mature in both their development – notably the integration of Information and communication technology, transmission network enhancements and advanced metering – and are already being deployed actively, while others require significant further development or demonstration on a large scale. The development and large-scale installation of customer-wide systems is probably the least advanced of the major technology areas. EV battery-charging and discharging technologies are also still at the development stage, but – as with customer-wide systems – are developing rapidly (IEA, 2011a).

The deployment of smart grid pilot and demonstration projects around the world has accelerated in recent years, thanks partly to a step-increase in government funding as part of the economic stimulus programmes launched in 2009 and 2010. For example, USD 4.5 billion was allocated to smart-grid projects under the American Recovery Reinvestment Act of 2009, including USD 435 million for regional demonstrations. According to the Microsoft Worldwide Utility Survey, carried out in 2011, around three-quarters of the 215 utilities polled are at least at the stage of preparing plans to install smart-grid technologies, while 39% are already at the deployment stage.[3] In Europe, smart-grid deployment is being boosted by a 2006 EU directive that mandates the use of smart meters that are able, at a minimum, to record time-of-use information in all households by 2020.

[3] http://blogs.technet.com/b/vertical_industries/archive/2011/03/10/microsoft-worldwide-utility-study-reveals-status-of-smart-grid-adoption.aspx

Implications of electric vehicles for load management using smart-grid technologies

How much difference could electric vehicles (EVs) make to electricity load?

Rapid growth in the number of EVs in use would have a significant impact on the need for investment in electricity network capacity and smart-grid technologies. Depending on their rate of penetration of the light-duty vehicle fleet, EVs could account for a substantial share of total electricity consumption and, more importantly, peak load. The greater the increase in consumption, the larger the potential benefits from smart-grid technologies that improve the ability of the electricity utility to manage load in order to schedule charging as much as possible outside of peak hours. This would mitigate the need to build additional power stations and to reinforce the capacity of the transmission and distribution system to meet a higher peak load. However, it is important to retain a sense of perspective: given the significant barriers to the widespread commercialisation of EVs, in particular, their higher overall cost and limited distance between charges, the deployment of EVs – and, therefore, their associated electricity demand – appears set to remain relatively modest in most countries for at least the next two decades (ITF 2012).

There is enormous uncertainty about how just quickly the number of EVs on the road is set to grow over the long term. Today, of the global vehicle fleet of around 1 billion, less than 50 000 are EVs, most of which were purchased within the last year or so.[4] The *World Energy Outlook*, produced by the International Energy Agency (IEA), projects that the total EV fleet will reach 1.6 million in 2020 and 31 million in 2035 in its central scenario, which takes account of planned policies (IEA, 2011b). That implies that even by 2035, EVs will make up less than 2% of all road vehicles. The electricity required to run these EVs amounts to a mere of 0.1% of total projected electricity consumption in 2035. However, some countries are expected to see a much faster rate of take-up of EVs. For example, were Israel to achieve its goal of becoming the first nation in the world to commit to an all-electric car infrastructure, the additional electricity needs for EVs would amount to about half of the country's electricity use based on current mobility levels and electricity use. And in certain geographic areas, notably in cities where EVs are currently of most interest, their number could grow very rapidly. Globally, the EV fleet could grow much faster than projected, were the cost of EVs to fall more quickly and government support to increase: in a scenario in which the internationally agreed target of limiting global temperature increase to 2º Celsius is achieved, the IEA Outlook projects the share of EVs in total electricity consumption reaches about 1% worldwide by 2035. The preference for battery EVs (BEVs) over plug-in hybrid EVs (PHEVs) will also influence the average electricity consumption per vehicle, since traditional petroleum-based fuels would continue to meet part of the latter's fuel needs, reducing the need for electricity from the grid for charging.

Of course, the potential for EVs to displace conventional vehicles and to boost electricity demand is much greater in the longer term. In the BLUE Map Scenario from the IEA's

[4] Data provided by the International Energy Agency in a private communication. EV sales in 2011 amounted to an estimated 37 000.

most recent *Energy Technology Perspectives (ETP)*, in which global carbon-dioxide emissions are reduced by 50% by 2050 compared with 2005 levels, EVs account for 11% of overall electricity consumption by then because of a significant increase in EVs (IEA, 2010a). On the most optimistic assumptions about the commercialisation of EVs, in which EVs displace virtually all conventional vehicles in the global fleet by 2050, EVs could add over 20% to global electricity demand.

Although the electricity consumed in charging EV batteries is likely to remain small relative to overall electricity demand for the foreseeable future, EVs could add significantly to peak load if vehicle charging is not managed intelligently. For as long as battery-charging times remain high, EVs are likely to be used predominately by private motorists for daily commuting, especially BEVs that have no conventionally-fuelled engine to provide back-up. Commuters will typically want to recharge the battery on returning home in the evening, coinciding with the normal daily peak in load – unless they have a financial incentive and the means to schedule charging during the night, when overall system load is much lower. EV batteries can normally be recharged from conventional power outlets in the home or at dedicated charging stations, a process that typically takes several hours. A simple arithmetic example illustrates this phenomenon. If EVs were to account for just 1% of overall electricity demand, the increase in peak load would be 4% on the assumption that two-thirds off all EVs are recharged during a four-hour period during the evening and that the system load factor (average load/peak load) is 0.5 for both total demand and EV demand during the charging period. The impact on the network would be much greater if EVs were concentrated in urban areas. The effect of EVs on peak load may depend on the ownership of the batteries: where a battery-swapping system is in operation (whereby flat batteries are swapped for fully charged ones at special exchange stations), EV charging load is less likely to coincide with the overall system peak load, as the exchange stations would be more likely to recharge the batteries during the night (assuming they profit from lower tariffs).

How can smart grids help optimise scheduling of EV charging?

Smart-grid technologies can enable charging load to be shifted to off-peak periods, thereby flattening the daily load curve and significantly reducing both generation and network investment needs. In so doing, they can also help to minimise CO_2 emissions from electricity generation. Advanced metering equipment is an essential component, enabling a two-way flow of information, providing customers and utilities with real-time data and enabling customers to schedule charging in a way that minimises costs to them and to the utility. Advanced meters collect, store and report customer consumption data for any required time intervals, including in real time. This information can be used to return price signals to the consumer, providing an incentive to avoid charging at periods of peak load, when prices are highest. Sophisticated algorithms and communication protocols are required to handle the telemetry required with such information flows. Advanced meters can also permit remote connection and disconnection; in practice, grid operators may opt for a system whereby they are entitled to partially disconnect by remote control a certain number of EVs being recharged if the grid capacity is saturated (an arrangement known as direct load control). Alternatively, automated charging equipment could be installed to allow the customer to schedule charging at off-peak times. Advanced meters facilitate other functions, including identifying the location and extent of outages, or losses, remotely and improving the utility's management of its revenues through more effective cash collection and debt management.

Similar technologies can be used for public battery-charging points in urban areas, such as those being installed in several cities, notably in Europe, the United States and Israel. For example, commuters can plug in their EVs while at work and leave them to charge throughout the day, extending the commuting range and eliminating range anxiety (the fear of not having enough power to reach the destination); advanced metering equipment would allow charging to start only after the morning demand peak has been passed. The charging of fleet vehicles could be scheduled in a similar fashion. This will become increasingly attractive as charging times fall with advances in battery technology: at present, most car batteries require several hours to charge fully, though some types can be charged very quickly (Box 1).

To what extent could EVs help meet peak load?

In the longer term, there may be some potential for smart-grid technology to enable EVs to be used as distributed storage devices, either to feed electricity stored in their batteries back into the system when needed (vehicle-to-grid, V2G[5]) or for use within the home or office (vehicle-to-home, or V2H). Vehicles are parked an average of 95% of the time, providing ample opportunity for their batteries to be used for V2G supply. This can help to reduce electricity system costs by providing a cost-effective means of providing regulation services, spinning reserves and peak-shaving capacity.[6] EV batteries may be particularly useful in handling sudden, very brief surges in load, such as during television breaks during or just after major sporting events. When an EV owner has no immediate need to use his vehicle, he may be willing to feed power into the grid if the price obtained for the power is high enough. With V2G, power supply to the grid would need to be metered separately from the power consumption in the home. The total storage capacity potentially available for V2G is a function of the number of EVs and the capacity of the batteries that fuel them; the capacity of BEVs is typically much higher than that of PHEVs.[7]

[5] The term V2G is sometimes used in a broader sense to describe a system in which EV communicate with the power grid to either delivering electricity into the grid or to throttle back their charging rate.

[6] Spinning reserves refers to generating capacity that is up and running, but not contributing power to the grid, providing back-up in the event of a sudden breakdown or loss of another generator; regulation service is used to continuously fine-tune the balance of voltage and frequency of the grid.

[7] For *ETP-2010*, the IEA assumes that the average storage capacity of BEVs will be 30 kWh and that of PHEVs 8 kWh (IEA, 2010).

Box 1: EV battery charging times

Most EVs on sale today or under development incorporate lithium-ion or other lithium-based variants (differences are mostly related to the cathode material), because of their high power and energy density. The storage capacity of a battery used in an EV ranges from 15 to 30 kWh. There are limits on how quickly such batteries can be recharged. Most batteries are designed not to accept charge at greater than their normal maximum charge rate, because higher rates have an adverse effect on their discharge capacity and lifetime. For this reason, fast charging may not become the preferred charging mode, unless battery technology changes.[8]

Charging time may also be constrained by the capacity of the grid connection, especially in the case of household charging. In many cases, the capacity of domestic power connections is well below the technical capacity at which the battery could be recharged, increasing the effective charging time. A normal household socket has a capacity of 1.8 kW (110 volts at 16A) in North America and 3.7 kW (230 volts at 16A) in Europe, which would allow for slow-charging only. For example, charging a flat 30-kWh battery with a socket capacity of 3.7 kW would take 8 hours. However, it would in principle be possible for special sockets for EVs to be installed to allow for faster charge rates. Long charging times are not necessarily an inconvenience to the motorist if the battery can be recharged overnight at home (which is often preferred to avoid the inconvenience of visiting a public charging station). Charging times at public stations are generally lower as their power ratings are higher.

Advances in battery technology are expected to increase charge rates in the coming years, reducing charging times. Some types of batteries, such as Lithium-titanate, LiFePO4 and certain types of nickel-metal hydride (NiMH) battery, can be charged almost to their full capacity in 10–20 minutes, but this requires a high-capacity power supply. Costs will have to be reduced further for them to become commercially attractive.

While, in principle, V2G is technically possible, it remains uncertain whether it will ever prove to be economically viable on a large scale. Potential barriers include the following:

- *Availability of V2G capacity during peak demand periods:* The total potential capacity for V2G supply for a given number of EVs within a region will vary according to the time of day: available V2G capacity will be lowest during peak driving times (typically early morning and early evening during the working week), when many EVs will be on the road, and highest during the night. In other words, effective V2G capacity is lowest when its value is highest as peak driving times usually coincide with periods of peak load. In addition, many EV owners may be reluctant to sell power to the grid during the day-time for fear that they may need to use their vehicle in the evening.

[8] For example, it is expected that 90% of EVs will be charged using slow charging and 10% using quick charging in France in the coming years; the expected ratio is 80%/20% in Germany (RWTH, 2010).

- *Battery efficiency:* Significant improvements in battery technology will be required for them to be able to provide effective V2G services. An increase in the charge/discharge rate will be required, especially if EV batteries are to be used for load following purposes. In addition, a significant amount of electricity is lost in charging a battery and then discharging it to return the power to the grid. Losses in charging a fairly efficient battery from the grid are typically at least 20%. Returning that energy from the battery to the grid by "inverting" the direct current (DC) power involves losses of about 10%, such that the overall efficiency is at best 72%. The value of V2G supplies, therefore, needs to be at least 40% higher than that of G2V supplies, after allowing for other costs.

- *The cost of cycling power:* Cycling – the process of charging and discharging power from a battery – wears out a battery. Lithium-ion batteries can be cycled fully a specified number of times (usually several thousand) at a given a charging rate.[9] In addition, the depth of cycling (i.e. the share of the total charge that is consumed before recharging) also affects the life of the battery; a 50% discharge wears out a battery more than a 25% discharge carried out twice (with a full recharge in-between). Thus, cycling, either partially or fully carries a cost, which needs to be factored against the value of the V2G power sold to the utility. The frequency of cycling may also increase the risk of damaging the battery and reducing the total number of cycles available. In principle, the cost of battery degradation could be included in the price compensation from the utility to the customer, but it would probably be hard to find a way of determining an appropriate value, especially since the depth and duration of discharge affects the overall cost. And where the battery is owned by the EV car owner, there may be considerable reluctance to make the battery available for V2G for fear that the price received for the power is inadequate to cover the cost associated with reduced battery life. In any case, EV battery warranties may not support V2G.

- *Cost of managing fragmented V2G supply:* While the smart-grid technology already exists to manage V2G supply, it has not been demonstrated yet on a large scale. The sheer number of EV connection points that would need to be managed may make it prohibitively expensive. For example, replacing a relatively small 100 MW peaking gas-turbine unit would require about 30 000 vehicles, each supplying 6.6 kW (assuming an availability of 50%). The complexity would be increased in the case of the vehicles that are parked away from the home, which would require installing a metering and billing system based on recognising the vehicle rather than simply the location of the charging point.

In view of these factors, V2G is likely to develop more slowly than G2V for the time being, unless charging times can be reduced significantly and battery storage capacity increased markedly. For the time being, V2G may prove to be commercially viable only

[9] In practice, the exact number of full cycles is influenced by a number of factors, including ambient temperatures and the way the battery is recharged (the number of cycles is reduced if the battery is regularly fully discharged before charging and increased if charging is typically carried out when the battery is only partially discharged). The number of cycles is also reduced if the battery is left fully discharged for long periods.

during supply emergencies; for example, during a blackout, a motorist could use his EV for V2H or, if the price offered is high enough (or it is a condition of the EV owner's electricity purchase agreement with his electricity supplier), for V2G. The ownership of the vehicle battery will have a significant impact on whether owners opt to make available V2H or V2G supply. The EV owner may be more inclined to supply V2G power if he leases the battery for a fixed monthly fee, as he would be less concerned about how it might affect the life and reliability of the battery than if he owned it outright. In any event, improvements in battery technology are likely to hold the key to the future of V2G.

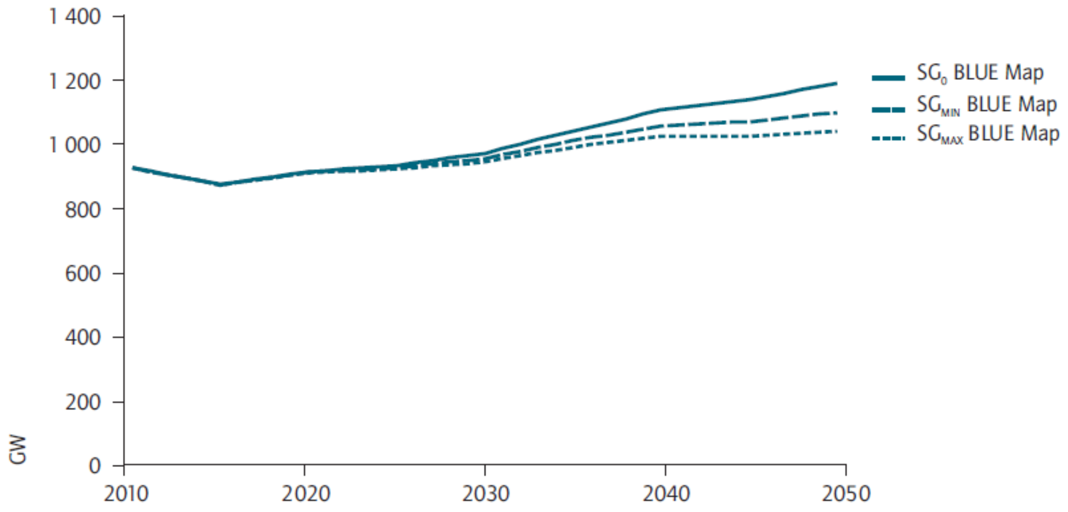
The IEA has attempted to model the extent to which smart-grid management of V2G and G2V could alleviate the need for peak capacity (IEA, 2011c). In OECD North America, the deployment of these technologies alone would constrain the increase in peak load between 2010 and 2050 to 19% with intelligent EV-load scheduling and 12% when combined with widespread use of V2G, compared with 29% in a baseline case in which no smart-grid technologies are deployed (Figure 3). The trend is similar in OECD Europe, OECD Pacific and China, which were also analysed.

How could EVs help manage intermittent renewables-based electricity supply?

The dual functionality of EV batteries – as a type of storage capacity as well as a source of shiftable load –made possible by smart-grid investments could support more widespread deployment of variable renewables-based electricity generating technologies. In principle, the storage capacity of EV batteries could provide back-up capacity to compensate for unpredictable and sudden fluctuations in wind power and solar capacity, by storing excess energy produced during windy and sunny periods (G2V) and in aggregate feeding it back into the grid during peak-load periods or when wind and solar power generation is low for weather-related reasons (V2G). EVs could effectively help to compensate for the variability of wind and solar power, yielding savings on investments in generating capacity, such as gas-fired plant, that would otherwise be required to provide system adequacy. EV battery storage capacity might also increase the value of power fed into the grid during off-peak periods – notably the middle of the day, when solar power generation is highest. Again, major advances in battery technology may be needed for this to happen.

By improving the management of EV-charging load, smart-grid technologies will also facilitate a better temporal match between that load and available renewables-based power supplies (Turton and Moura, 2008). This will be of particular importance where the market penetration of renewables is very high.

Figure 3: **The potential impact of smart grids and EV deployment on peak electricity demand in North America**



Note: SG_0 is a reference scenario that assumes that no smart-grid technologies are deployed; two policy support scenarios have been developed to adopt smart grids: at a minimum level, SG_{MIN}, in which G2V is managed in a limited way and V2G is minimal; and at a maximum level, $SG_{MAX,}$ in which G2V is managed on a widespred basis and V2G is deployed widely.

Source: IEA (2011c).

What will EVs mean for electricity pricing, regulation and utility business models?

Electricity market structures and regulatory frameworks, both at the retail and wholesale levels, will need to adapt to facilitate the demonstration and commercial deployment of smart grids, including the specific technologies needed to make G2V and V2G technically and commercially viable. It is vital that regulatory frameworks to be adapted to allow tariffs to be set to provide incentives for electricity transmission and distribution companies to invest in smart-grid technologies, for system operators to take decisions that ensure economically efficient operation of the entire system and for EV owners to schedule their charging load intelligently and to participate in V2G supply (where economic).

At present, electricity market structure and regulatory systems vary markedly across countries and regions, largely according to the degree to which the industry has been vertically unbundled (involving the separation of the operation or ownership of generation, transmission, distribution and marketing activities) and competition in generation and marketing introduced. In some countries, the traditional industry structure remains in place, whereby a monopoly vertically integrated company (often, publicly owned) is responsible for managing the entire supply chain and selling electricity to final consumers. Electricity tariffs are typically set by the authorities, usually on the basis of actual costs. At the other extreme, in some countries, market reforms have led to full unbundling and fully contestable markets in generation and retail supply, with transmission and distribution activities regulated as natural monopolies. Few countries have reached this stage, with most countries characterised by a limited degree of competition and continuing regulation of wholesale and/or retail tariffs (especially to small consumers).

In principle, investment in smart grids and incentives to encourage both G2V and V2G are compatible with both a vertically integrated monopoly and a competitive market-based industry structure. It can be argued that smart-grid investments are likely to be deployed more rapidly by vertically integrated utilities where the business case can more easily be made and the system-wide costs and benefits of various technologies can be measured and captured more easily, though a market-based structure is arguably likely to be more conducive to innovation and investment in the long term (IEA, 2011a). The key is for the regulatory framework to provide for the creation of incentives for efficient management of EV load and V2G potential through flexibility in pricing and other contractual terms. Regulation will need to evolve in response to changing market conditions, technology and consumer behaviour in order that economically efficient solutions can be put in place.

The tariff structure will strongly influence the timing of charging/discharging; pricing arrangements, supported by smart-grid technologies, must be designed to discourage G2V at peak and encourage V2G to support the grid at peak and other times when ancillary services are required. The most appropriate pricing structures will depend on how consumer behaviour evolves and the type of smart-grid technologies deployed. At a minimum, time-of-use (TOU) tariffs, which vary by intra-day periods, day of the week, and season to reflect the average cost of generating and delivering power during that period, would need to be applied. TOU rates are typically conveyed well in advance and based on static peak and off-peak rates that reflect the average cost of generating and delivering power during those periods. Alternatively, dynamic tariffs can be used to reflect real-time changes in actual operating conditions. Dynamic tariffs, which vary on a day-ahead or real-time basis, encourage customers to adjust their consumption patterns according to the cost of providing electricity at a particular time, which is directly related to load levels, reliability concerns and critical events. Dynamic tariffs can work in various ways (Mark *et al.*, 2011):

- *Real-time prices (RTP),* which fluctuate hourly to mirror the wholesale price of electricity and are typically conveyed on a day-ahead or hour-ahead basis.
- *Critical peak prices (CPP),* which blend TOU and RTP features by maintaining TOU under normal operating conditions and a higher price under predefined conditions such as when system reliability is compromised or fuel prices jump.
- *Peak time rebates,* which reward demand reductions rather than penalise consumption during specific periods.

Dynamic tariffs can be applied where direct load control is used to reduce EV load automatically using remote control and communications technologies, taking account of pre-programmed customers preferences. Passive programmes rely on the end-user to reduce consumption manually based on individual preferences and dynamic rates.

The emergence of EVs as a significant new market segment would probably not, in itself, be a major driver of changes in the structure of the electricity supply industry or fundamental business models. For home charging of EVs, the customer's existing electricity supplier (typically the local distribution company, or independent retailer) would meet the additional EV load. For public charging facilities, which are likely to play an important role in reassuring EV users especially in the early stages of market development (even though home or office charging may ultimately account for the bulk of EV demand), it is less clear what the most appropriate ownership model will be. Several models are possible: such stations may be operated by the local electricity distribution company or by a separate entity (private or public), which may be responsible for simply running the station or for selling the electricity as well (Eurelectric, 2010). One possibility is that existing service stations selling conventional oil-based transport fuels introduce electricity charging facilities alongside their fuel pumps.

Standards

The development of technical standards is an important element of efforts to speed up the deployment of smart-grid technologies. Several international organisations, including the International Electrotechnical Commission, the International Institute of Electrical and Electronics Engineers, the International Organization for Standardization and the International Telecommunications Union Standardization, are already working together to develop international standards upon which national standards can be based (IEA, 2011a).

Research activities and pilot projects on integrating EVs into the electricity system

Many of the smart-grid technologies needed to integrate EVs into a smart grid in an efficient manner are still under development and need to be demonstrated on a large scale. Although continued investment in research and development is needed to improve the efficiency and lower the cost of various technologies, including those related to EV charging infrastructure, it is perhaps even more important to increase investments in demonstration projects to test how the technologies work under real-world operating conditions and to determine how regulatory frameworks and business model structures need to adapt (IEA, 2011a). Ongoing research into EV demand patterns is also required as the EV fleet expands and vehicle and battery technologies evolve. Research, development and demonstration activities need to run well ahead of the expected expansion of EV fleets, as it will take time to build the infrastructure required to handle the increase in load from EVs and integrate potential V2G services. Collaboration between all the different stakeholders, including on standards, can help to speed up the deployment of smart-grid technologies and minimise costs.

A large number of organisations – including utilities, car manufacturers, academic institutions, public research agencies and private research institutes – around the world are conducting or funding research into smart grids. Most of the leading industrialised countries and the major economies have national research and development programmes, or actively support private research efforts. Many of these programmes incorporate various aspects of integrating EVs into smart grids, including G2V- and V2Grelated components. For example the Electric Power Research Institute (EPRI) in the United States launched, in 2008, a seven-year research programme, The EPRI Smart Grid Demonstration Initiative, which includes a sub-programme on EV charging supported by eight major utilities across North America (EPRI, 2011).

Better Place

By far the most advanced pilot projects to demonstrate EVs and related smart-grid technology are those being pursued in several locations around the world by Better Place, a venture-backed American-Israeli company based in Palo Alto, California that aims to develop and sell transportation infrastructure to support EVs.[10] Better Place is building the world's first large-scale public EV-charging network in Israel, plans similar networks in Denmark and Hawaii, and is in talks with at least 25 other countries or states, including Australia and California. The technology has been demonstrated in Yokohama, Tokyo and San Francisco.

The business model adopted by Better Place involves BEV users leasing their batteries and swapping them when they are flat at dedicated battery-swap stations. According to the company, the *QuickDrop* battery switch system will enable Renault Fluence ZE's battery – the first vehicle to be deployed in the Better Place network – to be swapped in approximately three minutes, by means of a fully automated process in which a robotic arm removes the depleted battery and replaces it with a fully charged one. To use the service, the customer has to swipe a membership card, which authenticates the car and subscription via an operations centre, to activate the battery switch. Battery-swap stations will reportedly be able to handle different batteries and EVs, as long as the battery can be removed from under the car.

Israel is the first nation to partner with Better Place to install an all-electric car infrastructure, in collaboration with Renault-Nissan. The company expects that by around 2016, more than 50% of cars sold will be BEVs. Better Place has signed a deal with the Baran Group – a multi-national engineering company – to build 51 battery-swap stations to cover all of Israel, the first of which opened in March 2011. Several thousand public charging points are also being installed to provide an alternative to switching the battery. Better Place has ordered 100 000 Renault Florence ZEs, of which 70 000 have already been sold on – mainly to commercial fleets. Better Place launched its network on 22 January 2012 by giving 100 of the cars to its employees and plans to deliver several thousand to its customers before the end of the year.

In Israel, EV charging infrastructure will be controlled by smart-grid software developed by Intel Atom and Microsoft, which permits monitoring of all the batteries in the network (residing inside vehicles and in switch stations), aggregating data on each battery's state of charge and anticipated energy demand. EV network software can communicate this data to utility partners in real-time, allowing them to optimize the allocation of energy based on available supply and EV drivers' demand.

[10] http://www.betterplace.com/

Other pilot projects

Demonstration and pilot projects currently underway in Europe and the United States include the following:[11]

- *SAVE (Seine Aval Véhicule Électrique), France :* SAVE, a joint initiative by Renault, EDF, the Yvelines General Council, EPAMSA (Contracting Authority for Seine Aval) and the Île-de-France region, is France's biggest trial programme of all-electric mobility, ultimately involving around 100 EVs and around 150 charging spots. Launched in April 2011, the project will run until July 2012. In addition to finding out more about EV driving behaviour, it aims to test the technology and business models of EVs, battery-charging infrastructure and associated services.
- *Alsace Auto 2.0, France:* BPL Global – a smart-grid technology company – recently announced the launch of a demonstration project, in partnership with Freshmile, The Hager Group, FAM Automobiles and the University of Technology in Belfort-Montbeliard, in the Alsace region of France.[12] Based on an EV subscription service, the objective is to optimize the impact of EV charging on the grid by aggregating the load and storage capabilities of the EV batteries and managing their charging patterns.
- *Movele, Spain:* This electric mobility pilot project is part of the government's energy saving and efficiency action plan. It aims to demonstrate the technical and economic feasibility of electric mobility in urban and suburban areas. Some 500 recharging points are being built in three cities – Madrid, Barcelona and Seville – to cater for 2 000 EVs of various types and brands. The government has set aside EUR 8 million in subsidies towards the purchase cost of EVs. The Madrid pilot has a budget of EUR 1.36 million. Most of the 280 recharging points in Madrid will be located in public car parks, with 40 designated for fleet parking areas and 40 for on-street parking. The first charging points were installed in May 2010. Endesa, Iberdrola and Gas Natural Fenosa are partners in the Movele project together with Peugeot, Mitsubishi, Toyota, Piaggio and Bergé. Endesa is also a partner with SGTE and Marubeni to develop fast charging systems.[13]
- *E-mobility, Italy:* This project, which was launched in December 2008 and will run to December 2013, involves the testing of 100 EVs and 400 recharging stations (300 of them public) in Rome, Milan and Pisa. The new charging points will make use of the smart metering and billing systems being developed by ENEl, the state electricity utility.[14]

[11] The European Commission's Joint Research Centre and the European electricity association, Eurelectric, maintain an inventory of smart-grid demonstration projects, which can be accessed at http://www.smartgridsprojects.eu/map.html
[12] http://www.smartgridnews.com/artman/publish/End_Use_Electric_Transportation/EV-project-in-France-uses-subscription-model-to-optimize-impact-on-grid-4449-page2.html
[13] http://www.smartgridopinions.com/article/spain-smart-grid-outlook
[14] http://www.e-mobilityitaly.it

- *Mobile Smart Grid,* Netherlands: The distribution utility, Enexis, has launched a collaborative project, known as Mobile Smart Grid, aimed at establishing a network of public charging sites using smart information and communication technology applications to manage charging intelligently and enable the existing power network to deal with the additional power demand.[15] If applied across the country, the technology is expected to result in net savings of almost €20 billion in investments in generating capacity and network expansion – far exceeding the cost of smart-grid investment.
- *MOBI.E, Portugal:* MOBI.E is an intelligent public charging network for EVs that is being built in Portugal. The network will incorporate smart-grid technologies to schedule charging and, eventually, allow for V2G services. In addition to charging, it provides a number of services including real-time information sent to smart phones to help users optimise their EV use. When completed, the network will comprise 1 300 normal charging stations and 50 fast charging stations on main roads and highways.[16]
- *Pecan Street, United States:* In Austin, Texas, a consortium of General Motors, Sony, Intel, SunEdison, Whirlpool, Best Buy, Freescale and Toshiba recently launched the Pecan Street smart-grid demonstration project to test technologies to optimise household electricity use by integrating EV batteries, solar panels and home energy management systems.[17] The programme is partially funded with a USD 10.5 million grant from the Federal Department of Energy. By summer 2012, General Motors will start making 102 plug-in Chevy Volts available to people living in the test area with a special offer of double the existing USD 7 500 federal rebate to spur purchases.
- *Smart City San Diego, United States:* A consortium formed in January 2011, made up of made up of city of San Diego, GE, UC San Diego, CleanTech San Diego and the utility, San Diego Gas & Electric, has launched a programme to develop EV charging infrastructure, which will involve testing charging, pricing and billing hardware and software for 850 EVs (BEVs and PHEVs).
- *Toronto Hydro Smart Experience, Canada:* At the end of 2010, Toronto Hydro and a subsidiary of Mercedes-Benz Canada launched a four-year EV pilot programme for household customers to study driving patterns, charging habits and the impact of EV use on the electricity grid.
- *Smart Transportation Roadmap, Korea:* This forms part of a national smart-grid programme being led by the Korea Smart Grid Institute. The roadmap aims to build EV charging infrastructure nationwide and establish a V2G system.[18]

Some utilities have been trialling V2G technology. Edison (Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks) is an on-going, partially state-funded research project on the island of Bornholm in Eastern

[15] http://www.mobilesmartgrid.eu
[16] http://www.mobie.pt/en/a-rede-mobi.e
[17] http://www.greentechmedia.com/articles/read/the-mother-of-all-ev-solar-smart-grid-integrations/
[18] http://www.smartgrid.or.kr/10eng4-1.php

Denmark, run by a consortium of IBM, Siemens the hardware and software developer EURISCO, Denmark's largest energy company DONG Energy, the regional energy company Østkraft, the Technical University of Denmark and the Danish Energy Association. The project aims to develop infrastructure that enables EVs to intelligently communicate with the grid to determine when charging, and ultimately discharging, can take place.

Two V2G programmes have been running recently in the United States: Pacific Gas and electricity (PG&E), the Californian utility, converted a number of company-owned Toyota Prius to PHEVs for testing V2G supply at Google's campus, while Xcel Energy, a US electricity and gas utility operating in eight states, tested V2G technology with several converted hybrid city fleet cars in Boulder, Colorado, as part of its SmartGridCity project. Neither project has moved out of the pilot stage, reportedly because of concerns that V2G would prematurely wear out the car battery.[19] In late 2011, the New-Jersey-based utility, NRG Energy, formed a new company with the University of Delaware to run a two-year demonstration project to test V2G technology, targeting initially commercial fleets. The programme will involve seven EVs. The University of Delaware has been conducting research on V2G technology for several years.

In January 2012, the Swedish technology group ABB, Nissan North America, 4R Energy and Sumitomo Corporation of America announced that they were forming a partnership to test and evaluate the all-electric Nissan Leaf battery for residential and commercial use as energy storage systems.[20] In August 2011, Nissan started selling a system in Japan that allows the Leaf to be used as backup electricity-storage system for homes.[21]

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[20] http://www.smartgridnews.com/artman/publish/Technologies_Storage/ABB-Nissan-to-explore-a-second-life-for-EV-batteries-energy-storage-4379.html

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