Technology Roadmap

Updated June 2011

Electric and plug-in hybrid electric vehicles

International Energy Agency

INTERNATIONAL ENERGY AGENCY

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Foreword

Current trends in energy supply and use are unsustainable – economically, environmentally and socially. Without decisive action, energy-related greenhouse gas (GHG) emissions will more than double by 2050 and increased oil demand will heighten concerns over the security of supplies. We can and must change the path that we are now on; low-carbon energy technologies will play a crucial role in the energy revolution it will take to make this change happen. To effectively reduce GHG emissions, energy efficiency, many types of renewable energy, carbon capture and storage (CCS), nuclear power and new transport technologies will all require widespread deployment. Every major country and sector of the economy must be involved and action needs to be taken now, in order to ensure that today's investment decisions do not burden us with sub-optimal technologies in the long-term.

There is a growing awareness of the urgent need to turn political statements and analytical work into concrete action. To address these challenges, the International Energy Agency (IEA), at the request of the G8, is developing a series of roadmaps for some of the most important technologies needed for achieving a global energy-related CO_2 target in 2050 of 50% below current levels. Each roadmap develops a growth path for the covered technologies from today to 2050, and identifies technology, financing, policy and public engagement milestones that need to be achieved to realise the technology's full potential. These roadmaps also include special focus on technology development and diffusion to emerging economies, to help foster the international collaboration that is critical to achieving global GHG emissions reduction.

The *Electric and Plug-in Hybrid Vehicle (EV/PHEV) Roadmap* for the first time identifies a detailed scenario for the evolution of these types of vehicles and their market penetration, from annual production of a few thousand to over 100 million vehicles by 2050. It finds that the next decade is a key "make or break" period for EVs and PHEVs: governments, the automobile industry, electric utilities and other stakeholders must work together to roll out vehicles and infrastructure in a coordinated fashion, and ensure that the rapidly growing consumer market is ready to purchase them. The roadmap concludes with a set of near-term actions that stakeholders will need to take to achieve the roadmap's vision. It is the IEA's hope that this roadmap provides additional focus and urgency to the international discussions about the importance of electric-drive vehicles as a technology solution.

Nobuo Tanaka
Executive Director

This roadmap has been updated through June 2011 to reflect recent developments with electric and plug-in hybrid vehicles. Throughout the publication, various data, tables, figures, and policy descriptions have been updated, in order to keep the roadmap current and relevant. One new figure (Figure 8) and one new table (Table 5B) have also been added. The roadmap was drafted by the IEA Sustainable Energy Policy and Technology Directorate. This paper reflects the views of the International Energy Agency (IEA) Secretariat, but does not necessarily reflect those of individual IEA member countries. For further information, please contact: transportinfo@iea.org

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Acknowledgements

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Key Findings

The mass deployment of electric and plug-in hybrid electric vehicles (EVs and PHEVs) that rely on low greenhouse gas (GHG) emission electricity generation has great potential to significantly reduce the consumption of petroleum and other high CO_2-emitting transportation fuels. The vision of the *Electric and Plug-in Hybrid (EV/PHEV) Vehicles Roadmap is* **to achieve by 2050 the widespread adoption and use of EVs and PHEVs, which together represent more than 50% of annual LDV (light duty vehicle) sales worldwide.** In addition to establishing a vision, this roadmap sets strategic goals to achieve it, and identifies the steps that need to be taken to accomplish these goals. This roadmap also outlines the roles and collaboration opportunities for different stakeholders and shows how government policy can support the overall achievement of the vision.

The strategic goals for attaining the widespread adoption and use of EVs and PHEVs worldwide by 2050 cover the development of the EV/PHEV market worldwide through 2030 and involve targets that align with global targets to stabilise GHG concentrations. These technology-specific goals include the following:

- **Set targets for electric-drive vehicle sales.** To achieve the roadmap's vision, industry and government must work together to attain a combined EV/PHEV sales share of at least 50% of LDV sales worldwide by 2050. By 2020, global sales should achieve at least 5 million EVs and PHEVs (combined) per year. Achieving these milestones will require that national governments lead strategic planning efforts by working with "early adopter" metropolitan areas, targeting fleet markets, and supporting education programmes and demonstration projects via government-industry partnerships. Additionally, EV/PHEV sales and the development of supporting infrastructure should first occur in selected urban areas of regions with available, low GHG emission electricity generation.
- **Develop coordinated strategies to support the market introduction of electric-drive vehicles.** Electric-drive vehicles are unlikely to succeed in the next five to ten years without strong policy support, especially in two areas: making vehicles cost competitive with today's internal combustion engine (ICE) vehicles, and ensuring adequate recharging infrastructure is in place. Governments need to coordinate the expansion of EV and PHEV sales, help provide recharging infrastructure, and, along with electric utilities, ensure adequate electricity supply.
- **Improve industry understanding of consumer needs and behaviours.** Wider use of EVs and PHEVs will require an improved understanding of consumer needs and desires, as well as consumer willingness to change vehicle purchase and travel behaviour. Currently, the profile of car buyers in most countries is not well known; the industry needs to gain a better understanding of "early adopters" and mainstream consumers in order to determine sales potential for vehicles with different characteristics (such as driving range) and at different price levels. This information will also inform the development of appropriate policies to overcome market barriers and increase the demand for electric-drive vehicles. Auto manufacturers regularly collect such information and a willingness to share this can assist policy makers.
- **Develop performance metrics for characterising vehicles.** Industry should develop consistent performance metrics to ensure that EVs and PHEVs are achieving their potential. These include metrics related to vehicle performance (*e.g.*, driving range) and technical characteristics (*e.g.*, battery requirements). EVs and PHEVs are different in important respects; thus, the set of performance metrics for each must be tailored to each technology separately. Additionally, governments should set appropriate metrics for energy use, emissions and safety standards, to address specific issues related to EVs, PHEVs and recharging infrastructure.
- **Foster energy storage RD&D initiatives to reduce costs and address resource-related issues.** Research, development and demonstration (RD&D) to reduce battery costs is critical for market entry and acceptance of EVs. In order to achieve a break-even cost with internal combustion engines (ICEs), battery costs must be reduced from the current estimated range of USD 500 to USD 800 per kilowatt-hour (kWh) of storage at high volume down to USD 300 to USD 400 per kWh by 2020, or sooner. RD&D to improve battery durability and life spans that approach vehicle life spans is also imperative. Over the medium-term, strong RD&D programmes for advanced energy storage concepts should continue, to help bring the next generation of energy storage to market, beyond today's various lithium-ion concepts. Additionally, industry needs to focus RD&D efforts on addressing resource requirement issues and establishing

secure supply chains. In particular, lithium and rare earth metals supply and cost are areas of concern that should be monitored over the near-to mid-term to ensure that supply bottlenecks are avoided. Governments should help offset initial costs for battery manufacturing plant start-up efforts to help establish and grow this important part of the supply chain.

- **Develop and implement recharging infrastructure.** Reliable electricity supply must be available for EV/PHEV recharging and recharging stations must be convenient to access. It is therefore critical to understand the likely impact of a given number of EVs and PHEVs on daily electricity demand, generation and capacity, and to provide a sufficient planning horizon for utilities. While it will be necessary to standardise the vehicle-to-grid interface, it is important to avoid over-regulating in order to allow for innovation. Policies should foster low-cost infrastructure to facilitate PHEV and EV introduction. Other valuable areas to explore include innovative electricity recharging systems (*e.g.*, battery swapping centres), grid powering from batteries, smart metering, and implications for drivers and utilities. To make these efforts most effective, the role of utilities and governments (including policymaking and regulatory agencies) in developing the recharging infrastructure should be clearly established.

The roadmap outlines additional recommendations that must be considered in order to successfully meet the technology milestones and strategic goals. These recommendations include the following:

- **Use a comprehensive mix of policies that provide a clear framework and balance stakeholder interests.** Governments should establish a clear policy framework out to at least 2015 in order to give stakeholders a clear view. To the extent that it is possible, policies should not favour particular technologies, but rather promote good performance. Policy goals should be grounded in societal goals (*e.g.*, energy security, low CO_2 emissions).
- **Engage in international collaboration efforts.** Industry and government can work together on an international level to help lower costs and accelerate EV/PHEV technology diffusion. Key areas for information sharing and collaboration include: research programs; codes and standards; vehicle testing facilities; setting of vehicle sales targets; alignment of infrastructure, charging and vehicle systems as appropriate; and policy development and experience in implementing different approaches. It will be important to track progress (*e.g.*, regional EV/PHEV production, infrastructure investments, etc.) and keep all stakeholders in all regions up to date.
- **Address policy and industry needs at a national level.** Successful implementation of this roadmap requires that governments around the world enact the policies supportive of the necessary technology development and dissemination, possibly via the policy recommendations for governments put forth in this document. Like this roadmap, national roadmaps can be developed that set national targets and help stakeholders better set their own appropriate targets, guide market introduction, understand consumer behaviour, advance vehicle systems, develop energy, expand infrastructure, craft supportive policy and collaborate, where possible. By formulating common goals, targets and plans, countries and the global community can work toward an electric-drive transport future.

The IEA will work in an ongoing fashion with governments and stakeholder organisations to coordinate activities identified in this roadmap and monitor and report on progress toward identified goals and milestones.

Introduction

Roadmap scope

The *Electric and Plug-in Hybrid (EV/PHEV) Vehicles Roadmap* has been developed in collaboration with governments, industry and non-government organisations (NGOs). The approach began with a review and assessment of existing domestic and international collaboration efforts by member governments and industry groups on EV/PHEV technology and deployment. These efforts included all technical and policy-related activities associated with moving this technology from the laboratory to widespread commercial use.

This roadmap covers the two main types of electrification for light-duty vehicles: pure battery-electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs). Non plug-in hybrids and other efficiency improvements in current ICE vehicles will be covered under a separate roadmap.

In the near term, electric-drive vehicles will most likely appear as personal vehicles—sedans, light trucks and electric scooters and bikes. Buses may also be relatively early adopters, especially in applications such as extended electric range hybrids and electric trolleys (*i.e.*, trolleys that can leave the overhead line system and run autonomously on batteries for part of the route). However, for heavier vehicles such as long-haul trucks, planes and ships, for example, the energy density and range limitations of batteries are likely to prevent significant market penetration until additional advances are made in lightweight, energy-dense battery (or other energy storage) technology. As such, this roadmap focuses on passenger vehicles and what stakeholders can do to expedite their electrification.

Roadmap vision

The vision of this roadmap is to achieve the future outlined in the ETP BLUE Map scenario, whereby EVs and PHEVs contribute approximately a 30% reduction in light-duty vehicle CO_2 emissions by 2050 (see box below). More generally, the vision is to achieve the widespread adoption and use of EVs and PHEVs worldwide by 2050 and, if possible, well before, in order to provide significant reductions in GHG emissions and oil use. These reductions must be achieved in an economically sustainable manner, where EVs and PHEVs and their associated infrastructure achieve commercial success and meet the needs of consumers.

The EV/PHEV roadmap vision

To achieve the widespread adoption and use of EVs and PHEVs worldwide by 2050 and, if possible, well before, in order to provide significant reductions in GHG emissions and oil use.

Roadmap purpose and content

The penetration rate of pure battery EVs and PHEVs will be influenced by a range of factors: supplier technologies and vehicle offerings, vehicle characteristics, charging infrastructure, and, as a function of these, consumer demand. Government policies influence all of these factors. The primary role of this roadmap is to help establish a "big picture" vision for the EV/PHEV industry; set approximate, feasible goals and milestones; and identify the steps to achieve them. This roadmap also outlines the role for different stakeholders and describes how they can work together to reach common objectives.

Energy Technology Perspectives 2010 BLUE Map scenario

This roadmap outlines a set of quantitative measures and qualitative actions that define one global pathway for EV/PHEV deployment to 2050. This roadmap starts with the IEA *Energy Technology Perspectives* (ETP) BLUE Map scenario, which describes how energy technologies may be transformed by 2050 to achieve the global goal of reducing annual CO_2 emissions to half that of 2005 levels. The model is a bottom-up MARKAL model that uses cost optimisation to identify least-cost mixes of energy technologies and fuels to meet energy demand, given constraints such as the availability of natural resources. The ETP model is a global fifteen-region model that permits the analysis of fuel and technology choices throughout the energy system. The model's detailed representation of technology options includes about 1 000 individual technologies. The model has been developed over a number of years and has been used in many analyses of the global energy sector. In addition, the ETP model was supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors.

It is important to be clear that some of the rates of change (*e.g.*, annual change in vehicle technology sales) in the BLUE Map scenario are unprecedented historically. To achieve such a scenario, strong policies will be needed from governments around the world. The scenario also assumes robust technological advances (*e.g.*, battery cost reduction) that, if they do not occur, will make achieving the targets even more difficult. On the other hand, some unforeseen advances may assist in achieving the scenario or certain aspects of it.

Electric Vehicles Initiative

The Electric Vehicles Initiative (EVI) was formed at the Clean Energy Ministerial in Washington DC in July 2010. It provides a forum for global cooperation on the development and deployment of electric vehicles (including EVs, PHEVs and fuel-cell vehicles).

Consistent with the IEA roadmap, the initiative seeks to facilitate the global deployment of 20 million EVs, including plug-in hybrid electric vehicles and fuel cell vehicles, by 2020. EVI will enable progress towards this goal by accomplishing the following:

- Encouraging the development of national deployment goals
- Launching pilot cities to promote EV demonstrations in urban areas, and share experiences and lessons learned
- Sharing information on funding levels and research and development programs to ensure that the most crucial global gaps in vehicle technology development are being addressed
- Exchanging information on EV deployment targets, as well as best practices and policies, to enable progress toward those targets
- Engaging private sector stakeholders to focus on the benefits of EV procurement for corporate fleets and public-private investments in technology innovation

As of June 2011, the Inititiave had 14 members, including the IEA and 13 countries: China, Denmark, Finland, France, Germany, India, Japan, Portugal, South Africa, Spain, Sweden, the United States, and the United Kingdom. The Initiative has held two major conferences so far, in Paris in September/October 2010 and in Shanghai, April 2011. More information is available here: www.cleanenergyministerial.org/EVI/index.html.

EV/PHEV Status Today

Overview

Battery-powered EVs use an electric motor for propulsion with batteries for electricity storage. The energy in the batteries provides all motive and auxiliary power onboard the vehicle. Batteries are recharged from grid electricity and brake energy recuperation, and also potentially from non-grid sources, such as photovoltaic panels at recharging centres.

EVs offer the prospect of zero vehicle emissions of GHGs and air pollutants, as well as very low noise. An important advantage of EVs over conventional ICE vehicles is the very high efficiency and relatively low cost of the electric motor. The main drawback is their reliance on batteries that presently have very low energy and power densities compared to liquid fuels. Although there are very few electric automobiles for road use being produced today (probably only a few thousand units per year worldwide), many manufacturers have announced plans to begin serious production within the next two to three years.

Hybrid electric vehicles (HEVs) use both an engine and motor, with sufficient battery capacity (typically 1 kWh to 2 kWh) to both store electricity generated by the engine or by brake energy recuperation. The batteries power the motor when needed, to provide auxiliary motive power to the engine or even allow the engine to be turned off, such as at low speeds. HEV/PHEV/EV vehicles have been sold for the past decade, and as of early 2011 their market penetration is approaching 2% in the United States and 9% in Japan. Over the past decade, over 2.5 million HEV/PHEV/EV vehicles have been sold worldwide.

None of today's hybrid vehicles has sufficient energy storage to warrant recharging from grid electricity, nor does the powertrain architecture allow the vehicles to cover the full performance range by electric driving. However, a new generation of PHEVs is designed to do both, primarily through the addition of significantly more energy storage to the hybrid system. The new PHEVs combine the vehicle efficiency advantages of hybridisation with the opportunity to travel part-time on electricity provided by the grid, rather than just through the vehicle's internal recharging system.

PHEVs are a potentially important technology for reducing the fossil fuel consumption and CO_2 emissions from LDVs because they can run on electricity for a certain distance after each recharge, depending on their battery's energy storage capacity – expected to be typically between 20 km and 80 km. PHEV nomenclature typically reflects this; for example, a "PHEV20" can travel 20 km on electricity after completely recharging while a "PHEV80" can travel 80 km on electricity. PHEVs offer the opportunity to rely more on the electricity sector for energy while retaining the driving range of today's ICE vehicles. Worldwide, a significant share of daily driving probably can be satisfied by PHEVs' all-electric range. For example, in the United Kingdom, 97% of trips are estimated to be less than 80 km. In Europe, 50% of trips are less than 10 km and 80% of trips are less than 25 km. In the United States, about 60% of vehicles are driven less than 50 km daily, and about 85% are driven less than 100 km.[1]

Though a handful of PHEV demonstration projects have been initiated around the world, no manufacturer currently produces PHEVs on a commercial scale; thus, the current market penetration of PHEVs is near zero. But some manufacturers have announced plans to initiate PHEV production over the next few years, and a few models have already appeared as demonstration vehicles in very low-volume production.

1 Estimates taken from comments made at the IEA EV/PHEV Roadmap Workshop.

EV technology

Battery-powered EVs benefit from the removal of the entire ICE system, the drivetrain and fuel tank, giving savings of up to USD 4 000 per vehicle as compared to PHEVs;[2] however, EVs require much greater battery capacity than PHEVs in order to have a minimum acceptable driving range and peak power. EVs provide a substantial energy efficiency advantage, with up to three times the engine and drivetrain efficiency of conventional ICE vehicles and over twice that of HEVs (hybrid electric vehicles). At typical retail electricity prices, the fuel cost per kilometre for EVs can be far below that for ICE vehicles.

Battery cost

Energy storage requirements create major hurdles for the success of EVs. For example, if drivers demand 500 km of range (about the minimum for today's vehicles), even with very efficient vehicles and battery systems that are capable of repeated deep discharges, the battery capacity will need to be at least 75 kWh. At expected near-term, high-volume battery prices of approximately USD 500/kWh, the battery alone would cost USD 35 000 to USD 40 000 per vehicle. Thus, to make EVs affordable in the near-term, most recently announced models have shorter driving ranges (50 km to 200 km) that require significantly lower battery capacities.

This roadmap assumes that EVs have a typical range of 125 to 150 km with 30 kWh of batteries, which reflects an average efficiency of 0.15 kWh/km to 0.2 kWh/km, with some additional reserve battery capacity. This translates to a battery cost for such a vehicle of USD 15 000. There would be a savings of up to USD 4 000 from eliminating the ICE and its transmissions sytem (depending on the engine size and the transmission type), which partially offsets the cost of the battery. However, if the battery needs to be replaced during the life of the vehicle, the lifetime battery costs will be significantly higher.

Recharging infrastructure

Many households around the world already have parking locations with access to electricity plugs. For many others, such access will require new investments and modifications of electrical systems. If charging components such as converters are located on board vehicles, many vehicles should be able to use standard outlets and home electrical systems, at least for slow recharging (such as overnight).

For daytime recharging, public recharging infrastructure (for example at office locations, shopping centres and street parking) will be needed. Currently, public recharging infrastructure for EVs is very limited or non-existent in most cities, though a few cities have already installed significant infrastructure as part of pilot projects and other programmes. To enable and encourage widespread consumer adoption and use of EVs, a system with enough public recharging locations to allow drivers to recharge on a regular basis during the day will be necessary. Such infrastructure will effectively increase the daily driving range of EVs (and PHEVs range on electricity).

Public charging infrastructure could include opportunities for rapid recharging, either via fast recharge systems (with compatible batteries) or via battery swapping stations that allow quick replacement of discharged battery packs with charged ones. While a battery swapping system would require a way to ensure full compatibility and similar performance between all batteries, it also has the potential to help decrease battery ownership costs for EV consumers via innovative business models where swapping charges cover both electricity and battery "capital" costs on an incremental basis. Even for home recharging-oriented systems, the cost of batteries could be bundled into the daily costs of recharging, allowing consumers to pay for batteries over time. Decoupling battery costs from vehicle purchase costs could enable EVs to be sold at more competitive prices – but doing so may be closely linked to the development of infrastructure and the associated business models adopted.[3]

2 Cost estimates for EVs, PHEVs, and batteries in this section are based on analysis presented in IEA (2009).

3 See Berkeley CET study by T. Becker (July 2009).

PHEV technology

PHEVs retain the entire ICE system, but add battery capacity to enable the extended operation of the electric motor, as compared to HEVs. PHEVs have an advantage of being less dependent on recharging infrastructure and possibly less expensive (depending on battery costs and range) than EVs, and therefore might be targeted for higher volumes in early years. While PHEVs need far less battery capacity than pure EVs, they will likely need at least five times the battery capacity of today's HEVs. PHEVs will also have to be capable of repeated deep discharges, unlike today's HEVs, which typically are operated in a near-constant "state-of-charge" mode and are prevented from experiencing deep discharge-recharge cycles. Further, since the battery capacity levels are still far below those of pure EVs, more power-oriented battery configurations are needed to deliver power at levels required for operating the vehicle when the engine is idle or during bursts of acceleration. Additionally, power-oriented batteries can be much more expensive per kWh capacity than energy-oriented batteries. The IEA publication *Transport, Energy and* CO_2*: Moving Toward Sustainability* (2009) estimates battery costs for PHEVs to be 1.3 to 1.5 times higher per kWh than for EVs, although total battery costs for PHEVs will likely be lower than for EVs because the total battery capacity for PHEVs is significantly lower.

Assuming near-term, mass production estimates for lithium-ion batteries close to USD 750/kWh of capacity, medium-range PHEVs (*e.g.*, a driving range of 40 km with 8 kWh of energy storage capacity) would require roughly USD 6 000 to cover battery costs. PHEVs may also need a larger motor, adding to their cost. Without discounting, a vehicle driven 200 000 km over its lifetime might save USD 4 000 in fuel costs; this saving is not enough to offset such a high battery cost. However, if battery costs for PHEVs can be reduced to around USD 500/kWh in the future, the resulting battery cost per medium range vehicle (around USD 4 000 for an 8 kWh system) could be competitive. Cost competitiveness will also depend on future electricity and oil prices, and consumer willingness to pay more (or possibly less) overall for PHEVs than similar ICE vehicles.

Table 1: Key differences between PHEVs and EVs

PHEVs	EVs
Infrastructure: • Home recharging will be a prerequisite for most consumers; public recharge infrastructure may be relatively unimportant, at least to ensure adequate driving range, though some consumers may place a high value on daytime recharge opportunities.	Infrastructure: • Greater need for public infrastructure to increase daily driving range; quick recharge for longer trips and short stops; such infrastructure is likely to be sparse in early years and will need to be carefully coordinated.
Economies of scale: • Mass production levels needed to achieve economies of scale may be lower than those needed for EVs, for example if the same model is already mass-marketed as a non-PHEV hybrid; however, high-volume battery production (across models) will be needed.	Economies of scale • Mass production level of 50 000 to 100 000 vehicles per year, per model will be needed to achieve reasonable scale economies; possibly higher for batteries (though similar batteries will likely serve more than one model).
Vehicle range: • PHEV optimal battery capacity (and range on grid-derived electricity) may vary by market and consumer group. Willingness to pay for additional batteries (and additional range) will be a key determinant.	Vehicle range: • Minimum necessary range may vary by region – possibly significantly lower in Europe and Japan than in North America, given lower average daily driving levels. 100 km (62 miles) to 150 km (93 miles) may be a typical target range in the near term.

PHEVs	EVs
Consumer adoption: • Many consumers may be willing to pay some level of price premium because it is a dual-fuel vehicle. This needs further research. • People interested in PHEVs may focus more on the liquid fuel efficiency (MPG) benefits rather than the overall (liquid fuel plus electricity) energy efficiency. Metrics should encourage looking at both. • Electric range should be set to allow best price that matches the daily travel of an individual or allow individuals to set their own range (*e.g.*, providing variable battery capacity as a purchase option).	Consumer adoption: • Early adopters may be those with specific needs, such as primarily urban driving, or having more than one car, allowing the EV to serve for specific (shorter) trips. More research is needed to better understand driving behaviour and likely EV purchase and use patterns. • With involvement from battery manufacturers and utilities, consumers may have a wider range of financing options for EVs than they have for conventional vehicles (*e.g.*, battery costs could be bundled into monthly electric bill). • EVs will perform differently in different situations (*e.g.*, weather) and locations (*e.g.*, Colorado versus California); therefore utility and operating costs may vary significantly.
Test procedures for PHEVs: • SAE J1711* (Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles) and UNECE R101** (Emissions of carbon dioxide and fuel consumption) adopted test procedures for measuring PHEV fuel economy and electric energy consumption.	Test procedures for EVs: • SAE J1634*** (Electric Vehicle Energy Consumption and Range Test Procedure) and UNECE R101**** (Electric energy consumption) adopted test procedures for measuring EV electric energy consumption.

* http://standards.sae.org/j1711_201006

** www.unece.org/trans/main/wp29/wp29regs/r101r2a2e.pdf

*** www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2010/veh_sys_sim/vss027_duoba_2010_o.pdf

**** www.unece.org/trans/main/wp29/wp29regs/r101r2e.pdf

Batteries: The key technology for EVs and PHEVs

Major technology challenges

Although few serious technical hurdles remain to prevent the market introduction of EVs and PHEVs, battery technology is an integral part of these vehicles that still needs to be significantly improved. Both current and near-term (*i.e.*, lithium-ion (Li-ion) batteries) battery technologies still have a number of issues that need to be addressed in order to improve overall vehicle cost and performance. These issues include:

- Battery storage capacity – Batteries for EVs need to be designed to optimise their energy storage capacity, while batteries for PHEVs typically need to have higher power densities. These differences may lead to the development and use of different battery technologies for EVs and PHEVs. However, economies of scale may favour the development of a single battery type, ultimately resulting in some compromises on other parameters (*e.g.*, lower peak power for PHEVs, with the gap filled by an increased complementary use of an ICE).
- Battery duty (discharge) cycles – Batteries for PHEVs and EVs have different duty cycles. PHEV batteries are subject to deep discharge cycles (in all-electric mode), in addition to frequent shallow cycles for power assist and regenerative braking when the engine is in hybrid mode (similar to conventional ICE-HEVs). Batteries for EVs are more likely to be subjected to repeated deep discharge cycles without as many intermediate or shallow

cycles. In both cases, these demands are very different than those on batteries being used on conventional ICE-HEVs, which experience almost exclusively shallow discharge/recharge cycling. Current battery deep discharge durability will need to be significantly improved to handle the demands of EVs and PHEVs.

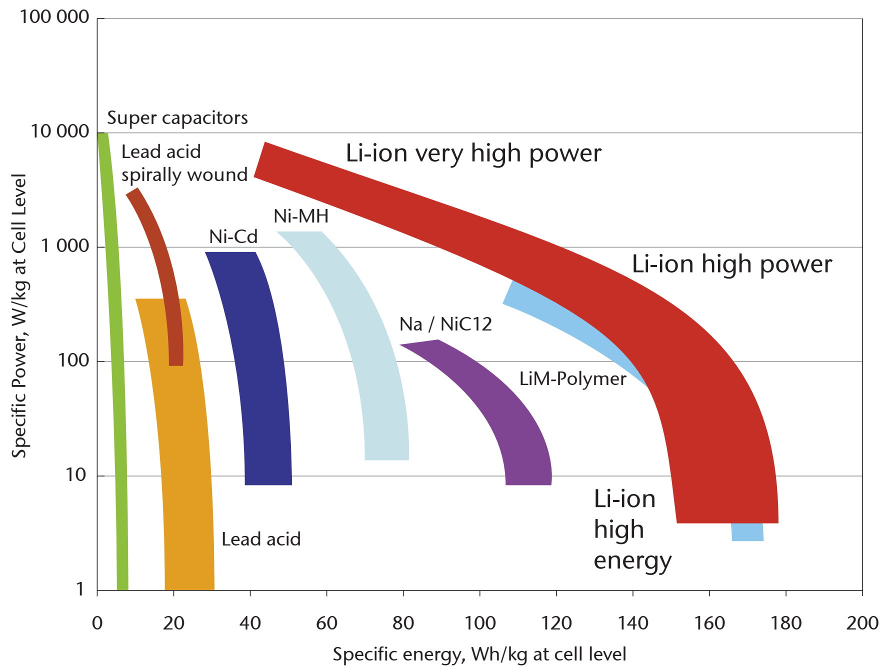
- Durability, life expectancy, and other issues – Batteries must improve in a number of other respects, including durability, life-expectancy, energy density, power density, temperature sensitivity, reductions in recharge time, and reductions in cost. Battery durability and life-expectancy are perhaps the biggest technical hurdles to commercial application in the near-term.

Since the above issues are inter-related, a central challenge is to create batteries that are better in all of the above respects without completely trading off one for another. For example, battery durability must include reliability over a wide range of operating conditions as well as have a consistently long battery life, which may be adversely affected by the number of deep discharge cycles. In addition, all of these remaining technology issues must be addressed in ways that ultimately reduce battery costs, or at the very least, do not add to cost.

Comparison of battery technologies

Figure 1 shows a general comparison of the specific power and energy of a number of battery technologies. Although there is an inverse relationship between specific energy and specific power (*i.e.*, an increase in specific energy correlates with a decrease in specific power), lithium-ion batteries have a clear edge over other electrochemical approaches when optimised for both energy and power density.

Figure 1: Specific energy and specific power of different battery types



Source: Johnson Control – SAFT 2005 and 2007.

***KEY POINT:** Among battery technologies, lithium-ion batteries have a clear edge over other approaches when optimised for both energy and power density.*

Within the lithium-ion family, there is a range of different types and configurations of batteries. These vary in terms of characteristics such as battery life, energy, power, and abuse tolerance.

A summary of five battery chemistries and the strengths and weaknesses along these dimensions is shown in Table 2.

Table 2: Lithium-ion battery characteristics, by chemistry

	Lithium cobalt oxide ($LiCoO_2$)	Nickel, cobalt and aluminum (NCA)	Nickel-manganese-cobalt (NMC)	Lithium polymer ($LiMn_2O_4$)	Lithium iron phosphate ($LiFePO_4$)
Energy Wh/kg or L	Good	Good	Good	Average	Poor
Power	Good	Good	Good	Good	Average (lower V)
Low T	Good	Good	Good	Good	Average
Calendar life	Average	Very Good (if charge at 4.0 V)	Good	Poor	Poor above 30°C
Cycle life	Average	Very good (if charge at 4.0 V)	Good	Average	Average
Safety*	Poor	Poor	Poor	Average	Good
Cost/kWh	Higher	High	High	High	High
Maturity	High	High	High	High	Low

Source: Guibert, Anne de (2009), “Batteries and supercapacitor cells for the fully electric vehicle”, Saft Groupe SA.

The future of battery technology

In the near-term, the existing suite of lithium batteries, and a few other types, will be optimised and used in PHEVs and EVs. In the longer-term (*i.e.*, after 2015), new battery chemistries with significantly higher energy densities need to be developed to enable the development and use of PHEVs and EVs with a longer all-electric range. It is expected that new chemistries can outperform existing chemistries by incorporating high-capacity positive electrode materials, alloy electrodes, and electrolytes that are stable at five volts. The United States Department of Energy is currently supporting exploratory research on several new lithium-ion battery chemistries; programmes investigating lithium alloy/high-voltage positive, lithium-sulphur, and lithium-metal/lithium-ion polymer. Additional support for the development of advanced batteries will likely speed rates of improvement and help accelerate deployment.

Ultimately, new battery chemistries with increased energy density will facilitate important changes in battery design. Increased energy density means energy storage systems will require less active material, fewer cells, and less cell and module hardware. These improvements, in turn, will result in batteries, and by extension EVs/PHEVs, that are lighter, smaller and less expensive.

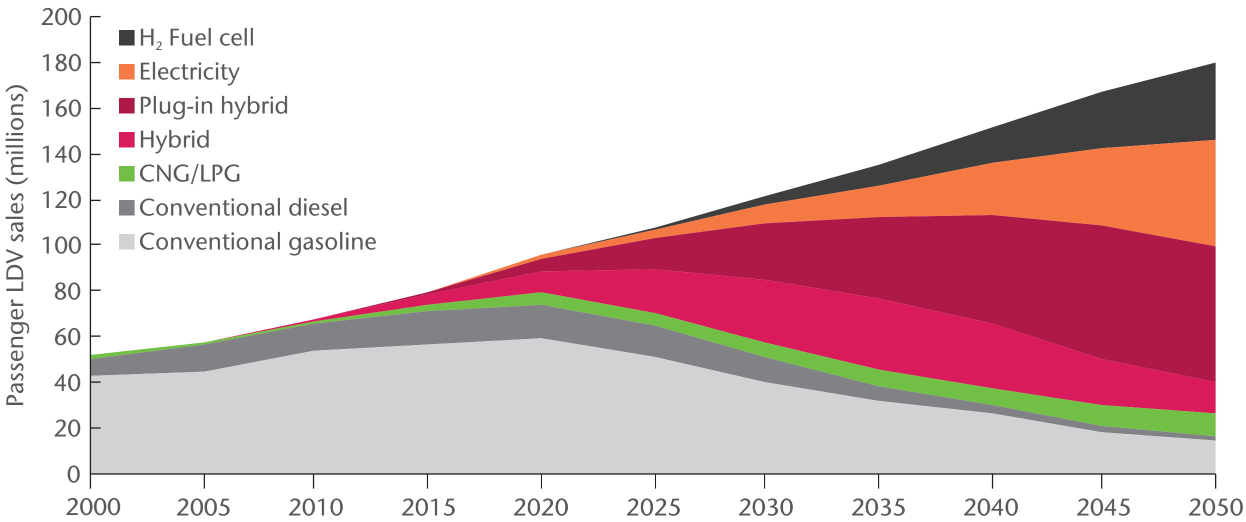
EV/PHEV Deployment: Market Impact Projections and CO_2 Abatement Potential

Overview of BLUE Map scenario targets and assumptions

The *Energy Technology Perspectives (ETP) 2010* BLUE Map scenario sets an overall target of a 50% reduction in global energy-related CO_2 emissions by 2050 compared to 2005 levels. In the BLUE Map scenario, transport contributes to this overall reduction by cutting CO_2 emissions levels in 2050 to 30% below 2005 levels. This reduction is achieved in part by accomplishing an annual sale of approximately 50 million light-duty EVs and 50 million PHEVs per year by 2050, which is more than half of all LDV sales in that year.[4] The EV/PHEV roadmap vision reflects the future EV/PHEV market targets set by the BLUE Map scenario.

Achieving the BLUE Maps requires that EV/PHEV technologies for LDVs evolve rapidly over time, with very aggressive rates of market penetration once deployment begins (see Figure 2). PHEVs and EVs are expected to begin to penetrate the market soon after 2010, with EVs reaching sales of 2.5 million vehicles per year by 2020 and PHEVs reaching sales of nearly 5 million by 2020 (see Figure 3, Figure 5 and Table 3). By 2030, sales of EVs are projected to reach 9 million and PHEVs are projected to reach almost 25 million. After 2040, sales of PHEVs are expected to begin declining as EVs (and fuel cell vehicles) achieve even greater levels of market share. The ultimate target is to achieve 50 million sales of both types of vehicles annually by 2050.

Figure 2: Annual light-duty vehicle sales by technology type, BLUE Map scenario



Source: IEA 2010.

KEY POINT: *This roadmap sees rapid light-duty vehicle technology evolution over time.*

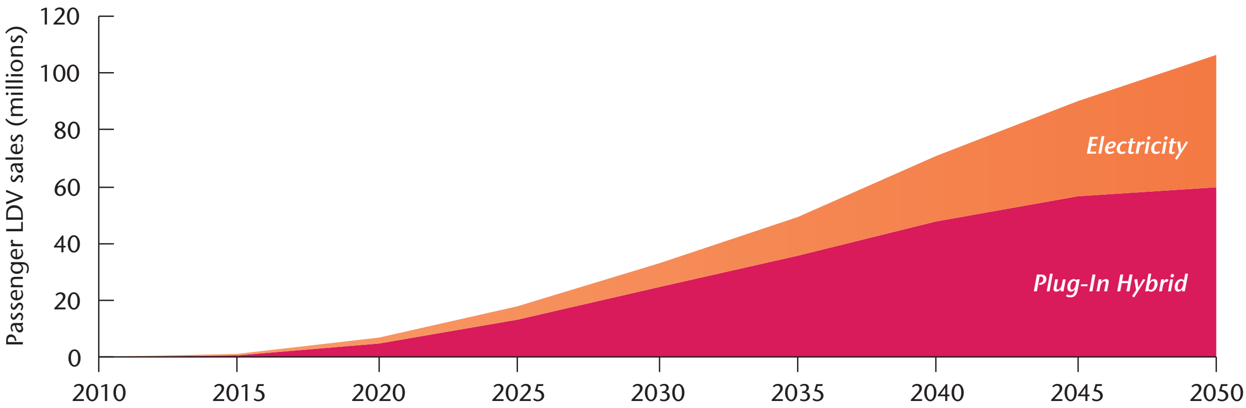
4 A slightly revised BLUE Map scenario for transport has been developed for *Transport, Energy and CO_2: Moving Toward Sustainability* (IEA, 2009). This scenario retains the important role for EVs and PHEVs in meeting 2050 targets that is depicted in ETP 2010, but in addition to focusing on LDVs, also acknowledges that some electrification will likely occur in the bus and medium-duty truck sectors.

Table 3: Global EV and PHEV sales in BLUE Map, 2010–2030 (millions per year)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
PHEV	0.0	0.7	4.9	13.1	24.6	35.6	47.7	56.3	59.7
EV	0.0	0.3	2.0	4.5	8.7	13.9	23.2	33.9	46.6
Total	**0.0**	**1.1**	**6.9**	**17.7**	**33.3**	**49.5**	**70.9**	**90.2**	**106.4**

Source: IEA 2010.

Figure 3: Annual global EV and PHEV sales in BLUE Map scenario



Source: IEA 2010.

***KEY POINT:** EV/PHEV sales must reach substantial levels by 2015 and rise rapidly thereafter.*

It is important to note that for the near- to medium-term (2010 to 2020) data in the figures above, the BLUE Map scenario was revised in 2009 to account both for the economic crisis that began in 2008, which decreased projected car sales, as well as for PHEV/EV product plans announced since the ETP was published, which suggest the possibility of a higher level of EV sales through 2020 (IEA 2009). This is an ambitious but plausible scenario that assumes strong policies and clear policy frameworks, including provision of adequate infrastructure and incentives.

While it may be possible to reach CO_2 targets in other ways, if this target level of EVs and PHEVs relying on low-carbon electricity is not introduced, then other low CO_2-emitting solutions will be needed. Altering the BLUE Map strategy in this way will likely result in an equally or even more difficult challenge.

BLUE Map assumptions

There are two particularly important assumptions in the BLUE Map projections for EV/PHEV sales and resulting CO_2 reduction impacts:

- **Vehicle model types and sales growth rates**
  It is assumed that a steady number of new models will be introduced over the next ten years, with eventual targeted sales for each model of 100 000 units per year. However, it is also expected that this sales rate will take time to achieve. During 2010 to 2015, it is assumed that new EV and PHEV models will be introduced at low production volumes as manufacturers gain experience and test out new designs. Early adopter consumers are expected to play a key role in sales, and sales per model are expected to be fairly low, as most consumers will wait to see how the technologies and market develop. As a result, it is assumed that from 2015 to 2020, the existing number of models and sales per model will increase fairly dramatically as companies move toward full commercialisation.

- **Vehicle efficiencies** – EVs are assumed, on average, to have a range of 150 km (90 miles) and PHEVs' all-electric ranges are assumed to start at 40 km (25 miles), rising on average over time due to improvements in battery technologies and declining costs. Both types of vehicles are assumed to have an average in-use fuel efficiency of about 0.2 kWh/km (0.3 kWh/mile). While vehicles could potentially be made more efficient, which would increase the range for a given battery capacity or decrease battery capacity requirements, the chosen efficiency assumptions reflect a more probable outcome.

Other important assumptions included in these projections involve battery range and cost. The scenario assumes an average 150 km-range EV and 40 km-range PHEV, and simplifies the likely range of variation around these averages.

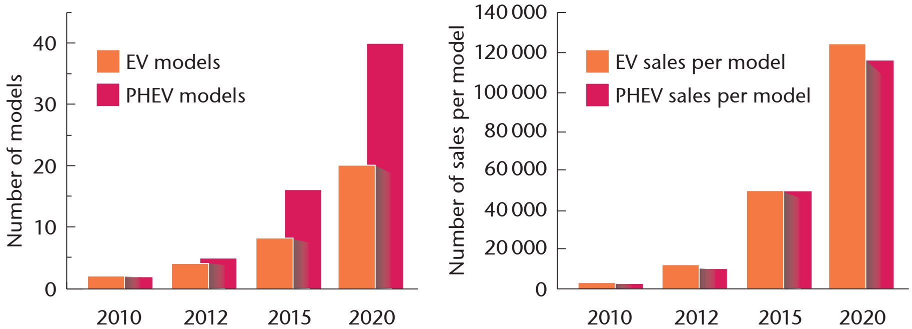
For PHEVs, the percentage of kilometres driven on electricity is assumed to rise over time as recharging times diminish, electric recharging infrastructure spreads, and the number of opportunities to recharge the battery during the day increases[5]. The cost of batteries for EVs is assumed to start at about USD 500 to USD 600/kWh at high volume production (on the order of 100 000 units), and drop to under USD 400/kWh by 2020. Higher per-unit battery costs are assumed for PHEVs, due to higher power requirements. PHEV batteries are assumed to start around USD 750/kWh for high-volume production and then drop to under USD 450 by 2020. These cost reductions depend on cumulative production and learning, so if production levels remain low over the next ten years, it reduces the probability of gaining the target cost reductions and hence reaching BLUE Map deployment targets.

Market growth projections in model types and model sales

In order to achieve the deployment targets in Table 3, a variety of EV and PHEV models with increasing levels of production is needed. Figure 4 demonstrates a possible ramp-up in both the number of models offered and the annual sales per model. This scenario achieves 50 000 units of production per model for both EVs and PHEVs by 2015, and 100 000 by 2020. This rate of increase in production will be extremely challenging over the short time frame considered (about ten years).

However, the number of new models for EVs and PHEVs in Figure 4 easily fits within the total number of new or replacement models expected to be offered by manufacturers around the world over this time span (likely to be hundreds of new models worldwide) and typical vehicle production levels per model. A bigger question is whether consumer demand will be strong enough to support such a rapid increase in EV and PHEV sales.

Figure 4: EV/PHEV number of models offered and sales per model through 2020



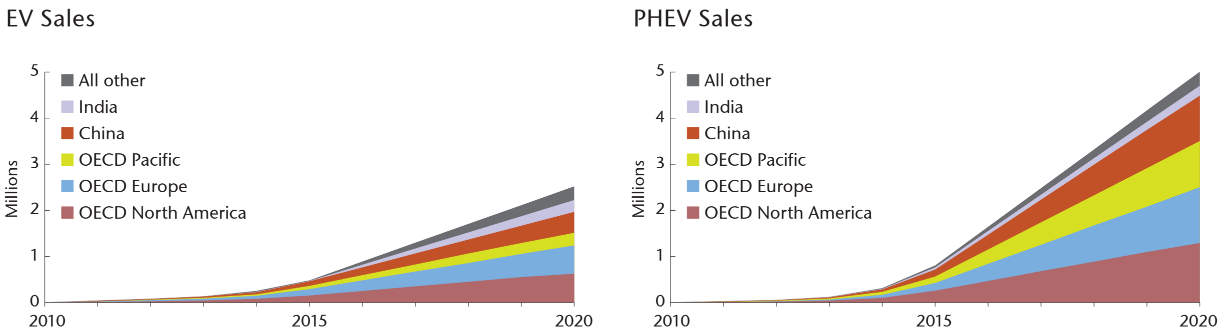
Source: IEA projections.

***KEY POINT:* Sales per model must rise rapidly to reach scale economies, but the number of models introduced must also rise rapidly.**

5 A paper by D. M. Lemoine, D. M. Kammen and A. E. Farrell explores this in depth for California, and looks at a range of factors that might push PHEV use towards more electric or more liquid fuel use. The paper can be found at: www.iop.org/EJ/abstract/1748-9326/3/1/014003

On a regional basis, Figure 5 offers a plausible distribution of EV/PHEV sales by region, consistent with this roadmap's global target of achieving an annual sale of approximately 50 million light-duty EVs and PHEVs by 2050. Regional targets reflect the expected availability of early-adopter consumers and the likelihood that governments will aggressively promote EV/PHEV programmes. EV and PHEV sales by region are also based on assumed leadership by OECD countries, with China following a similar aggressive path. Sales in other regions are assumed to follow with a market share lag of five to ten years.

Figure 5: EV/PHEV total sales by region through 2020



Source: IEA projections

***KEY POINT:** In this roadmap, EV/PHEV sales increases are seen in all major regions.*

Although the ramp-up in EV/PHEV sales is extremely ambitious, a review of recently announced targets by governments around the world suggests that these combined targets add up to a similar ramp-up through 2020 (Table 4 and Figure 6). Additionally, most of these announcements considered were made in the past 12 months, demonstrating the high priority that developing and deploying EV/PHEV technology has on an international level. If all announced targets were achieved, about 1.5 million EVs/PHEVs would be sold by 2015 and about 7 million by 2020. These figures are not far from IEA BLUE Map targets in Figure 5. Thus at this time, the targets set by these countries are sufficient to put them on a BLUE Map trajectory, at least through 2020. The challenge will be achieving these ambitious targets..

A key question is whether manufacturers will be able to deliver the vehicles (and battery manufacturers the batteries) in the quantities and timeframe needed. As mentioned, the IEA scenario has been developed with consideration for providing time for vehicle demonstration and small-scale production so manufacturers can ensure that their models are ready for the mass market. To achieve even the 2050 sales targets, a great deal of planning and co-ordination will be needed over the next five to ten years. Whether the currently announced near-term targets can all be achieved, with ongoing increases thereafter, is a question that deserves careful consideration and suggests the need for increased coordination between countries.

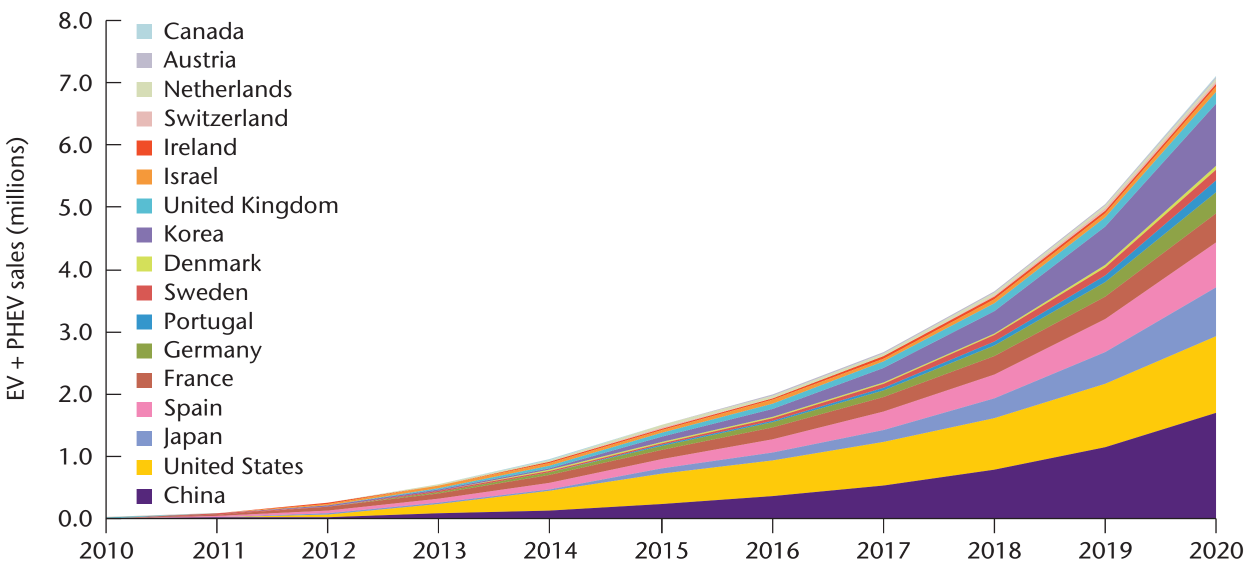
Table 4: Announced national EV and PHEV sales targets

Country	Target	Announcement / Report Date	Source
Australia	2012: first cars on road 2018: mass adoption 2050: up to 65% stock	04 Jun 2009	Project Better Place Energy White Paper (referencing Garnault Report)
Australia	2020: 20% production	10 Jun 2009	Mitsubishi Australia
Canada	2018: 500 000 2020: 18 000 (EV sales in Ontario)	Jun 2008 15 Jul 2009	Government of Canada's Canadian Electric Vehicle Technology Roadmap.
China	5 000 000 stock	March 2011	Electric Vehicle Initiative (EVI)
China	540 000 by 2015	8 Jul 2009	Pike Research
China	2008: 21 000 000 electric bike stock	27 Apr 2009	*The Economist*
China	2030: 20% to 30% market share	Oct 2008	McKinsey & Co.
Denmark	2020: 200 000 2020: 50 000		ENS Denmark EVI
France	2020: 2 000 000	March 2011	EVI
Germany	2020: 1 000 000	March 2011	EVI
Ireland	2020: 350 000	28 Apr 2009	Houses of the Oireachtas
Ireland	2020: 230 000 2030: 40% market share	1 Oct 2009	Electricity Supply Board (ESB)
Israel	2011: 40 000 EVs 2012: 40 000 to 100 000 EVs annually	9 Sep 2008	Project Better Place
Japan	2020: 20% market share (800 000 based on IEA estimate of 4 million)	March 2011	EVI
Netherlands	2015: 20 000 stock 2020: 200 000 stock	May 2011	Dutch Energy Agency
New Zealand	2020: 5% market share 2040: 60% market share	11 Oct 2007	Prime Minister Helen Clark
Spain	2020: 2 500 000	March 2011	EVI

Country	Target	Announcement / Report Date	Source
Sweden	2020: 600 000	March 2011	EVI
Switzerland	2020: 145 000	Jul 2009	Alpiq Consulting
United Kingdom	2020: 1 200 000 stock EVs + 350 000 stock PHEVs 2030: 3 300 000 stock EVs + 7 900 000 stock PHEVs	Oct 2008	Department for Transport, "High Range" scenario
United States	2015: 1 000 000 PHEV stock	Jan 2009	President Barack Obama
Worldwide	2015: 1 700 000	8 Jul 2009	Pike Research
Worldwide	2030: 5% to 10% market share	Oct 2008	McKinsey & Co.
Worldwide	2020: 10% market share	26 Jun 2009	Carlos Ghosn, President, Renault
Europe	2015: 250 000 EVs	4 Jul 2008	Frost & Sullivan
Europe	2015: 480 000 EVs	8 May 2009	Frost & Sullivan
Nordic countries	2020: 1 300 000	May 2009	Nordic Energy Perspectives

Source: Individual Country Roadmaps and Announced Targets, as listed in the references.

Figure 6: National EV/PHEV sales targets if national target year growth rates extend to 2020



Source: IEA data.

***KEY POINT:** National EV/PHEV targets are consistent with IEA BLUE map targets through 2020.*

Electric vehicle markets in emerging economies

China

Twenty million electric vehicles are already on the road in China in the form of two-wheeled electric bikes (e-bikes) and scooters (*The Economist* 2009). The number of e-bikes has grown from near-zero levels ten years ago, thanks to technological improvements and favourable policy. Improvements in e-bike designs and battery technology made them desirable, and the highly modular product architecture of electric two-wheelers (E2Ws) resulted in standardization, competition and acceptable pricing. Policies favour e-bikes by eliminating the competition; gasoline-powered two-wheeled vehicles are banned in several provinces. Shanghai, for example, banned gasoline-powered two-wheeled vehicles from 1996 (Weinert 2009).

Sales volumes for four-wheeled vehicles are much smaller compared to growing LDV sales in China, which have increased by 350% – from 4 million to 13.8 million – between 2005 and 2010. However, more than 90 EV/PHEV models were poposed from Chinese automaker in 2010 and more than 10 models are announced to get into the market in 2011. Production capacity and sales volumes are expected to increase, as evidenced by the arrival of new players in China's electric-drive vehicle industry. The Renault-Nissan Alliance entered a partnership with the Ministry of Industry and Information Technology of China (MIIT) to bring electric vehicles to China in early 2011 (Nissan 2009).

The Chinese government has enacted programmes to promote vehicle electrification on a national scale. In late 2008, Science and Technology Minister Wan Gang initiated an alternative-energy vehicles demonstration project in eleven cities. 500 EVs are expected to be deployed by late 2009 and total deployment should reach 10 000 units by 2010 (Gao 2008). The national government also provides an electric-drive vehicle subsidy of RMB 50 000 (USD 7 300) that was launched in December 2008, but the F3DM is the only vehicle that currently qualifies (Fangfang 2009).

Both industry and government have lofty goals for the near future. The ten largest automotive companies formally targeted an electric-driven future in July 2009, when they established an "EV Industry Alliance" to work together to set EV standards, including standards of key vehicle parts (Chinese Association of Automobile Manufacturers 2009). According to government officials and Chinese auto executives, China is expected to raise its annual production capacity to 500 000 plug-in hybrid or all-electric cars and buses by the end of 2011 (Bradsher 2009), with plans to eventually export EVs. Although China has set a number of electric-drive vehicle goals for the next few years, it has not set any compulsory targets.

India

Electric-drive vehicles have already achieved mass production scale in India in the form of two-wheeled bikes and scooters, and four-wheeled vehicle production capacity could soon reach a similar point as GM India recently partnered with Reva to produce an electric car (Indian Drives 2011). The Indian manufacturer Mahindra Reva is aiming to sell 2 500 cars domestically by 2012, through an expansion of its current 10 dealerships to 60-70 by January, 2012 (Economic Times 2011). Reva, which has already put 4 000 electric cars on the road worldwide, is expanding its current annual production capacity from 6 000 to 30 000, with a new plant to open next year (Pepper 2009). There are currently three electric cars available in the Indian market, the Mahindra Reva and EVs by Tara International and Bavina Cars India Limited (CarDekho 2011).

Despite global recognition of India as a growing centre of EV production, most Indian EV manufacturers contend that low volumes and the present duty structure make manufacturing unviable. Electricity supply and reliability may also concerns. The Society of Manufacturers of Electric Vehicles, incorporated in September 2009, estimates that two-wheeler makers and importers sold about 100 000 units last year – a 10% market share – and the vast majority of the electric scooters sold in India last year were imported (Srivastava 2009). Yo Bykes, a producer of electric bikes and scooters, has an installed capacity of 250 000 units per year (Electrotherm 2009).

So far sales are low for electric cars but this could soon change; Reva sold only 600 in 2008-2009, but is targeting 5 000 cars in 2012. Manufacturers suggest that low sales figures are the product of high costs, attributable to high taxes. Reva estimates that it pays INR 35 000 to 40 000 (USD 720 to USD 825) extra in excise tax (10% of its vehicles' INR 400 000 [USD 8 250] price). Value-added tax (VAT) is another point of contention. Indian electric vehicle manufacturers jointly requested to reduce VAT to 4% from 12.5% in early 2009. Additionally, few public charging stations have been installed so far, perhaps due to the high upfront cost, estimated to be about INR 50 000 (USD 1 030) per station, not including land costs.

The Indian Government is aiming for a full policy in place by 2012 to promote PHEVs/EVs (CarDekho 2011). However the government already provides an incentive for electric vehicles, for up to 20% of the ex-factory price of a given vehicle (CarWale 2011). This incentive is only for the first 140 cars sold in the current fiscal year, but is expected to increase to cover 700 cars in 2012 (EVHub 2011).

States and municipalities have also begun to provide EV incentives. In states such as Madhya Pradesh, Kerala, Gujarat and West Bengal, VAT rates for EVs have been brought down to 4%, resulting in a substantial increase in sales. Some cities refund road tax and registration charges (Centre for Science and Environment 2008).

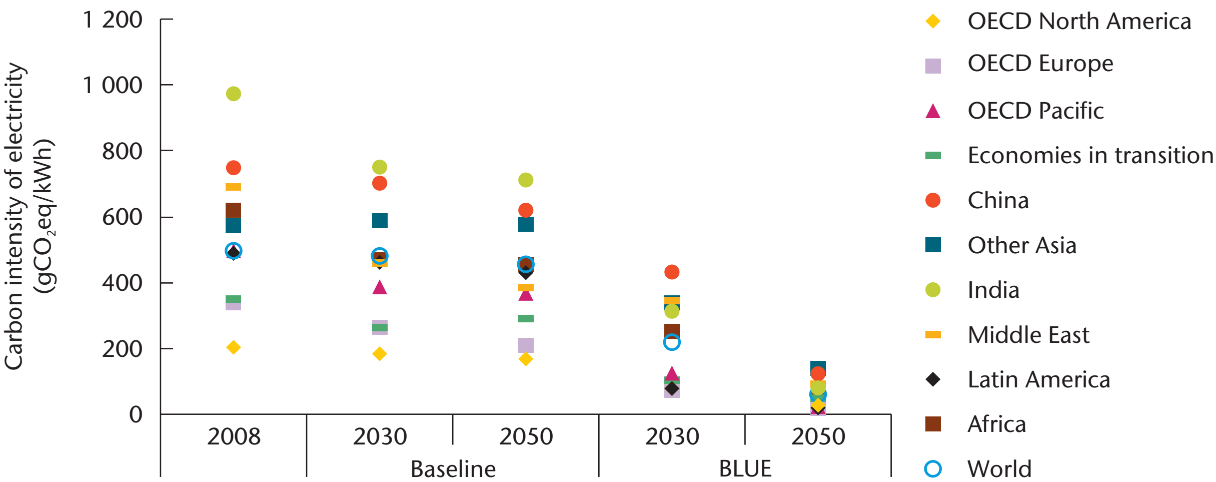
Impacts on fuel use and CO_2 emissions

The estimates of EV and PHEV sales and use in this roadmap are based on achieving the BLUE Map scenario's 2050 CO_2 reduction targets, which can only be met with the enactment of aggressive policies. CO_2 reductions also depend heavily on changes in electricity generation; BLUE Map targets require the nearly full decarbonisation of electricity generation around the world by 2050. As shown in Figure 7, the CO_2 intensity of electricity generation in the BLUE Map scenario drops steadily over time until, by 2050, all regions have nearly decarbonised their electricity. This steady decrease is an important assumption; if the achievement of low CO_2 electricity generation around the world does not occur in the 2030 to 2050 timeframe, the CO_2 benefits of EVs and PHEVs will be much lower. The IEA is also developing roadmaps on achieving BLUE Map electricity CO_2 intensity targets.

For PHEVs, CO_2 reduction levels will depend on the proportion of miles driven using battery electricity from grid recharging in lieu of petroleum consumption from an ICE. While it will take time to understand the relationship between the PHEV driving range as a function of the battery capacity, it is likely even a modest battery power range (*e.g.*,40 km) will enable many drivers to cut petroleum fuel use by 50% or more, as the battery will cover their first 40 km of driving per day. In countries where average driving distances per day are relatively short (*e.g.*, Japan), a higher percentage of driving distance is expected to be covered by battery power than in countries with longer average driving distances (*e.g.*, the United States).

Overall, given the BLUE Map scenario projections for the numbers of EVs and PHEVs deployed in the locations specified, and assuming that these vehicles replace conventional gasoline vehicles (which themselves improve over time in the baseline), about 0.5 billion tonnes of CO_2 are projected to be saved per year worldwide in 2030, and about 2.5 billion tonnes are projected to be saved worldwide in 2050. With a BLUE Map target of close to 500 million EVs on the road in 2050, and a CO_2 reduction of 2 tonnes (on a well-to-wheels basis) per vehicle per year compared to displaced gasoline ICE vehicles, EVs would provide about 1 billion tonnes of CO_2 reduction in that year. Approximately 800 million PHEVs would provide an additional 1.5 billion tonnes reduction.

Figure 7: CO_2 intensity of electricity generation by region, year and scenario



Source: IEA ETP 2010, IEA 2010.

***KEY POINT:** The BLUE Map scenario targets strong GHG intensity reductions for electricity generation by 2030 and 2050.*

Vehicle and battery manufacturer partnerships and production targets

Given the importance of batteries for EVs and PHEVs, most major vehicle manufacturers have announced partnerships with battery companies. While these partnerships help position each manufacturer and increase the reliability of battery supplies in the future, they could also impact the rate of innovation in the market. A list of vehicle/battery company liaisons announced in the media as of July 2009 is provided in Table 5A. BYD Auto, which is working on both vehicles and batteries internally, is a notable exception to the pairing trend, as they were originally a battery manufacturer, but have since expanded into automobile manufacturing.

In addition, several auto manufactures have announced (or reported) their EV and/or PHEV production plans, which as of early 2011 totals 0.9 million units by 2015 and about 1.4 million units per year by 2020 (Table 5A). However, it is still far less than 7 million national sales target projection (Figure 8) and it will be important to closely track manufacturer plans for vehicle production against the production targets announced by governments and those contained in this roadmap. Specifications of several type of EVs/PHEVs sold or expected to be sold in 2011 are shown in Table 5B.

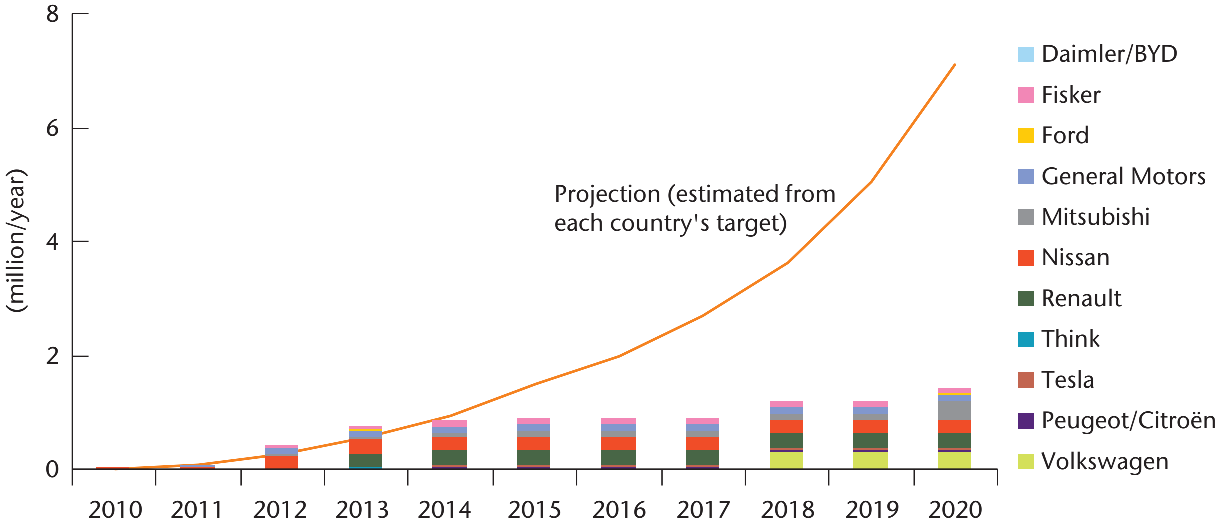
Table 5A: Manufacturers of EVs/PHEVs and partnering battery manufacturers, with production targets where available

Car manufacturer	Announced/reported production/sales targets	Battery manufactures (may contains development partners and former partnership)
Daimler	10 000 in 2013 (5)	Johnson Controls-Saft (JCS), Sanyo, SK Innovation, Li-Tec Battery
Fisker	50 000 in 2013 (1) 85 000 in 2014	A123 Systems
Ford	18 000 in 2012 21 000 in 2013	LGChem, JCS, MAGNA E-Car Systems, Toshiba, Sanyo
General Motors	120 000 in 2012 (1)	LG Chem, JCS
Mitsubishi	40 000 in 2012 (2) 5% in 2015 20% in 2020	GS Yuasa Corporation, Lithium Energy Japan, Toshiba
Nissan	50 000 in 2010 in Japan 150 000 in 2012 in United States 50 000 in 2013 in United Kingdom	AESC
PSA	40 000 in 2014 (4)	Lithium Energy Japan, GS Yuasa, JCS
Renault	250 000 in 2013	AESC, LG Chem, SB Limotive (SBL)
Tesla	10 000 in 2013 (1) 20 000 in 2014	Panasonic Energy Company
Th!nk	10 000 in 2013 (1) 20 000 in 2014	A123 Systems, Enerdel, FZ Sonick
Volkswagen	3% in 2018 (3)	Sanyo, Toshiba, SBL,Varta Microbattery
BMW		SBL, E-One Moli Energy
BYD Auto		BYD group
Chrysler-Fiat		SBL, LG Chem
Coda Automotive		Coda Battery Systems
Hyundai		LG Chem, SBL, HL Green Power, SK Innovation
SAIC		JCS
Magna		GS Yuasa Corporation
Subaru		AESC
Suzuki		Sanyo
Tata		Electrovaya,EIG
Toyota		Primearth EV Energy, Sanyo
Volvo		EnerDel, LG Chem

(1) www.energy.gov/media/1_Million_Electric_Vehicle_Report_Final.pdf.
(2)www.mitsubishi-motors.com/publish/pressrelease_en/corporate/2011/news/detail0771.html.
(3) www.treehugger.com/files/2010/03/volkswagen-plans-sell-300000-electric-cars-year-2018.php.
(4) www.ft.com/cms/s/0/3a4324f4-4353-11e0-aef2-00144feabdc0.html#axzz1FLb87CdI.
(5) www.bloomberg.com/apps/news?pid=20601100&sid=aT_u.QS7Y4tg.
(6) http://gm-volt.com/2011/04/15/lg-chem-opens-ochong-battery-plant-expects-major-market-share/.

Sources: Various, updated by IEA May 2010.

Figure 8: Goverment target and EV/PHEV production/sales reported by OEM*



** Production/sale capacity levels shown here are assumed to remain constant after year of construction. In practice, capacities may rise after plants enter service.*

Elements of an EV business model

There are a number of obstacles that must be overcome for EVs to succeed commercially. Successful business models will need to be developed to overcome the following obstacles:

Battery cost – the up-front cost of batteries, that may be USD 10 000 per vehicle or more in the near-term, will be difficult to overcome unless these costs to the consumer can be spread over several years. An advantage of amortizing battery costs is that these costs could, in theory, be bundled in with monthly payments for electricity, taking advantage of the relatively low cost of electricity compared to gasoline fuel. Thus the fuel savings of EVs can be used to offset the battery costs in a manner that may be much more acceptable to consumers than facing high up-front vehicle costs.

Vehicle range – a car with a limited driving range (*e.g.*, 150 km) will need to have plenty of opportunities to recharge. Recharge stations will be needed at high-traffic locations such as train stations, shopping malls, and public parking areas. Rapid recharge or battery swapping systems may also be important, particularly on highways and along other routes where a quick recharge will be needed.

Driver information – another key feature for any public infrastructure will be for drivers to easily locate stations. With the widespread use of GPS technology, this challenge is being addressed. EVs can be sold with GPS systems specially designed to show available recharging centres – even the available number of parking spaces at particular locations. This will reduce much of the uncertainty and stress that limited refuelling infrastructure can have on individuals.

Critical mass and economies of scale – strategic planning, which concentrates vehicles and infrastructure in certain areas can help gain operating densities and economies of scale, rather than attempt too wide a range of coverage at the start. Initially targeting fewer cities with more infrastructure and vehicles may be a more successful approach. Scale economies must also be sought in terms of total vehicle and battery production – once a plan is developed, it should be executed relatively quickly. The faster that manufacturers can get to 50 000 or even 100 000 units of production (*e.g.*, for a particular model of EV), the faster costs will come down. The same holds true for batteries (which can gain in scale from using identical or similar battery systems in multiple vehicle models) and for infrastructure (*e.g.*, common recharging architectures across cities will help lead to scale economies and more rapid cost reductions).

Table 5B: Specifications of several plug in vehicles sold or expected to be sold in 2011

OEM	Country	Model name	Type	Battery Capacity (kWh)	Mileage	Size (mm) L x W x H			Weight (kg)	Start of sales	Price
Nissan	Japan	Leaf	EV	24	200km (JC08) 160km (LA4)	4 445	1 770	1 545	1 520	2010(JPN,US) 2011(EU)	3.76 mJPY (incl.tax) 32.8k USD
Mitsubishi	Japan	iMiEV	EV	16	160km (10-15)	3 395 3 680 (US)	1475 1585 (US)	1610 1615 (US)	1 100 1 172 (US)	2009 (JPN) 2011(EU,US)	3.98mJPY 30k USD
BYD	China	E6	EV	60	300 to 400km	4 554	1 822	1 630	2 020	2011	35k USD
GM	US	Volt	PHEV	16	40 to 80km (EV mode)	4 500	1 788	1 438	1 715	2010 (US) 2011	41k USD
Tesla	United States	Roadster	EV	56	394km (LA4)	3 940	1 852	1 126	1 236	2008	128.5k USD, 112k Euro
Mahindra	India	NXG	EV	14	ca. 200km	2 620	1 640	1 550	825	2011(EU)	23k Euro (excl.bat)

Technology Development: Strategic Goals, Actions and Milestones

The discussions during the IEA EV/PHEV Roadmap Workshop and the recommendations that have come out of that workshop have helped to define the following strategic goals for the development and commercialisation of EVs and PHEVs. These goals cover the development of the EV/PHEV market worldwide through 2020, and include recommended milestones and actions that align with the long-term 2050 targets of the IEA ETP BLUE Map scenario.

This roadmap identifies six strategic goals for accelerating EV/PHEV development and commercialisation:

1. **Set targets for electric-drive vehicle sales.**
2. **Develop coordinated strategies to support the market introduction of electric-drive vehicles.**
3. **Improve industry understanding of consumer needs and behaviours.**
4. **Develop key performance metrics for characterising vehicles.**
5. **Foster energy storage RD&D initiatives to reduce costs and address resource-related issues.**
6. **Develop and implement recharging infrastructure.**

1. Set targets for electric-drive vehicle sales

To meet the aggressive vision of 50 million light-duty EVs and PHEVs sold annually by 2050, countries need to achieve as many EV and PHEV sales as possible by 2015 and 2020. Increasing the number of vehicle models, reasonably heightening production rates by model, and ensuring the availability of an adequate recharging infrastructure that is designed to work well with the types of vehicles being introduced are all issues that must be addressed. Other considerations include costs and the need to avoid placing EVs in areas with unreliable or high-CO_2 electricity generation. Vehicle manufacturers, battery manufacturers, electric utilities and other stakeholders will need to work together to make this happen and governments will need to lead this coordination effort and provide a supportive policy framework.

This roadmap recommends the following milestones and actions:

- By 2050, achieve a combined EV/PHEV sales share of at least 50% of LDV sales worldwide.
- By 2020, achieve at least 5 million EV and PHEV combined global sales per year, or more if possible (the BLUE Map suggests 7 million in 2020).[6]
- By 2020, roll out the first EV/PHEV sales in regions and urban areas that have the best chance to deliver adequate infrastructure and low-GHG electricity, have adequate government support and planning, and potentially are home to sufficient early adopter target customers to reach target levels.

2. Develop coordinated strategies to support the market introduction of electric-drive vehicles

Electric-drive vehicles are unlikely to succeed in the next five to ten years without strong policy support, particularly in two areas: making vehicles cost-competitive with ICEs and ensuring adequate recharging infrastructure is in place. Each country interested in successfully introducing EVs and PHEVs to the market will need to first identify and develop adequate policies to achieve these conditions.

Governments need to coordinate the launch and ramp-up of EV and PHEV sales, the development of the recharging infrastructure and transition of electricity supply to carbon-free generation. This need for coordination is a primary reason for developing a detailed roadmap – to ensure everyone sees and conducts the roll-out plans in a similar way. National and local governments, the auto industry,

6 Targets are subject to constraints in terms of rates of investment, manufacturing capability, recharging infrastructure and consumer demand.

electric utilities, relevant NGOs and academic researchers need to continually communicate, work together and coordinate their efforts. Additionally, the development of national roadmaps can help individual countries recognise their internal constraints and establish national goals to clearly lay out the roles for automobile manufacturers, suppliers, researchers, and the government itself in facilitating a transition to electric mobility as quickly and smoothly as possible.

The successful market introduction of electric-drive vehicles also requires the identification of a "break-even" metric – the point at which EVs pay for themselves (or become sufficiently attractive to consumers relative to the replaced ICE vehicle). It is at this point that the achievement of target sales levels becomes possible. The importance of non-cost attributes such as range, refuelling/recharge time, environmental impact, and vehicle-to-grid (V2G) opportunities should be included in this metric. Variation across different consumer groups should also be explored. Once this metric has been identified, incentives will likely be needed to reach break-even points for most consumers in the near-term. The extent of incentives will depend in part on how much (if any) premium consumers are willing to pay for electric-drive vehicles.

When EVs and PHEVs gain a sufficient long-term market share, increased taxation on electricity may be needed to maintain state revenues currently lifted by taxation on fossil fuels. This may be partly counterbalanced by cost reductions resulting from technological advances and learning. Countries may also shift toward different taxation systems, possibly based on factors such as GHG emissions, infrastructure use, pollutant emissions, noise, and/or the occupation of public land. Additional analysis should be carried out in order to figure out how electric-drive vehicles would perform in different taxation scenarios.

This roadmap recommends that, as soon as possible, the following milestones and actions should be achieved:

- Improve national and regional market potential estimates.
- Ensure that national targets and auto company production planning are coordinated.
- Identify a "break-even" metric and implement policies to make vehicles cost-competitive with ICEs.
- Identify and implement policies to ensure that adequate recharging infrastructure is in place at the time of, or slightly before, vehicles that will rely on the infrastructure enter service.
- Coordinate the launch and ramp-up of EV and PHEV sales, the provision of recharging infrastructure, and the changes in electricity supply. Coordination should include national and local governments, auto industry, electric utilities, relevant NGOs and academic researchers, and – very importantly – consumers.
- Evaluate the near- and expected medium-term cost competitiveness of EV/PHEVs in the context of potential evolution of required support, and develop comprehensive policies to ensure a smooth transition phase is undertaken with a view toward achieving commercial viability of EVs and PHEVs as soon as possible.

3. Improve industry understanding of consumer needs and behaviours

Consumer acceptance of EVs and PHEVs is a key factor determining the ultimate success or failure of EV technologies. Estimation methods that help predict battery cost and ownership and potential EV/PHEV sales depend on a thorough understanding of consumer needs, desires and choice making behaviours with respect to EVs, PHEVs and competing vehicle types. Consumer willingness to change travel behaviour and accept different types of vehicles and, perhaps, driving patterns is an important area of uncertainty. Identification of potential early adopters and mainstream consumers requires good information on consumers broken out by demographics and other characteristics that can be related to the sizes of different population subgroups. Such information (at least on a public basis) is lacking or inadequate in most potential EV markets.

To effectively understand consumer needs and behaviours, industry must answer questions such as the following:

- How do demographics of car buyers vary in different markets (*e.g.*, older customers in developed countries versus younger customers in developing countries)?
- What are the typical characteristics of those who buy car types that EVs may compete with (such as smaller urban vehicles)?
- How important is the multi-car family (*e.g.*, electric-drive vehicles as second cars)? How many multi-car families are there in different countries?
- Will electric-drive vehicles' appeal to low- to medium-mileage drivers? (Range limits may make it difficult to drive EVs and PHEVs far enough to pay for vehicle costs through fuel savings.)
- What is the distribution of driving (*e.g.*, in km per day) for different types of consumers, in different locations? How does this distribution impact electricity demand, and oil or CO_2 reductions?
- How many and what type of consumers may be willing to pay a premium for EVs or PHEVs? How many may be willing to purchase such vehicles with various levels of incentives?
- What role might businesses play in becoming early adopters? Are there large fleets that may be interested in making bulk purchases?

This roadmap recommends the following actions be undertaken at a national and municipal level as soon as possible:

- Collect better data, especially on markets and consumer behaviour; utilise metrics for gauging consumer aspects and market potential (see Table 6).
- Actively include consumers in the planning process of government and industry and ensure that consumers' needs and desires are met.
- Develop good outreach and information programmes to help consumers understand the benefits of EVs and PHEVs, and increase their interest in adopting them.
- Get good feedback systems in place to allow early adopters to provide feedback that helps planners optimize infrastructure and other EV/PHEV-related systems.

Table 6: Metrics for gauging consumer aspects and market potential

Metric	Possible targets and notes
Consumer willingness to pay for EVs and PHEVs	Net higher cost for electric-drive vehicles (first cost and/or total life-cycle cost) that consumers are willing to pay compared to competing ICE vehicles; willingness to pay a premium likely to be more for early adopters than mainstream consumers. Fleet and private customer needs to be treated separately.
Driving behaviour – daily driving distance	Distribution of driving distance per day (important both for setting PHEV optimal range and for determining maximum needed range for electric-drive vehicles).
Driving behaviour – actual in-use vehicle efficiency and range	Vehicle energy use per km based on actual in-use data, with indications of variation based on driving style and driving conditions.
Recharging behaviour	When and for how long will consumers recharge on average? Metrics on recharging distributions (load profiles) by 24-hour period, day of week, for both PHEV and EV customers.

4. Develop performance metrics for characterising vehicles

EVs and PHEVs will need to meet various performance-related criteria in order to maximise their market potential. Identifying specific performance metrics can help in this regard. Vehicle attributes that likely will be important for the success of EVs and PHEVs include vehicle first cost, efficiency and annual fuel cost, maintenance cost, electric driving range, speed of recharging, performance (such as acceleration), reliability, safety, and CO_2 and pollutant emissions. EVs and PHEVs should, to the extent possible, achieve levels and values for these attributes that are comparable to similar sized and purposed ICE vehicles. However, some attributes will inevitably be different, such as driving range and emissions. Some metrics will matter more for one than the other – for example, the percentage of driving on electricity versus liquid fuel and the fuel efficiency on each fuel are important metrics for PHEVs but irrelevant for EVs.

Metrics also need to be developed to ensure that EVs and PHEVs meet applicable emissions and safety standards. Certain safety standards specific to EVs and the way they are used should be factored into these metrics to ensure their use is not unnecessarily impeded. Driving cycles specific to EVs/PHEVs should be studied and test procedures developed as necessary, since EV/PHEV driving patterns may be different than for today's ICE vehicles. Such test procedure development is underway at both the Society for Automotive Engineers (SAE) and the UN Economic Commission for Europe (UN-ECE). Standard metrics for safety aspects such as recharging security are also needed (especially high voltage).

This roadmap recommends the following actions be completed in the near-term:

- Establish common, consistent metrics for characterizing EVs and PHEVs around the world.
- Using these metrics, consider and set needs and desirable levels of attributes for EVs and PHEVs separately.
- Take into account interactions and tradeoffs among vehicle attributes when identifying targets.
- Utilise and, as needed, refine the metrics recommended in this roadmap (see Table 7).

Table 7: Metrics for characterising EV/PHEVs

Metric	Possible performance metric and notes
Driving range on electricity	More market research is needed to better inform targets and limits; the 100 km range is considered a possible minimum for mainstream EVs; anywhere from 20 km to 80 km may be appropriate for PHEVs (possibly scalable – customers choose their range).
Performance (*e.g.*, acceleration)	Should match or exceed that for similar ICE vehicles.
Safety (passive and crash)	Should match or exceed that for similar ICE vehicles, though some differentiated standards may be needed (*e.g.*, for small EVs).
Reliability (*e.g.*, average maintenance cost and service requirements per year)	Should match or exceed that for similar ICE vehicles.
Efficiency (kWh/km; L/100 km – equivalent)	Actual in-use efficiency measurement will also be important. EV/ PHEV performance in heavy traffic, in cold/hot weather, and in hilly terrain must be understood and communicated to potential consumers to avoid unwanted surprises.

Table 7: Metrics for characterising EV/PHEVs (continued)

Metric	Possible performance metric and notes
Fuel cost per km	Depends on efficiency and fuel prices; EVs will need a significant fuel cost advantage to make up for higher first cost. Possible near-term scenario: EV (0.2 kWh/km at USD 0.15/kWh translate to a fuel cost per km of USD 0.03/km); comparable gasoline ICE (8 L/100 km at USD 0.75/L translates to a cost of USD 0.06/km); and comparable diesel ICE (7.2 L/100 km at USD 0.75/L translates to a cost of USD 0.05/km). Higher oil prices/taxes would increase the difference in cost per km while improved ICE efficiency (*e.g.*, hybrids) and higher taxes on electricity would reduce the cost per km differential.
Average travel per vehicle	May be lower for EVs than "comparable" ICE vehicles due to range limitations, which would reduce their impacts on energy use and their cost-effectiveness. But empirical data is needed to better understand this issue.
Vehicle resale value	Affects pricing strategies and willingness of people to purchase EVs (market size).

5. Foster energy storage RD&D initiatives to reduce costs and address resource-related issues

Battery cost reduction is critical to achieve EV break-even cost with ICEs. Estimated achievable lithium-ion battery costs under mass production in the near-term (2012 to 2015) range from USD 300 to USD 600 per kWh of storage capacity (possibly higher for PHEVs if they will require power-oriented batteries). For EVs with 20 kWh of capacity (the minimum requirement for a pure EV), this yields a battery cost per vehicle of USD 6 000 to USD 12 000. Moving toward the lower end of this range as quickly as possible will greatly help to achieve commercialisation. There is hope that this can occur via large battery production scales and learning, but it is uncertain. In the next two to three years, key battery technology performance should be verified via in-use testing, after which companies may be able to quickly go to mass production to achieve cost reductions. Model years 2010 to 2012 appear key for proof of concept and moving toward mass production of batteries. Appropriate performance metrics should be established, especially for battery energy/power density and specific energy targets, to ensure adequate battery and EV/PHEV performance.

Resource requirements for electric vehicles and batteries also need to be understood, and secure supply chains established. Today there are very few world-class battery manufacturers; most of them have strong strategic partnerships with original equipment manufacturers (OEMs). Governments should strongly encourage and support promising start-up battery manufacturers, particularly those with innovative approaches. This support includes ensuring that investment cost and risk are not obstacles to construction of battery manufacturing plants and capacity expansion. The supply of batteries (and materials to make them) needs to be sufficient to align with incremental EV/PHEV production and capacity expansion. Access to necessary inputs must be ensured for all manufacturers. Lithium and possibly rare earth metal supply/cost are also medium-term areas of concern and should be monitored, to ensure that supply bottlenecks are avoided. Conducting effective RD&D to foster greater use of advanced (*e.g.*, light-weight) materials and innovative designs, can also help reduce the need for resources in building electric and other types of vehicles. Supply chains of materials required for vehicle manufacture should also be optimised. For example current battery supply chains and battery shipping can be very expensive (*e.g.*, due to high weight and relatively low volumes). Production locations close to assembly locations may help cut such costs.

Batteries could be useful after their retirement from service in vehicles, mainly as stationary energy devices. New business models and battery designs may help decrease total cost, by extending battery life via multi-stage battery use. However, secondary uses should not detract from the first and primary purpose of the battery – energy storage on-board vehicles. Batteries should have minimal life-cycle environmental impacts, including production and disposal. Maximising recycling is a key way to ensure minimal impacts and resource recovery; systems and rules dictating its use and implementation need to be established early on.

To ensure the continued improvement of electric-drive vehicle batteries and battery systems, strong RD&D programmes for advanced energy storage concepts should continue. Flywheels and ultracapacitors continue to improve and should not be ignored; a "next-generation" of energy storage beyond current Li-ion battery concepts must be sought.

This roadmap recommends the following milestones and actions by 2015 or sooner:

- Reduce battery costs via large scale production, optimisation and improved logistics.
- Develop innovative vehicle/battery cost and financial models for vehicle ownership.
- Establish appropriate metrics and empirically verify battery performance via in-use testing.
- Develop and optimise supply chains and ensure sufficient battery and hybrid electric system supply through incremental production capacity expansion aligned with EV/PHEV vehicle volume.
- Incentivise battery manufacturers to achieve large-scale production and adopt advanced designs in a timely manner, in concert with expected roll-out of vehicles.
- Establish strategies for retiring batteries from vehicle use (*e.g.*, secondary use or recycling programmes).
- Continue to support and accelerate innovative energy storage research.
- Develop standards for battery construction and disposal, with emphasis on recycling, for use around the world.
- Utilise the key metrics included in this roadmap (see Table 8).

Table 8: Cost-relevant metrics and targets

Metric	Possible targets and notes
• Energy density per unit weight, volume	Proposed targets include an energy density of approximately 150 Wh/litre to 200 Wh/litre (potential improvement ratio of 1.5 to 2) and specific energy of approximately 100 Wh/kg (potential improvement ratio of 1.5 to 2).
• Power density per unit weight, volume	The United States is considering a target for specific power of 460 W/L and increasing to 600 W/L
• State of charge (percentage of full battery charge) limits	Designs should allow for repeated deep discharges with minimum battery deterioration
• Battery recharge time and rate	Slow recharge is acceptable for overnight (*e.g.*, home recharging). For recharging during the day, faster recharge rates are desirable. Fast recharging on highways may be the most important. Possible target: 10 minutes charging for 100 km of range.

Metric	Possible targets and notes
• Battery cost per kWh capacity	Estimated achievable lithium-ion battery costs under mass production in the near-term (2012 to 2015) for pure EVs range from USD 300 to USD 600 per kWh of storage capacity. For EVs with 20 kWh of capacity (probably the minimum requirement for a pure EV) this yields a vehicle cost of USD 6 000 to USD 12 000. Manufacturers will need to shift to the lower end of this range as quickly as possible to achieve commercialisation. Costs per kWh of battery will be somewhat higher for PHEVs, given smaller battery packs with higher power requirements. PHEVs will be able to tolerate somewhat higher unit costs since battery energy storage requirements will be much smaller.
• "Round trip" battery efficiency	Measured as energy out of battery divided by energy in; should achieve (90% to 95%) in in-use conditions, over battery life. Plug efficiency is also important, which is the energy out of battery divided by metered energy out of wall plug and into battery.
• Battery life (total charge-discharge cycles; calendar life)	Two metrics include the number of deep discharge cycles and total calendar life. Reasonable targets are 2 000 to 3 000 discharge cycles and calendar life of 10 to 15 years. (For reference, the US Department of Energy uses: 300 000 power assist cycles for plug-ins plus 1 000 full discharges).
• Battery performance deterioration over time	Minimising battery performance deterioration over life is essential. Maximum 20% deterioration in key performance metrics (*e.g.*, capacity) over ten years is a good target.
• Battery performance deterioration, depending on ambient conditions	Targets must hold over a wide range of conditions, such as the typical range of weather and temperature conditions in inhabited parts of the planet. Reliable operation under a range of drive cycles and road conditions must also be ensured.
• Battery safety	At least as safe, in use, as current liquid fuel systems.
• Battery disposal and recycling	Need nearly full recovery of battery components, especially toxic components; need clear methodologies for measuring battery life-cycle environmental impacts.

6. Develop and implement recharging infrastructure

Reliable electricity supply must be available for EV/PHEV recharging, with convenient access to recharging stations. For PHEVs, overnight recharging appears to be the main initial requirement, whereas for pure EVs, recharging opportunities away from home are a more critical concern to achieve widespread demand for and use of vehicles.

The likely impact of a given number of EVs and PHEVs in use, on total and time-of-day electricity demand, generation, and capacity must be understood. The role of day/night recharging is a key issue. The role of electricity pricing (*e.g.*, differential day/night, real time pricing) to meet both consumer and producer needs must be fully explored.

The standardisation of the vehicle-to-grid interface will also be necessary, at least within continents, but it is also important to avoid over-regulating in order to allow for innovation. The International Standards Organisation (ISO), the International Electrotechnical Commissions (IEC), SAE, the Underwriters' Laboratories (UL), and other organisations can play important roles in coordinating and setting standards. Likely areas for early standardisation are:

- Plug types.
- Recharging protocols.

- Communications protocols between cars and recharging infrastructure.
- Regulations for public recharging that ensure safety with minimal administrative challenges.
- Battery recycling standards and regulations.
- Utility regulations conducted by state/provincial authorities to ensure orderly participation in this market.

Infrastructure cost is estimated to run on the order of USD 1 000 to USD 2 000 per car.[7] However, governments and industry need to determine who will pay these costs, at what point during EV expansion should different investments be made, and how investments will be recovered. PHEVs may need less recharging infrastructure, at least to gain viability, than pure EVs. A low-cost strategy could rely on initial sales and stock accumulation of PHEVs to build-up the night-time recharging market, help lower battery costs, and encourage initial investments in public recharging infrastructure. Pure EVs could then be phased in as more daytime infrastructure becomes available. For each country, a clear PHEV versus EV roll-out scenario will help determine infrastructure requirements.

EV and PHEV expansion will be primarily driven by infrastructure investment. National governments can help coordinate early adoption sites, targeting large cities and urban areas that have ample recharging access. By 2012 or sooner, it should be determined which local and regional units of government are welcoming electric-drive vehicles through such efforts, and they should be coordinated to ensure a transition toward a national system. Governments should also ensure local electrical capacity and systems to accommodate whole areas plugging in their electric-drive vehicles at night; the development of local grid/distribution plans will help. Another key issue is determining how and when to join up cities for EVs by developing recharging opportunities on intra-city travel routes. Ultimately, to enable long-distance travel by EVs and access to all parts of a country, easily accessible, fast-charging facilities will be needed on motorways.

Innovative electricity recharging systems should be considered. Battery exchange systems can provide very rapid replacement of depleted batteries with those that are fully charged, although many questions remain in regard to cost, extra required battery supply, compatibility of the battery systems used by different original equipment manufacturers (OEMs) and replacement of new batteries with potentially older batteries. Battery technologies and licensing systems would also need to be compatible. Additionally, fast charging will be important for battery exchange systems, since it increases the effective supply and lowers the number of batteries that must be kept in reserve to meet peak demand.

Grid powering from batteries could be very useful for provision of peak power and load balancing, but needs to be controllable by vehicle owners. There could be important limitations on how much depletion in battery capacity that vehicle users will tolerate (*e.g.*, the driver must be able to leave the car parked at work and be able to get home again). Adverse impacts on battery life must also be understood and minimised.

The role of smart metering should be fully explored via trials, with good information sharing. All forms of advanced charging systems (*e.g.*, vehicle-to-grid power flow, day/night price differentials, restricted charging during peak demands) will require smart metering systems. But different levels of technology will involve different costs. Optimisation and standardisation will eventually be necessary.

Lastly, the role of utilities and regulators should be clearly established. Utilities will be expected to play a lead role in investing recharging infrastructure; regulators must ensure that utilities have incentives that allow them to earn a fair return on their investments. Utilities will need to work closely with cities, regions and vehicle OEMs in order to achieve a coordinated roll-out strategy that centres on consumer needs.

This roadmap recommends the following milestones and actions:

- Analyse each region to better estimate the relationship between EV/PHEV electricity supply and demand, especially during a fast growth phase after initial introduction (the system should anticipate the possibility of large numbers of vehicles in the 2020 time frame; simulation model tools are available and should be used in each region to determine the optimal location of charging points and timing of installation).

7 This estimate is for all recharging infrastructure; it is therefore likely to be much lower for simple home recharging.

- Establish appropriate codes and standards for recharging, electricity supply and smart metering.
- Draft national EV/PHEV infrastructure roll-out strategies that identify infrastructure priorities and priority areas, timelines, and funding.
- Define the roles and responsibilities of different actors (governments, regulators and utilities, vehicle OEMs, consumers) clearly and develop cooperative and collaborative strategies among multiple levels of government along with electric utilities and OEMs.
- Prioritise home recharging, but plan to bring in commercial recharging centres rapidly as vehicles accumulate (early build-up of commercial recharging may be less important for a PHEV-led transition strategy; urban centres may take priority over intercity recharging facilities).
- Explore the viability of various approaches to rapid recharge systems (*e.g.*, battery exchange systems).
- Evaluate the role for and system designs of vehicle-to-grid electricity provision, including the need for next-generation infrastructure, such as smart metering technologies. Assess willingness of drivers to sell electricity back to the grid under various circumstances.
- Utilise the metrics recommended in this roadmap (see Table 9).

Table 9: Electricity supply and prices, and recharging infrastructure

Metric	Possible targets and notes
• EV market potential	Indications of potential market size overall and among different demographic groups; early adopter market size versus mainstream (maximum potential) market size; impacts of relevant vehicle costs, other vehicle attributes and policy-related variables.
• Impacts per unit infrastructure investment (or per unit investment overall), measured in value of net benefits to society	In order to avoid massive risky investments, early investments should provide a clear impact/benefit. PHEVs are the near-term focus in US because massive infrastructure investments are not required.
• Supply-related metrics	Number of models available, production capacity, trends in production over time (average and maximum rates of expansion).
• Infrastructure-related metrics	Recharging opportunities (percent of plug-capable homes; number of and density of public recharging facilities; and ratio of recharging facilities to numbers of vehicles). One data point from roadmap workshop – both the US and a number of large European countries appear to have about 50% of homes that are EV plug-capable at zero or low cost.

Additional Recommendations: Actions and Milestones

The successful implementation of this roadmap will only be possible when policy framework supporting technology development and dissemination is in place, and governments have established methods for coordinating their efforts domestically and internationally.

Use a comprehensive mix of policies that provide a clear framework and balance stakeholder interests

A comprehensive policy framework should be established through 2020 in order to give stakeholders a clear view of the road ahead, enable early decisions to be made, and reduce investment risks. Governments need to establish a consistent and dependable incentive framework to support the implementation of electric-drive vehicles. OEMs are currently seeking to secure near- to medium-term markets through policy agreements that ensure adequate volumes for OEM returns. Overall policy goals should be established (*e.g.*, energy security, low CO_2 emissions) with appropriate incentives so manufacturers can tailor their production to achieve these policy goals.

To the extent possible, policies should not favour particular technologies but promote good performance (*e.g.*, low CO_2 emission vehicles, fuel diversification and improved energy security). Thus, CO_2 and other exhaust emission-based standards, taxes, etc., are generally superior to ones that directly promote the use of EVs/PHEVs. However, some "technology picking" policies may be unavoidable, such as supporting the provision of EV/PHEV recharging infrastructure.

Policies should aim towards achieving first cost and full ownership (life-cycle) cost-equivalence between EVs/PHEVs and similar ICE vehicles, at least during the transition period aimed at building sufficient confidence from all stakeholders (*e.g.*, customers, battery and vehicle manufactures and recharging grid investors). Based on empirical data, some consumers (especially early adopters) may tolerate some level of ownership cost increment for EVs/PHEVs as compared to ICEs, but the smaller this increment, the larger the likely market size for EVs/PHEVs.

To limit policy (and taxpayer) cost of encouraging electric-vehicle development and deployment, governments can set market penetration targets, cost reduction targets, maximum spending caps or time limits for programmes. However, there is a risk of ending programmes before they succeed. Any limits should be clear to all stakeholders so these can be factored into decision making (both for investors and potential EV/PHEV buyers).

Policies must be based on policy-relevant metrics, including:

- Geography of incentives, or "net value" of incentives to consumers.
- Consumer behaviour (*e.g.*, average driving distance).
- Reliability of electricity, especially in developing countries.
- Sales in fleets versus Households.
- Types of purchase contracts.
- Life-cycle CO_2 emissions

Policy elements should target fleet markets, which are among likely early adopters of EVs/PHEVs. Necessary infrastructure and purchase contract issues may be quite different from the personal vehicle market. Governments can also spur markets by acquiring EVs/PHEVs for official use. Large, coordinated vehicle purchases can help ensure minimum levels of demand to encourage commencement of vehicle production. Implementation of recharging infrastructure should also be coordinated with expected vehicle purchases. Governments will need to lead such coordination efforts.

Government-industry partnerships can support education and demonstration to increase consumer awareness of the availability and benefits of EVs/PHEVs. Labelling programmes and high-visibility trials (*e.g.*, taxi fleets) can raise awareness. There is also a need for accurate information on in-use performance (*e.g.*, range, recharging times, recharging grid location information and expansion plan) to raise consumer confidence.

Policies are also needed to promote R&D, especially for advanced energy storage; these can include corporate tax incentives and direct spending on R&D programmes.

This roadmap recommends the following milestones and actions be completed by national governments (and in some cases local/regional governments), as soon as possible:

- Establish clear national policy frameworks through 2020, complete with establishment of clear market incentives, evidence of commitment, and well-bounded timeframes.
- Maintain technology neutrality, to the extent possible.
- Use policies to achieve first cost and full ownership (life-cycle) cost-equivalence between EVs/PHEVs and similar ICE vehicles during a fixed transition period.
- Combine a mix of policy elements that are harmonised and not in internal conflict, and adjust existing policies to remove any potential conflicts.
- Incorporate caps to limit the costs of policies, and indicate the time extent of policies (*e.g.*, sunset provisions), but do so clearly and give adequate time for market development.
- Base CO_2-related policy incentives on life-cycle CO_2 emissions.
- Encourage regional strategies through multi-level governance.
- Develop infrastructure development plans in cooperation with government and industry.
- Encourage business/government fleets to serve as early adopters.
- Develop information campaigns via government-industry partnerships.
- Make a strong commitment to ongoing public RD&D programs.
- Utilise the metrics recommended by this roadmap (see Table 10).

Table 10: Policy-relevant metrics

Metric	Possible targets and notes
• Policy impact: net cost differential between EVs and similar ICE vehicles	The result of all various policy elements in terms of their impacts on first cost and annual vehicle ownership cost on EVs, in comparison to competing vehicles (perhaps converted to an annual average using amortisation where necessary). A good metric should also include quantification of "hedonic" factors such as non-cost attributes and policies giving preferential treatment (*e.g.*, access to city centres) to electric-drive vehicles.
• Policy cost: net level of public subsidy per vehicle	The net public (tax) dollar cost per vehicle per year for all policy support.
• Policy benefit: net social benefits	Net impacts on CO_2, oil use, pollution emissions, traffic congestion, and noise reduction can be compared to policy cost.

The preceding discussion on policy recommendations focused on the goals of the policies. These goals can be accomplished through a variety of policy elements. Table 11 summarises the types of policies and policy elements that could play a role in incentivising electric-drive vehicles. Optimally, governments would use a mix of policies that is least-cost and provides just enough incentive to build the market at the target rate. This roadmap does not attempt to analyse specific sets of policies.

Table 11: Types of policies and policy elements that could play a role in incentivising electric-drive vehicles

Vehicle-fuel price related	Not cost-related
• Favourable financing terms – *e.g.*, battery leasing to minimise up-front and monthly cost. • Feebate (vehicle fee/rebate) system at time of vehicle purchase, based on performance (*e.g.*, life-cycle CO_2 emissions). • Differential CO_2-based fuel taxes. • Reductions in highway tolls and other vehicle fees (annual registrations). • Incentives for providing recharging infrastructure in commercial/public areas. • Subsidisation of the cost of recharging infrastructure for households/apartment buildings.	• Differential treatment for EVs/PHEVs in terms of regulations, such as access to otherwise vehicle-restricted zones in city centres, preferential parking spots with charge points. • Guarantees for re-sale values, battery replacements. • Additional credits under regulatory systems (*e.g.*, in EU vehicle CO_2 regulations, EVs/PHEVs are considered zero emissions, so automakers get an advantage for producing them; similar credits exist in the US Corporate Average Fuel Economy (CAFE) law). • Electric-drive vehicles would be favoured by strong regulations addressing pollutants (apart from CO_2). • Initial introduction of EVs by government fleets to help spur manufacture. • Public transport vehicles, two/three-wheeled vehicles – exploit EVs in these segments to promote EVs for individual consumers and increase battery production scales. • Direct provision of recharging infrastructure in public areas.

Source: IEA EV/PHEV Workshop, January 2009.

Engage in international collaboration efforts

Governments around the world must work together to ensure sufficient coordination of activities and avoid working at cross purposes, as well as to accelerate technology development and adoption in the most efficient way. There are a number of key areas for information sharing and collaboration:

- Research programmes.
- Codes and standards.
- Vehicle testing facilities.
- Setting of market development targets, such as vehicle sales.
- Alignment of infrastructure, charging and vehicle systems as appropriate.
- Policy development and experience in implementing different approaches.

A number of activities can help improve international collaboration and information sharing. Governments should maximise the use of websites to publically share information and learning, and identify best practices. Regular international meetings can help governments learn from experiences in other countries and increase contacts. Multi-stakeholder workshops – among governments, utilities, OEMs and others – are also important to improving collaboration and sharing best practices in areas such as, standardisation, recharging types/sites, customer driving profiles and demand patterns. Information should also be shared about policies that are particularly effective or ineffective to avoid duplication of mistakes and encourage repeat successes across countries. Early involvement of developing countries in international collaboration and information sharing should be ensured (especially emerging economies with large vehicle markets, *e.g.*, Brazil, Russia, India and China). Some developing countries may be early adopters or market leaders (*e.g.*, China). In any case, EVs/PHEVs may begin to be resold to developing countries by 2015 to 2020 and these countries need some preparation to handle this.

Technology and research should also be shared. Hardware and software relating to analysis, recharging infrastructure, and other aspects should be shared to harmonise approaches. Expertise sharing and exchanges of experts should be explored. Common research agendas can address shared problems (*e.g.*, supplies of lithium, rare earth materials and battery materials). Global recycling system for batteries, common electricity demand, and GHG impact methodologies will all be needed.

The IEA Secretariat can play a role in convening workshops and in coordinating activities, including planning, data collection, international analysis and research methodologies.

- Through its roadmapping efforts, the IEA can help coordinate planning in linked areas, including EV/PHEV development, smart grid development, and planning for low-CO_2 electricity generation around the world.
- The IEA Implementing Agreement on Hybrid and Electric Vehicles plays an important role in running joint research programmes. Countries and private organisations can join for specific projects. Currently eight specific projects ("Annexes") are operating.
- The IEA is a member of the "Global Fuel Economy Initiative", which can provide a framework for engaging governments on the adoption of advanced technology vehicles such as EVs and PHEVs, and help them develop strategies and adopt targets and principles as outlined in this roadmap.
- There are several other potential and active forums for international collaboration on EVs/PHEVs, *e.g.*, the Electric Drive Transport Association (EDTA) and the Asia-Pacific Economic Cooperation (APEC) agency.

This roadmap recommends the following milestones and actions:

- Achieve standardised safety and performance regimes.
- Develop websites and have regular international meetings for information and research sharing (includes hardware and software sharing).
- Identify countries (including developing countries) that are candidates to become early adopters, and help to get them involved.
- Convene workshops and coordinate activities.
- Publish periodical reports and "scorecards" on progress; report on best practices, issues arising and how these can be overcome.

Encourage governments to address policy and industry needs at a national level

Several countries have already initiated the development of their own national roadmaps for EVs and PHEVs. Canada, for example, initiated the "Canadian Electric Vehicle Technology Roadmap (evTRM)" in mid-2008, which included conducting a series of workshops to define the national outlook on the future of electric-drive vehicles in Canada and to set a target for future EV/PHEV market penetration. The United Kingdom also released a high-level roadmap called "Ultra-low Carbon Vehicles in the UK" that includes high-level short-, medium- and long-term goals for transport. Additionally, Japan and the United States have issued several documents to date, the combination of which form roadmaps that include goals for EV/PHEV-critical technologies like batteries, converters, and motors, and quantify characteristics such as cost, power density, and energy density.[8] Other countries have announced ambitious targets regarding future EV/PHEV penetration (see Figures 6A and 6B).

Like this roadmap, national roadmaps can show how stakeholders can better set appropriate targets, guide market introduction, understand consumer behaviour, advance vehicle systems, develop energy, expand infrastructure, craft supportive policy, and collaborate where possible. In addition to making recommendations about how national governments, researchers, and automobile manufacturers and suppliers can identify their route to significant EV/PHEV penetration by 2050, this roadmap strongly encourages stakeholders to formally develop and share their own national roadmaps. By formulating common goals, the global community can work toward an electric-drive transport future.

8 A summary of the Japanese and American roadmaps can be found in the Appendix.

Conclusion: Near-term Actions for Stakeholders

This roadmap has responded to the G8 and other government leaders' requests for more detailed analysis regarding future deployment of EVs and PHEVs. It outlines a set of strategic goals, milestones, and actions to reach a high level of EV/PHEV market penetration around the world by 2050.

The existence of a roadmap document is not enough. This roadmap is meant to be a process, one that evolves to take into account new developments from research breakthroughs, demonstration projects, new types of policies, and international collaborative efforts. The roadmap has been designed with milestones that the international community can use to ensure that EV/PHEV development efforts are on track to achieve the GHG emissions reductions that are required by 2050. As such, the IEA will report regularly on the progress that has been made in achieving the roadmap's vision.

To ensure co-ordination and harmonisation of activities, there needs to be a clear understanding of the roles of different stakeholder groups, along with commitments to achieving various objectives and targets over time. Table 12 identifies near-term priority actions for the full set of stakeholders that will need to be taken to achieve this roadmap.

The IEA has benefited from major inputs from representatives from government agencies, the automobile and electric utility industries, and other experts and NGO representatives. These groups should continue to collaborate, along with others, to work together in a harmonised manner in the future. Specifically, the IEA proposes to develop an EV/PHEV Roadmap Implementation and Monitoring committee that would work together in an ongoing fashion. The committee could undertake various data collection and monitoring activities, as well as coordination activities. It could build on (and include participants from) existing structures, such as the IEA Hybrid and Electric Vehicle Implementing Agreement.

For more information about the ongoing roadmap process and progress in implementation, visit www.iea.org/roadmaps/index.asp.

Table 12: Near-term actions for stakeholders

Stakeholder	Action item
Economics/ finance ministries	• Incentivise battery manufacturers to achieve large scale production quickly and adopt advanced designs in a timely manner. • Evaluate the long-term cost competitiveness of EVs/PHEVs in the context of potential evolution of the taxation structure. • Develop innovative vehicle/battery cost and financial models for vehicle ownership. • Explore the financial viability of various approaches to rapid recharge systems (*e.g.*, battery exchange systems). • Identify a "break-even" metric and implement policies to make vehicles cost-competitive with ICEs. • Use policies to achieve first cost and full ownership (life-cycle) cost-equivalence between EVs/PHEVs and similar ICE vehicles during a fixed transition period.

Stakeholder	Action item
Environment/ energy/ resource ministries	• Target a combined EV/PHEV sales share of at least 50% of LDV sales worldwide by 2050. • By 2020, achieve at least 5 million EV and PHEV combined global sales per year or more, if possible. • Improve and refine regional and national market potential estimates. • Draft national EV/PHEV infrastructure roll-out strategies that identify infrastructure priorities and priority areas, timelines and funding. • With automobile manufacturers and suppliers, ensure that all national targets can be matched to auto company production planning, and vice versa. • Coordinate the launch and ramp-up of EV and PHEV sales, provision of recharging infrastructure, and electricity supply among national governments. • Collect better data, especially on markets and consumer behaviour. • Develop good outreach and information programmes to help consumers to understand the benefits of EVs and PHEVs and increase their interest in adopting them. • Develop websites and have regular international meetings for information sharing. • Establish appropriate codes and standards for recharging, electricity supply, smart metering, etc. • Establish standards for battery construction and disposal, with emphasis on recycling. • Achieve standardised safety and performance regimes. • Clearly define the roles and responsibilities of different actors (governments, regulators and utilities, vehicle OEMs and consumers); develop cooperative and collaborative strategies among multiple levels of government along with electric utilities and OEMs. • Base CO_2-related policy incentives on life-cycle CO_2 emissions. • With utilities, cooperatively develop infrastructure development plans. • With science ministries, design, implement and make a strong commitment to ongoing RD&D programmes.
Training/ science ministries and universities	• Reduce battery costs for EVs to USD 300/kWh or below by 2015. • Establish appropriate metrics and empirically verify battery performance via in-use testing. • Continue strong energy storage research. • Conduct research, testing and benchmarking to establish standards for battery construction and disposal, with emphasis on recycling. • Conduct research, testing and benchmarking to establish appropriate codes and standards for recharging, electricity supply, smart metering, etc. • Explore viability of various approaches to rapid recharge systems (*e.g.*, battery exchange systems). • Design, implement and make a strong commitment to ongoing RD&D programmes.

Stakeholder	Action item
Automobile manufacturers and suppliers	• Improve and refine regional and national market potential estimates. • With governments, ensure that all national targets can be matched to auto company production planning, and vice versa. • Identify and implement policies to ensure adequate recharging infrastructure is in place at the time of, or slightly before, vehicles enter service that will need it. • Governments and industry must include consumers in the planning process and ensure that their needs and desires are met. • Develop good outreach and information programmes to help consumers understand the benefits of EVs and PHEVs, and increase their interest in adopting them. • Consider and set needs and desirable levels of attributes for EVs and PHEVs separately. • Develop innovative vehicle/battery cost and financial models for vehicle ownership. • Optimise the supply chain and ensure sufficient battery and hybrid electric system supply through incremental production capacity expansion aligned with EV/PHEV vehicle volume. • Help identify business/government fleets that can serve as early adopters.
Electric utilities	• Ensure adequate recharging infrastructure is in place at the time of, or slightly before, vehicles enter service that will need it. • Include consumers in the planning process and ensure that their needs and desires are met. • Help develop innovative vehicle/battery cost and financial models for vehicle ownership. • Work with business/government fleets as early adopters. • Establish appropriate codes and standards for recharging, electricity supply, smart metering, etc. • Explore role for and system designs of vehicle-to-grid electricity provision, including the need for "next-generation infrastructure," such as smart metering technologies; explore willingness of drivers to sell electricity to the grid under various circumstances. • Governments and utilities should cooperatively develop infrastructure development plans.
State, provincial and local governments	• Target regions and urban areas that have the best chance to deliver adequate infrastructure and low-GHG electricity by 2020 for initial EV/PHEV sales. • Focus initial recharging infrastructure development on home recharging, but with plans for bringing in commercial recharging centres rapidly as vehicles accumulate. • Incentivise battery manufacturers to achieve large scale production quickly and adopt advanced designs in a timely manner. • Maintain technology neutrality to the extent possible. • Encourage regional strategies (multi-level governance). • Share hardware, software and research.

Stakeholder	Action item
Non-governmental organisations	• Encourage, coordinate, and facilitate the sharing of hardware, software and research. • Study and make recommendations regarding the launch and ramp-up of EV and PHEV sales, provision of recharging infrastructure, and electricity supply among national governments. • Document efforts and make recommendations regarding coordination among national and local governments, auto industry, electric utilities, relevant NGOs and academic researchers. • Establish strategies for retiring batteries from vehicle use, *e.g.*, secondary use or recycling programmes.
Supranational organisations (*e.g.*, the IEA)	• Co-ordinate sharing of hardware, software and research among countries. • Co-ordinate and monitor the launch and ramp-up of EV and PHEV sales, provision of recharging infrastructure, and electricity supply among national governments. • Identify countries (including developing countries) that are candidates to become early adopters, and help to get them involved. • Convene workshops and coordinating activities. • Publish periodical reports and "scorecards" on progress; report on best practices and issues arising (including how to overcome them).

A Comparison of National Electric-Drive Vehicle Roadmaps

UNITED STATES

Year	2009	2010	2011	2012	2013	2014	2015	2017	2020	2025	2030	2050	2080	2100
Motor	Build and test integrated motor/ generator													
Motor Cost		19 USD/kW		12 USD/kW					8 USD/kW					
Motor Specific Power		> 1.06 kW/kG					> 1.2 kW/kG		> 1.4 kW/kG					
Motor Power Density		> 2.6 kW/L					> 3.5 kW/L		> 4.0 kW/L					
Motor Efficiency		> 90%					> 93%		> 94%					
Converter														
Converter Cost		< 75 USD/kW					< 50 USD/kW		< 25 USD/kW					
Converter Specific Power		> 0.8 kW/kG					> 1.0 kW/kG		> 1.2 kW/kG					
Converter Power Density		> 1.0 kW/L					> 2.0 kW/L		> 3.0 kW/L					
Converter Efficiency		> 92%					> 95%		> 96%					
Battery														
Battery Capacity		30 kWh					40 kWh		40 kWh					
Battery Cost		800-1 000 USD/kWh					300 USD/kWh	270 USD/kWh	150 USD/kWh[2]					
Battery Power Density							460 W/L		600 W/L					
Battery Energy Density							150 Wh/kg		200 Wh/kg					
Battery Life		15 years					10 years		10 years					
EV Range														
Market Penetration														
Recharging Infrastructure														

JAPAN

Year	2009	2010	2011	2012	2013	2014	2015	2017	2020	2025	2030	2050	2080	2100
EV PHEV sales (gov. target) [sales%]									15 to 20[1]		20 to 30[1]			
EV Battery – Energy density [Wh/kg]		100					150		250		500	700		
EV Battery – Energy density [Wh/L]		250					400		600		1000	1500		
EV Battery – Power density [W/kg]		1000					1200		1500		1000	1000		
EV Battery – Power density [W/L]														
EV Battery – Calender life [years]		5 to 8					8 to 10		10 to 15					
EV Battery – Cost [JPY/kWh]		100k to 200k					30k		20k		10k	5k		
EV Battery – Type		Li-ion								Revolutionary battery (e.g. Metal-air)				
HEV Battery – Energy density [Wh/kg]		70					100		200					
HEV Battery – Energy density [Wh/L]		200					250		500					
HEV Battery – Power density [W/kg]		2000							2500					
HEV Battery – Power density [W/L]														
HEV Battery – Calender life [years]		5 to 8					8 to 10		10 to 15					
HEV Battery – Cost [JPY/kWh]		100k to 200k					30k		20k					
HEV Battery – Type		Li-ion												
Motor		efficiency improvement							SR motor					
Motor							In-wheel motor							
Inverter		Ultra Low Ron SiC device Low parastic impedence High power density assy.								High frequency HFET				
Infrastructure									Charger (normal) 2 million units[1] Charger (quick) 5k units[1]					
Infrastructure		Connector standardisation												
Infrastructure							Charge from house (200V) Discharge to grid (V2G)							

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All other: www.meti.go.jp/english/press/data/20100614_02.html (METI Strategic Technology Roadmap 2010 in Japanese) and http://app3.infoc.nedo.go.jp/informations/koubo/other/FA/nedoothernews.2010-05-17.7840439413/ (NEDO Battery Roadmap 2010 in Japanese)

2. http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/vt_mypp_2011-2015.pdf

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Appendix II. Abbreviations and Acronyms

AER	PHEV all-electric range
BLUE Map	The energy policy scenario in IEA's Energy Technology Perspectives analysis that aims to achieve a 50% reduction in global CO_2 emissions from 2005 levels by 2050
BYD	Build Your Dreams
CAFE	corporate automotive fuel economy
CCS	carbon capture and storage
CO_2	cabon dioxide
E2W	electric 2-wheeler
ETP	IEA's Energy Technology Perspectives publication
EU	European Union
EV	battery electric vehicle
FCV	fuel cell vehicle
GHG	greenhouse gas
H_2	hydrogen gas
HEV	hybrid electric vehicle
ICE	internal combustion engine
IEA	International Energy Agency
IEC	International Electrotechnical Commissions
INR	Indian rupee
ISO	International Standards Organisation
LDV	light-duty vehicle
Li-ion	lithium-ion
MIIT	Ministry of Industry and Information Technology of China
NGO	non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
R&D	research and development
RD&D	research, development and demonstration
RMB	Chinese yuan
SAE	Society of Automotive Engineers
SUV	sport utility vehicle
UL	Underwriters Laboratories
UN-ECE	United Nations Economic Commission for Europe
USD	United States dollars
V2G	vehicle-to-grid
VAT	value added tax

Units

kg	kilogram
km	kilometre
kWh	kilowatt-hour
L	litre
MPG	miles per gallon
W	watts

Technology Roadmap Electric and Plug-in Hybrid Electric Vehicles (EV/PHEV)

2010

2015

2020

2025

2030

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