Strategic roadmap for plug-in electric and hybrid vehicle charging infrastructure
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Members of the expert working group

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1 - The group of experts was supported by a technical secretariat made up of Ademe staff Laëtitia Tazi, Maxime Pasquier and Michel Gioria.
Foreword

On 17 February 2009 Luc Chatel, Secretary of State in charge of Industry and Consumer Affairs and government spokesperson, and Chantal Jouanno, Secretary of State in charge of Ecology, appointed a working group to draw up a French national strategy for the development of charging infrastructure for plug-in vehicles. This infrastructure is necessary to support the uptake of plug-in electric and hybrid vehicles that are recharged via the power grid.

This working group, a component of the plan to promote low-CO$_2$-emissions vehicles announced by the French President at this year’s Paris Motor Show, was made up of automobile manufacturers, energy utilities, local authorities, building and construction professionals and managers of public spaces.

The group’s aim was to elaborate a development plan for charging infrastructure, experimenting with various options for charging station locations (place of work, home, public roadways) and testing different charging technologies, such as slow charging, fast charging, or battery exchange stations.

This work was directed by Jean-Louis Legrand, Cabinet coordinator for low-emissions vehicles under Jean-Louis Borloo, Minister of Ecology, Energy, Sustainable Development and the Sea.

This strategic roadmap for plug-in electric and hybrid vehicle charging infrastructure has been drawn up on the basis of the analyses and expertise of the specialists in the working group.
Strategic roadmap for plug-in electric and hybrid vehicle charging infrastructure

**Plug-in vehicles**

Conventional internal combustion engines run on diesel fuel or petrol (gasoline). Among new types of vehicles being developed for industrial production are electric vehicles, powered by batteries, and hybrid vehicles that combine thermal and electric motors, with batteries that are recharged during certain driving phases. When these same batteries can be recharged via the power grid the vehicles are called plug-in hybrid vehicles. In this roadmap both electric vehicles and plug-in hybrid vehicles are designated by the term “plug-in vehicles”.

> 1. Issues at stake

The development of plug-in vehicles (see box above) is an emblematic step towards a more environmentally friendly economy and action to promote “green” growth.

One of the keys to success for these vehicles is establishing user confidence in their driving range and safety. To ensure sufficient driving range a charging infrastructure is required, backed by a national installation strategy.

This infrastructure must be deployed in all sectors of daily life, in particular:

- **enterprises**: charging infrastructure must be installed for captive fleets of plug-in vehicles, such as corporate fleets. The possibility of “plug-in benefits” must be considered, i.e. the conditions under which employees can recharge their personal or company cars at their place of work, at no or low cost. The ways in which this added power demand will be managed will also have to be taken into account;

- **public domain**: plug-in vehicles and charging infrastructure must also be deployed in public areas such as roadways and public parking garages. Suitable options for use must be proposed, for instance mobility services such as shared vehicles and vehicles on demand (see box below);

- **residential sector**: plug-in vehicles and charging infrastructure must be made available to individual users, with or without vehicle ownership.

**Multi-owner, shared and on-demand vehicles**

New mobility services are being developed. Several users can share a vehicle that they jointly acquire and own. Others may prefer to rent shared vehicles (fleets available at public locations) or use on-demand vehicles managed by a rental service that delivers and takes back the vehicle at a designated point.
Upstream of the deployment of charging infrastructure, experimental research will have to be conducted to anticipate the long-term evolution of this sector. Forward-looking visions of research priorities, the need for research demonstrators and long-term deployment will be articulated around the three areas of implementation.

Nonetheless the prime focus is to frame this infrastructure deployment in the context of the environmental objectives elaborated at the Grenelle conference, and in the longer term to be compatible with the Factor 4 goal.

The Factor 4 objective, contained in the Energy Policy bill (Programme d’Orientation de la Politique énergétique française, POPE) enacted in France in 2005, is to reduce French greenhouse gas emissions by 75% from their 1990 level by 2050.

Meeting this ambitious goal will mean paying close attention to:
• electric vehicle power ratings and consumption;
• energy resources mobilised to supply electricity to the future electric vehicle fleet. In other words, use of energy resources that generate low or no greenhouse gas emissions must be encouraged. After 2030 energy sources that generate greenhouse gases will have to be coupled with systems to capture CO₂ and store it underground;2
• life-cycle analysis of the electric vehicle chain, covering all environmental impacts.

In addition to these global stakes, four other challenges are underscored by the experts:

1. **Integrating the automobile industry in new mobility solutions**

In 2009 the global automobile industry suffered its worst economic crisis ever, calling into question all the fundamental aspects of this sector. One of today’s challenges is to ensure that this industry makes the transition to providing new mobility services.

Public authorities must accompany this mutation by fostering, among others, the development and industrial production of plug-in vehicles. Recently adopted measures and public incentives are a step in this direction. They are of an unprecedented scope, particularly in favour of charging infrastructure development, one of the keys to successful deployment of plug-in vehicles.

Going beyond accompanying measures, the entire regulatory system must be modified, to make investment profitable. New mobility solutions will have to be proposed and put into place in the different spheres of plug-in vehicle deployment (businesses, homes and public spaces).

2. **Taking advantage of a favourable industry and energy ecosystem**

The situation in France is favourable for a full-fledged low-carbon vehicle industry, which includes plug-in vehicles, simply because electricity in France emits little CO₂ as it is essentially nuclear and hydro power.

France also benefits from the new positions taken by auto makers in production of plug-in vehicles, in all segments of the value chain: electric powertrains, charging equipment, batteries, services.

The major industrial challenge is to thus to build a complete and viable industry that integrates every link of the value chain. This means that various roadblocks and bottlenecks must imperatively be cleared away, among others those that affect charging infrastructure.

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2 - Capturing the CO₂ contained in industrial flue gases and storing it underground is one pathway to greenhouse gas emissions reductions that is being studied in many international projects.
3. Building a “public service electricity supply for mobility”

Even if at term publicly available charging stations in parking lots and garages or along roadways represent only 10% of outlets and 5% of total use, they reassure users that they will have access to charging facilities outside of service stations, the home or work place. They thereby constitute a token of reliability for the system as a whole, which is indispensable to break down the lack of confidence towards plug-in vehicles among end users.

Indeed, this regulation, these investments and the commitment of public authorities have an influence not only on decisions to purchase plug-in vehicles, they also guarantee better insertion of these vehicles in society.

4. Taking the constraints of electricity distribution networks into account

Slow charging, rapid charging

Depending on battery voltage and charging station power capacity, vehicles can be recharged at home in several hours (6 to 12 hours in general for slow charging), or in service stations and public charging stations in a matter of minutes (fast charging). Vehicles can be adapted to one or the other charging mode, or to both.

Massive deployment of plug-in vehicles and the associated charging infrastructure will generate additional electricity demand, with consequences for:

• the average CO₂ content per kWh of electricity (depending on the type of power generation, nuclear, hydroelectric, thermal, etc.),
• the architecture, management and operation of electricity distribution networks,
• peak load management, especially for fast charging (see box below),
• local reinforcement of the power grid.

The extent of these impacts will be determined by decisions made by industrialists, equipment suppliers, public authorities and energy producers regarding:

• technological options such as slow or fast charging,
• regulating aspects such as electricity pricing that encourages slow recharging during off-peak hours.
2. The scope of the roadmap

Geographic scope

This analysis refers primarily to the French national context, including overseas departments and jurisdictions. This notwithstanding, local, European and international dimensions may be introduced in order to:

- take specific features of local electricity distribution networks into account;
- coordinate research priorities and the necessary research demonstrators (technologies tested in an experimental stage situated between research and industrial production) with European initiatives such as the European Green Car3;
- obtain an international perspective, in particular with reference to Japan, Germany and the United States concerning:
  > research priorities,
  > research demonstrator needs,
  > industrial actors and their strategy in the area of plug-in vehicle charging infrastructure.

Time frame

As outlined above, the time frame for proposals for deployment of plug-in vehicle charging infrastructure extends up to 2050, in order to fit with the Factor 4 goal.

These long-term visions are supplemented by perspectives for 2020 that describe the situation that will prevail, assuming that the Grenelle environmental objectives for the transport sector are attained.

The technological, organisational and socioeconomic options that will be tested in research demonstrators are expected to lead to commercial deployment by 2020. This is one of the major differences between these demonstrators and the experimental research projects funded under PREDIT (Programme de recherche et innovation dans les transports terrestres), for example.

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3 - This initiative was launched in December 2008 as part of the European economic stimulus plan aimed at helping the sectors most affected by the crisis. The European Green Car Initiative funds research for sustainable road transport.
> 3. Three key parameters

These key parameters are variables that as they evolve over the long term will significantly inflect charging infrastructure deployment options.

The first parameter is the choice of standards for the various components of the plug-in vehicle/charging infrastructure “ecosystem”. Ultimately this involves elaborating a French position within European and world standards bodies.

The second parameter focuses on the nature and long-term viability of the economic and business models that will govern the entire ecosystem. This includes plug-in vehicles and batteries, and also the setting up and operation of infrastructure and associated services.

The third parameter is the level and nature of interaction between vehicles, users and the charging infrastructure, in other words matching supply to demand for charging infrastructure.
1. Standardisation

The question of standardisation arises at national and European levels. In the near term the ways in which vehicles are charged will probably vary, and charging installations differ from one place to the next.

Several significantly different scenarios can envisioned for infrastructure deployment, depending on the actors involved, economic models and the pace of plug-in vehicle sales. All scenarios should nonetheless retain the following basic principles.

- **Interoperability of charging infrastructure:** the technological options that are chosen must be functional regardless of vehicle type, model range, use and manufacturer; multiple voltage and multiple capacity solutions should be envisioned from the outset to enable all charging modes (slow and fast).

- **Safety of people and belongings:** guaranteeing security is naturally a matter of principle; it is also an important condition that will allow the market to take off. Work must cover users’ security when manipulating equipment (cables, etc.) and information (warning in the event of incidents during recharging, etc.) and the safety features of charging stations.

- **Infrastructure competitiveness:** vigilance is required to keep the cost of infrastructure as reasonable as possible, in order to boost development of plug-in vehicles. Implementation of industrial technology that has been standardised will help keep this cost down.

- **User comfort and convenience:** these parameters will be crucial for users who charge their vehicles frequently, perhaps as often as every day.

- **Optimum management of power consumption:** one of the main advantages of plug-in vehicles, particularly in France, is that they help reduce CO₂ emissions in the transport sector. This benefit must be optimised, for instance by recharging vehicles during off-peak electricity demand periods.

2. Economic and business models

**Driving range and charging infrastructure**

The limited driving range of plug-in vehicles means that they must be introduced in specific geographic areas. Each charging outlet is considered to be a source point. Several source points can be linked in a network to create a distribution loop that defines the geographical scope of the driving range for plug-in vehicles.

Plug-in vehicles will penetrate more or less quickly, depending on purchase price, operating costs and resale value. Initially take-up will be conditioned by mechanisms such as subsidies, investment aids and low-cost loans. But in the long term only a regulatory framework and/or viable business models will ensure their success. It is up to the actors in this production chain (equipment makers, electricity suppliers and distributors, vehicle manufacturers, providers of related services) and to public authorities to foster business models that will:

- transform the cost of acquisition of plug-in vehicles, today twice that of a conventional vehicle, into a per-kilometre cost that is competitive with alternative transport modes such as public transport or bicycles. This involves changing the financing model for vehicles/batteries/infrastructure;
- give customers assurances about battery life, as this component represents one half of the purchase price. Business models based on standard exchange of batteries at the end of a first life cycle are one option;
- take the second-hand vehicle market into consideration. A number of important issues exist concerning resale value, battery financing, change of use zone (see box above);
- anticipate end-of-life treatment for charging infrastructure, plug-in vehicles and their components (batteries, electrical wiring, power electronics).
3. Charging

In order for plug-in vehicles to develop there must of course be customers ready to buy them. Nonetheless, thinking that embraces the surrounding ecosystem, in particular the availability of charging infrastructure, will to a large extent determine how massively these vehicles can be deployed. This supposes that supply matches needs for charging infrastructure.

These needs are determined by actual vehicle performance, as well as by the types of use and economic models adopted. For example, there is a contradiction between seeking a greater driving range for electric vehicles and the intention to massively deploy charging infrastructure. Achieving a balance between these interactions is a key parameter to be taken into account in the strategy for deployment of charging infrastructure.

Furthermore, this is a dynamic equilibrium. To date no operator has been able to develop an economically profitable activity anywhere in the world, given the prohibitive cost of charging infrastructure (system manufacturing and installation costs). The time frame for a return on these investments is several decades, a period that is naturally incompatible with industrial activity.

A strong commitment on the part of the State up to 2020 is needed to ensure the equilibrium of this ecosystem. In the time frame leading up to 2050, new economically and industrially viable business models must take over, without State intervention. This means developing new economical charging infrastructure that is compatible with all types of plug-in vehicles.

> 4. Forward-looking visions

The situation in 2050 will largely depend on the intermediate choices made in the medium term, up to 2020. The 2020 context will depend on public policy measures (the type and scope of which remain to be determined) implemented in the period 2010–2020, and on the extent of infrastructure deployment, i.e. the investments made at homes, places of work and public parking areas.

**2020 visions**

**Unrestricted circulation of polluting vehicles**

**Scenario 1**: infrastructure investment concentrated at businesses and homes

- Measures adopted by public authorities:
  - purely economic incentives for the purchase of low-carbon vehicles: continuation of the environmental bonus that compensates for the cost premium, making the purchase economically neutral,
  - infrastructure investment concentrated at both businesses and at single family homes and multi-family residences (with economic and regulatory support and incentives for multi-family properties).

- Development scenario:
  - market development built on captive fleets and households that have strong environmental awareness and individual home garages or parking facilities where vehicles can be recharged at night,
  - investment focused on slow charging infrastructure in the private sector (individual users, businesses). Under this option only 1%, roughly, of rapid charging is accessible outside of the home, i.e. an estimated 2,000 stations in 2015 and 22,000 in 2025.
**Scenario 2** : Investment covering public parking facilities, and to a lesser extent public roadways

- Measures that complement those in the preceding scenario:
  > support for investment in public parking facilities (1 plug-equipped parking space for 5 plug-in vehicles on the road), specifically targeted investment for stations along roadways, close to mass transport hubs (train stations) and at the periphery of city centres (1 space for 30 plugs on the road),
  > no particular incentives for investment in commercial parking facilities.

- Development scenario:
  > similar to the preceding scenario, with higher penetration due to more extensive public charging facilities. Under this option roughly 5% of rapid charging is accessible outside of the home, i.e. an estimated 14,000 stations in 2015 and 160,000 in 2025.

**Restricted circulation of polluting vehicles**

- Measures that complement those in the preceding scenarios :
  > regulations banning polluting vehicles in city centres and urban areas.

- Development scenario :
  > widespread development of this market for all urban uses including shared vehicles and some collective transport modes,
  > management of initial infrastructure such as battery exchange and fast charging stations along major motorways between large urban areas,
  > emergence of “mobility operators” who invest heavily in infrastructure and offer a portfolio of charging options (flat rate, fast charging, etc.). Under this option roughly 10% of fast charging is accessible outside of the home, i.e. an estimated 90,000 stations in 2015 and 600,000 in 2025.
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**2050 visions**

The different scenarios discussed by the group of experts led to four contrasting visions for the long-term deployment of charging infrastructure for plug-in vehicles.

These visions are meant to represent, sometimes with exaggeration, various ways in which charging infrastructure and plug-in vehicles might be deployed, as a function of different technological, organisational and socioeconomic options. They more or less correspond to action to meet the global challenge of achieving Factor 4 emissions reductions, and to other challenges such as a paradigm shift for the automobile industry and identifying issues pertaining to electricity distribution networks.

Without claiming to predict the future as it will be in 2050, these visions seek to circumscribe the scope of what is possible, and then infer a broad set of bottlenecks, roadblocks, research priorities and needs for research demonstrators. The actual situation will most likely be a combination of the four 2050 visions outlined below.

<table>
<thead>
<tr>
<th><strong>Vehicles to store electricity</strong></th>
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<tbody>
<tr>
<td>It is possible to imagine using plug-in vehicles as a way to store electricity, much like a hot water storage tank. This would hold down electricity consumption in buildings, favouring positive-energy buildings (that produce more energy than they consume), and would supplement electricity grids and lighten their load, particularly in a context of strong penetration of intermittent energy sources.</td>
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**Smart grids**

Using control and command techniques, **smart grids** optimise electricity generation and distribution, and allow a better match between producer supply and consumer demand.

<table>
<thead>
<tr>
<th><strong>Summary presentation of long-term deployment visions for charging infrastructure and plug-in vehicles</strong></th>
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<tbody>
<tr>
<td><strong>Low level of standardisation</strong></td>
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<td><strong>Low interaction with electricity grids</strong></td>
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<td><strong>High interaction with electricity grids</strong></td>
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</table>
Vision 1: charging infrastructure and plug-in vehicles are highly disparate

Only the basic functions and parameters such as security norms are governed by common industry standards. Charging infrastructure and plug-in vehicles are deployed at the minimum regulatory level.

Each operator proposes a specific offer and/or technology, limiting interoperability between infrastructure and vehicles, in a system resembling concessions. In a given territory – a city, an business estate, even a region – a limited number of operators are selected by tender to install, operate and maintain charging infrastructure over a relatively long period (15 to 20 years) so as to be able to make a profit.

Infrastructure functionalities (time clocks and meters, management methods and pricing of mobility services) are not harmonised. These functions are determined by the concession contracts awarded by conceding agents (local authorities, public or private-sector vehicle fleets).

Charging infrastructure and plug-in vehicle deployment is above all guided by the goal of achieving mobility by electric means. This vision does not extend to the possibility of using plug-in vehicles to store power. Only the management of charging periods to limit load peaking and recourse to high GHG generating capacity is included, to remain in step with the Factor 4 reduction target.

Vision 2: electromobility is standardised but little interaction with smart grids

Charging infrastructure is highly standardised, in terms of security naturally, but also to ensure full interoperability and deployment of a range of associated services. All types and makes of vehicles can be recharged at all stations.

The pace of plug-in vehicles and charging infrastructure deployment is accelerated, and infrastructure cost is reduced due to more easily standardised production.

The infrastructure offers a range of services, such as variable electricity pricing depending on the type of user, specific tariffs for shared and multi-owner vehicles. This facilitates deployment by national or European operators who construct their business model in part on these associated services.

Unlike vision 4 below, however, there is little coordination between deployment of charging infrastructure and the implementation of other components of smart grids such as grid storage, positive-energy buildings and demand response mechanisms aimed at managing electricity consumption.
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Vision 3: electromobility in a segmented electrosociety
Charging infrastructure is one of the building blocks of an energy-optimised society based on smart electricity grids and positive-energy buildings. Deployment in territorial segments is preferred, creating energy clusters. The clusters vary in size, from the scale of an activities park to that of an urban area. They are energy-independent, but connected to a centralised energy transmission grid for security reasons and for economic efficiency.

The nature, functions and meshed deployment of charging infrastructure are designed to allow clusters to be independent in energy terms. The infrastructure helps balance energy supply and demand within the cluster, and enables energy convergence of buildings and transport.

In addition to satisfying mobility needs, plug-in vehicles are used for mobile storage of electricity (see box p. 12). They can serve as back-up power sources for electricity grids, in response to the variability of intermittent renewable electricity sources, among others. A specific business model can be envisioned on this basis.

Standardisation is limited however, charging infrastructure and its functions are harmonised within, but not between, clusters. As in vision 1, the logic of a concession system prevails, in this case at the cluster scale.
Vision 4: electromobility in an electrosociety

As in the preceding vision, charging infrastructure is one of the building blocks of an energy society based on smart electricity grids (see box page 12) and positive-energy low-carbon buildings (residential, commercial and institutional, new and existing buildings). They also enable strong penetration of intermittent renewable energy resources such as wind energy and photovoltaic power, and ambitious demand-side management of electricity consumption. Savings could amount to several megawatts of electricity.

To achieve this a massive standardisation effort is undertaken, to ensure full communication between all the building blocks of this electrosociety, in particular:

- vehicle charging infrastructure,
- smart electricity distribution grids,
- demand control and management mechanisms at point of final consumption,
- positive-energy buildings that could use electric vehicles as mobile storage units (see box page 12).

Charging and storage aggregators

This type of service company does not yet exist. In principle aggregators pool electricity capacity in sufficient quantity to be able to negotiate with power distribution grids. A large number of plug-in vehicles could constitute reserve storage for this purpose.

This standardisation results in:

- strong convergence between buildings and transport. Business and office parking facilities are mobilised for installation of two-way charging infrastructure. Vehicle can be recharged as needed, or inversely some of the energy stored in vehicles fed into nearby buildings;
- power grid regulation systems are developed to include plug-in charging infrastructure from the design phase. This could lead to new electricity pricing structure, or the emergence of charging aggregators (see box above).

Standardisation and integration of charging infrastructure in the context of coordinated evolution of the electricity system and positive-energy buildings holds down the added cost of this infrastructure, favours the emergence of robust business models and accelerates the deployment of plug-in vehicles and the associated charging infrastructure.
### Strategic roadmap for plug-in electric and hybrid vehicle charging infrastructure

#### Strengths and weakness of the different visions for 2050

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<th>Strengths</th>
<th>Weaknesses</th>
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<td>Vision 1: charging infrastructure and plug-in vehicles are highly disparate</td>
<td>Low cost of coordination between energy producers/distributors and auto makers</td>
<td>Risk of slow deployment</td>
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<td></td>
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<td>High costs due to absence of standardisation</td>
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<td>French actors not strong in Europe or rest of world</td>
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<td>Risk of standards/actors/business models imposed from abroad</td>
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<tr>
<td>Vision 2: electromobility is standardised but little interaction with</td>
<td>Service economy developed around charging infrastructure</td>
<td>Business models based solely on an economy of plug-in vehicles and associated mobility services</td>
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<tr>
<td>smart grids</td>
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<tr>
<td>Vision 3: electromobility in a segmented electrosociety</td>
<td>Economically profitable business models for smart grids and positive-energy buildings are possible</td>
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<td></td>
<td>High costs due to absence of standardisation</td>
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<tr>
<td>Vision 4: electromobility in an electrosociety</td>
<td>Economically profitable business models for smart grids and positive-energy buildings are possible</td>
<td>Strong need and high cost of coordination between actors (at least during initial phases of deployment)</td>
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</table>
5. Bottlenecks

When analysing the emergence and long-term deployment of these visions, two major categories of bottlenecks can be identified which are rather different in nature: technological obstacles, and socioeconomic and organisational roadblocks.

### Technological bottlenecks

#### Bottleneck 1.1
Reliability, security, robustness and interoperability of information systems used in charging infrastructure, in particular to develop services aimed at reducing greenhouse gas emissions and boost energy efficiency – mobility services such as shared vehicles, electricity demand management, storage aggregators (see box above).

#### Bottleneck 1.2
Interoperable and modular charging infrastructure that can be used for:
- different types and makes of vehicles,
- services other than vehicle charging – parking fees, shared vehicles.

#### Bottleneck 1.3
Grid technology (infrastructure, components) compatible with massive and environmentally efficient deployment of charging infrastructure.

#### Bottleneck 1.4
Flexible charging infrastructure that can adapt to possible future evolution in the surrounding environment, notably:
- diversity of feed-in energy sources such as renewable energy resources,
- changes in the urban environment, such as positive-energy buildings.

#### Bottleneck 1.5
Charge/discharge management systems in both charging infrastructure and plug-in vehicles. Interfaces between vehicle users and grid operators that enable the latter to balance electricity supply.

### Socioeconomic and organisational bottlenecks

#### Bottleneck 2.1
Public policy designed to be in step with the evolving maturity of the plug-in vehicles/charging infrastructure industry.

#### Bottleneck 2.2
Evolution of the distribution of profitability across the production chain and between different type of products (see box below).

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Illustration of the evolution of the value chain generated by the deployment of a “plug-in vehicle ecosystem”

In economic terms the introduction of plug-in vehicles will entrain substantial transfers of operating profits: added value created upstream for battery suppliers and downstream for service providers, notably providers of financial services.

Large-scale development of plug-in vehicles will also induce adaptations such as:
- reduced revenues from taxes on petroleum (TIPP in France) to be compensated by other forms of taxation not applied exclusively to electricity (today the cost of electricity per kilometre is five to seven times lower than the cost of petrol per kilometre),
- shifting of profits towards batteries and services (battery manufacturers, financial companies, mobility operators),
- investment to bolster distribution networks and electricity generating capacity,
- conversion of a part of the development and production capacity dedicated to internal combustion engine and transmission gearboxes.

These activities employ some 30,000 people in France (manufacturers, parts suppliers, etc.).
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Bottleneck 2.3
Regulation mechanisms, and more specifically:
• design, testing and implementation of pricing structures that are compatible with the deployment of an economy of plug-in vehicles and charging infrastructure; time-of-use pricing, tariffs that discourage vehicle charging during peak consumption periods, tariffs that encourage the emergence of mobility services;
• design, testing and deployment of business models (including legal aspects) for charging infrastructure in different spheres of deployment – homes, businesses, public spaces.

Bottleneck 2.4
Consumer behaviour. Two facets of behaviour are involved:
• tracking and understanding uptake of new products and services related to deployment of charging infrastructure;
• interaction between uptake of these new products and services, and other consumer behaviour and trends, e.g. electricity consumption, urban mobility, plug-in city vehicles.

Bottleneck 2.5
Compatibility between the charging infrastructure deployed and urban constraints, particularly along public roadways.

Bottleneck 2.6
Training of qualified personnel for operation and maintenance of charging infrastructure, including in the event of incidents involving plug-in vehicles and charging infrastructure (risk management, intervention by the fire brigade, emergency responders).

Summary of technological and organisational bottlenecks

<table>
<thead>
<tr>
<th>Type of bottleneck</th>
<th>Bottlenecks</th>
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<tbody>
<tr>
<td>Technological bottlenecks</td>
<td>Bottleneck 1.1: reliability, security, robustness and interoperability of information systems used in charging infrastructure</td>
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<td>Economic and organisational bottlenecks</td>
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<td>Bottleneck 2.3: regulation mechanisms (pricing, business models)</td>
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<td>Bottleneck 2.4: consumer behaviour (uptake of new products and services, changing consumption patterns)</td>
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<td>Bottleneck 2.5: compatibility between the charging infrastructure deployed and urban constraints, particularly along public roadways</td>
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<td>Bottleneck 2.6: training of qualified personnel for operation and maintenance of charging infrastructure, including in the event of incidents (risk management, intervention by the fire brigade, emergency responders)</td>
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</table>
6. Research priorities

Considering these bottlenecks, the experts have identified high-priority research areas, grouped in three categories: environmental, technological and thirdly organisational and socioeconomic research.

These research topics are also defined in relation to the three main spheres of charging infrastructure deployment – homes, businesses and public spaces.

Environmental research priorities

Work in this area covers:

- achieving efficient power capacity and electricity consumption in future plug-in vehicles,
- optimising the energy resources that will supply the future fleet of plug-in vehicles,
- life-cycle analysis for the entire supply chain.

Technological research priorities

These topics fall into two categories, depending on the type of equipment:

- **Electrotechnical equipment** for charging infrastructure and energy networks,
- **Information systems and smart grid management** to handle the progression of charging infrastructure deployment and associated services.

Technological research priorities:

<table>
<thead>
<tr>
<th>Electrotechnical equipment for charging infrastructure and grids</th>
<th>Design and development of protection systems for distribution networks compatible with deployment of charging infrastructure</th>
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<td>Design and development of sensors and remotely controlled shut-down devices</td>
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<td>Design and development of systems and architectures suitable for operation of charging infrastructure in degraded or fail-safe mode</td>
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<td>Design and development of models and monitoring tools to track, anticipate and detect ageing of equipment and locate breakdowns in charging infrastructure</td>
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</table>

<table>
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<tr>
<th>Information systems and smart grid management for charging infrastructure deployment and associated services</th>
<th>Design and development of short- and long-term forecasting tools to anticipate energy demand linked to charging infrastructure deployment</th>
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<tr>
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<td>Design and development of cross-sectoral tools and standards related to exchange and circulation of information between actors in the system</td>
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<td>Design and development of tools to manage entry and exit phases of energy islands (as defined in vision 3) within charging infrastructure</td>
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<td></td>
<td>Design and development of interfaces for optimised information transmission between actors and components of the electric vehicle/mobility ecosystem: homes, source stations for example (see box page 9)</td>
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<td></td>
<td>Design and development of real-time operations tools for charging infrastructure: status outlook, automated failure management, voltage regulation, etc</td>
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<tr>
<td></td>
<td>Design and development of planning tools for deployment of charging infrastructure and associated distribution networks</td>
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</tbody>
</table>
Strategic roadmap for plug-in electric and hybrid vehicle charging infrastructure

Socioeconomic and organisational research

These topics are grouped around eight themes.

• Improving understanding of consumer uptake of products and services offered by plug-in vehicles and the associated charging infrastructure.

• Enhancing knowledge of consumers’ short-, medium- and long-term reactions to price signals.

• Developing methodology for tracking behaviour of consumers who have adopted innovative products related to charging infrastructure, over the medium and long term.

• Developing cost-benefit analysis methods for charging infrastructure deployment, in particular to establish financing based on relevant criteria.

• Developing forward-looking studies on the evolution of the technological environment for charging infrastructure – plug-in vehicles, charging technologies, smart grids – in order to assess the impact of these changes on charging infrastructure options.

• Developing business models and a regulatory environment that foster the emergence of new activities, particularly in the context of long-term charging infrastructure deployment.

• Institutional frameworks (rules, standards, legal aspects) that are adapted to the role of different actors (local authorities, distribution grid operators, mobility services operators).

• Ensuring a stable environment for commercial competition that is indispensable for putting into place the substantial investment required for the transition from today’s power grids to future smart grids.

Close attention should be paid to the choice of consumer segments to be tracked (uptake, rebound effect4), and to the forward-looking studies to be carried out to evaluate different technological options (e.g. positive-energy buildings, electric and hybrid vehicles).

4 - All or part of the gains achieved by introducing more advanced technology or systems may be cancelled out by changes in use patterns of the same technologies and/or goods and services that incorporate them; this is called the rebound effect.
7. Research demonstrator needs

On the basis of the preceding analyses it is possible to rank the needed research demonstrators that constitute an experimental stage for technologies between the research phase and industrial implementation.

The demonstrators will provide the framework for a future call for expressions of interest with respect to plug-in vehicle charging infrastructure.

Close attention will be paid to making the most of feedback from research demonstrators that are already underway, in particular pertaining to road vehicles with low greenhouse gas emissions.

Complementarity with future research demonstrators for mobility, positive-energy buildings and smart grids will also be a criterion.

The group of experts does not wish to prescribe specific technological, organisational or socioeconomic options. The areas in which research demonstrators are needed are specified according to four functions.

Future project developers are invited to demonstrate that the technological, organisational or socioeconomic solutions that they propose are the best way to carry out these functions.

Function 1: interoperability and adaptability of charging infrastructure at national and European levels

Criteria for charging infrastructure are:

- **multi-voltage capability**, to be able to deliver very low voltage to vehicles not equipped with an on-board charger,
- **compatibility with different vehicle models, makes and ranges**, from electric bicycles to tractor-trailer trucks,
- suitable and appropriately sized systems for **fleets of plug-in vehicles of different volumes**,
- able to accept **different types of energy supply**, in particular from renewable resources,
- suitable or adaptable to **different types of delivery points**, e.g. single charging outlets on public roadways, multiple outlets in charging stations,
- **flexible in conception and operation**, to adapt to different volumes when deployed, depending on the implantation (home, business, public space).

Design, implantation and maintenance will also have to be conceived to allow stations to **evolve and integrate advances in electric vehicle charging technology** (induction for instance).

Function 2: security, reliability and robustness of charging infrastructure nationally and in Europe

In addition to the capacity to prevent incidents in home, business and public charging stations (roadways, parking lots and garages), the technologies chosen for charging infrastructure, both people and vehicles, must be able to operate in **degraded mode**, in the event of acts of terrorism, among other things.

The stations must be compatible with European standards for plug-in vehicle charging infrastructure that is now in preparation.

Function 3: communications enabled and smart charging infrastructure

Charging infrastructure must be equipped with both communication features and smart systems.

Communication systems will allow information to circulate between the vehicle, the charging station and the user, providing information on station availability or required voltage, for instance.

Smart systems will manage the charging, and also handle vehicle use tasks such as date and time stamping, shared vehicle rental or parking fees. Charging infrastructure and electricity grid management will also have to be associated, to allow for recharging during off-peak periods, or inversely to allow power grids to draw on the residual storage capacity of vehicles that are connected to the network.

Through research demonstrators it will be possible to test various communication protocols and adapt them to different spheres of deployment.

Function 4: insertion in a business model that is compatible with the different spheres of deployment under consideration

The objective is to devise, test and then deploy business frameworks (including legal and regulatory environments) that are adapted to the settings in which charging infrastructure will be deployed: homes, businesses and public spaces. Each sphere is subject to its own specific economics, for example different levels of debt supported, leading to different financial constraints.

Business models and regulatory systems will have to be tried out for each sphere.
Strategic roadmap
for plug-in electric and hybrid vehicle charging infrastructure

The research demonstrators proposed must be integrated and interdisciplinary projects that address at least two of the four functions described above.

They can be situated anywhere on the national territory – in mainland France and in overseas departments and jurisdictions. Projects developed in a framework of cross-border cooperation for plug-in vehicles and charging infrastructure are eligible for consideration, on the condition that a significant part of the project activity is located in France.

Close attention will be paid to possibilities for reproducing and/or transferring to similar urban settings the technological, organisational and socioeconomic options deployed. This is a crucial factor, for ramping up to industrial-scale activity in this sector and for attaining Factor 4 targets by 2050.

The demonstrators must comprise real equipment and deploy and test a significant number of charging stations in different settings. Nonetheless, certain research topics may be treated by modelling and simulation, or involve laboratory testing. As an example, the impact of deploying a substantial number of charging outlets can be modelled to assess distribution loops for one or several power sources (see box page 9).

The demonstrators must be large enough to constitute substantial evidence for the feasibility and pertinence of the technological, organisational and economic options proposed, in the context of the commitment to put one to two million electric vehicles on the road by 2020.

In addition to the requirements of the above functions, proposals will be examined with the following criteria in mind:

- environmental outcomes, in particular reduction of greenhouse gas emissions, and economic impacts of the proposed demonstrators and subsequent replications;
- impact of the technological, organisational and socioeconomic options tested on the sizing, operation and management of electricity distribution grids.

And lastly, the research demonstrators should indicate to decision-makers the standards and legal framework to be put into place, and the cross-sectoral concerns that arise, in particular the need for training schemes for the maintenance of charging infrastructure.

> 8. Some bibliographical references

“Roadmap for smart grids and electricity systems integrating renewable energy sources”
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2008

“Roadmap for positive-energy and low-carbon buildings and building clusters”
ADEME
2010

“Strategy paper, Smart System for the full Electric Vehicle”
EPoSS
2008

“Strategy paper, Electrification Approach to Urban Mobility and Transport”
ERTRAC/EPoSS
2009

“European Roadmap Electrification of Road Transport”
ERTRAC/EPoSS/Smartgrids
2009

The deployment of electric vehicles may vary greatly from one country to the next, depending on the features of the charging infrastructure.

Accordingly, several international initiatives involving auto makers and energy suppliers are now underway to test clean urban mobility with electric and plug-in hybrid vehicles and charging infrastructure on a city-wide scale.

Among the most ambitious initiatives:

- the British government wants to make the United Kingdom the capital of electric vehicles, and intends to install 250 charging stations, in addition to the 75 that already exist;
- projects in Norway and Denmark for building 400 and 20,000 charging stations respectively are accompanied by innovative enterprises such as Better Place (infrastructure) and Think (vehicles);
- Volkswagen and E.on will have 20 hybrid plug-in vehicles in road testing in Berlin by the end of 2010;
- under the E-Mobility scheme supported by the German government, Daimler and the RWE group are planning a full-scale test to develop charging stations for future electric vehicles in several European cities;
- in Japan TEPCO and Japanese auto makers are working on a plug-in hybrid vehicle endowed with a fast charging system;
- the Better Place project in Israel aims to install 150,000 battery exchange and recharging platforms;
- the Department of Energy’s EV Project in the United States calls for initial deployment of charging infrastructure in the main cities of five states by the summer of 2010. Also in the United States, the University of Delaware and the city of Newark (New Jersey) are studying and testing the Vehicle-to-Grid concept (V2G);
- the French and German governments are pursuing a proactive policy to develop a cross-border network of charging stations, with the world’s first electric vehicle demonstration project in the Strasbourg-Stuttgart-Mannheim-Karlsruhe region. This project is intended to demonstrate the common vision of France and Germany regarding standards, in order to accelerate the adoption of a single European standard for electric vehicles and design the necessary infrastructure.

In the technical domain, much work is being done to define a standard electrical input plug for vehicles. This work is based on exchange of standards between the ISO, CEI (Europe, world) and SAE (United States) working groups. The absence of a standard connecting device for charging infrastructure has led to a proliferation of different plugs, with Asian and American manufacturers on one side and European manufacturers on the other.

In the United States and Japan the standard is converging towards monophase current for normal charging and direct current for fast charging. In Europe the tendency is to monophase or triphase current for slow charging and triphase current for fast charging.

The CEI/ISO groups are studying the configuration of communications between vehicles and charging outlets. As of this writing the issues of wired or wireless communication and flow rate have not been resolved.

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5 - The International Standards Organisation (ISO) is the world’s largest producer and publisher of international standards.

6 - The Commission Electrotechnique Internationale (CEI) is the main global body that draws up and issues international standards in all areas related to electricity, electronics and related technologies.

7 - The Society of Automotive Engineers (SAE), founded in the United States in 1905, draws up standards pertaining to the automobile and aerospace industries.
About ADEME

The French Environment and Energy Management Agency (ADEME) is a public agency under the joint authority of the Ministry for Ecology, Sustainable Development, Transport and Housing, the Ministry for Industry, Energy and Digital Economy, and the Ministry for Higher Education and Research. The agency is active in the implementation of public policy in the areas of the environment, energy and sustainable development.

ADEME provides expertise and advisory services to businesses, local authorities and communities, government bodies and the public at large, to enable them to establish and consolidate their environmental action. As part of this work the agency helps finance projects, from research to implementation, in the areas of waste management, soil conservation, energy efficiency and renewable energy, air quality and noise abatement.

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