

# **A road map to 2050 for the private vehicle – fuel combination**



**May 2007**

## Preamble

The findings presented in this report **result from the work of a group of independent experts**. Under no circumstances, do these findings reflect the position of the organisations to which these different experts belong.

Those taking part in this study agree that perspectives for the private vehicle – fuel combination proposed in this road map are **similar to those embraced or potentially embraced by French car manufacturers**.

The views provided here integrate **currently predictable changes** in terms of not only technological, organisational, economic and societal advances, but also possible developments in the fight against climate change and energy security between now and 2050. For this reason, **regular updates** of this road map will be edited to integrate technical breakthroughs strongly impacting the perspectives proposed in this road map. This exercise is specifically aimed at grading research priorities.

Editing of this road map has been based on the work of a group of 8 experts, namely **Pierre BEUZIT** (Renault then ALPHEA), **G rard BELOT** (MPSA), **Alexandre ROJEY** (IFP), **Daniel LE BRETON** (Total), **Patrick NOLLET** (EpE), **Fran ois MOISAN**, **Daniel CLEMENT** and **Alain MORCHEOINE** (ADEME).

Group members were supported in their approach by Revis JAMES (EPRI), Gabriel PLASSAT (ADEME) and Michel GIORIA (ADEME), who ensured secretarial services and support for the expert group from a methodological standpoint.

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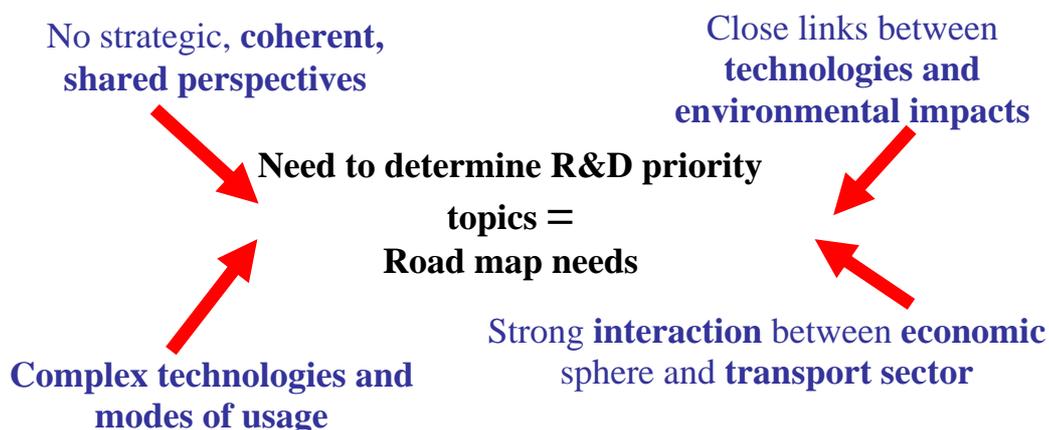
# A road map to 2050 for the private vehicle – fuel combination

## 1. Statement and motivation

Today, **stakeholders** (e.g. car manufacturers, fuel producers, part manufacturers, public authorities, consumers) with an **impact** on the evolution of **private vehicle – fuel combination** technologies have no common vision compatible with dividing the anthropomorphic GHG emissions of this combination by 4 at the French national level (“factor 4”) and by 2 at world level (“factor 2”). Experts taking part in the present exercise agreed that responses to transport-related energy and environmental issues would also involve organisational aspects (spatial and urban development, mobility, modal choice, etc.), whilst group thinking would focus on the private vehicle – fuel combination, which entails a number of strategic technological options.

Public authorities and private stakeholders therefore come up against real problems when, amongst other things<sup>1</sup>, **managing research budgets** to maximise the chances of ultimately ensuring **technology management** from 2020 onwards<sup>2</sup> (e.g. plug in hybrid, hydrogen and fuel-cell, all-electric vehicles), **organisations** (e.g. user-based vehicle pool segmentation) and **organisational coordination** compatible with “factor 2” and “factor 4” objectives.

### Why use a road map for the vehicle – fuel combination



<sup>1</sup> This lack of common vision causes problems when trying to retain options in terms of demonstration operation, production capacity investment, etc.

<sup>2</sup> Choice of 2020 as a horizon for the commercial deployment of different technologies and organisations can be explained in particular by the inertia characterising car pool renewal.

In this type of situation, we need to resort to **flexible, variable decision tools** allowing complicating factors<sup>3</sup> (e.g. ranges of possible technological options, close interactions between technological and economic options, actions of different stakeholders, development of restriction/incentives system) to be introduced step by step, leading to ultimate development of **common and coherent vision of the future**.

EpE<sup>4</sup> and ADEME<sup>5</sup>, supported by EPRI<sup>6</sup>, are thus committed to a process designed to build up a **technological road map for the type of private vehicle – fuel combination compatible with both “factor 4” and “factor 2” objectives** for 2050.

Preparation of this road map has been based on the work of a panel of **8 experts** from private companies (Renault, PSA, Total), research institutes (IFP), government agencies (ADEME) and non-governmental organizations (EpE).

## 2. Long-term aims of energy policies

The private vehicle – fuel combination can be influenced in the long term by many factors (e.g. relative energy prices, company sales strategy, appearance of new stakeholders, energy policy of emerging countries]. The participants favoured viewing strategic options within the context of two particular aspects, namely:

- **level of national energy security;**
- **value of the tonne of CO<sub>2</sub>.**

The group of experts agreed on the fact that these two factors are “**proxies**“, whose variations could account for most of the long-term determinants of the private vehicle – fuel combination. All visions for the private vehicle – fuel combination proposed by the participants therefore assume **a high price of the tonne of CO<sub>2</sub> and a high level of energy security**.

This consensus is justified particularly by the fact that **energy security and reduction of GHG emissions** are **explicit objectives** of **French and European** energy policies. Worldwide, energy security is one of the objectives of energy policy in virtually all emerging and developing countries. In relation to reducing GHG emissions, group members retained the hypothesis that this objective was in the process of **being adopted by most emerging and developing countries outside the European Union**.

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<sup>3</sup> cf. graph below.

<sup>4</sup> Entreprises Pour l’Environnement [companies for the environment].

<sup>5</sup> Agence de l’Environnement et de la Maîtrise de l’Energie [French agency for environment and energy management].

<sup>6</sup> Electric Power Research Institute.

Additionally, participants assumed that all decisions concerning restrictions and incentives (e.g. variation in compulsory energy stocks, quota system) in relation to energy security and GHG emissions reductions are made on the basis of the most exhaustive information. Although this assumption is significant<sup>7</sup>, it is essential for **clarifying the different visions proposed** by the participants.

### 3. Responding to energy demand or supply

In view of the two main long-term aims of energy policies, the group of experts consider that the private vehicle – fuel combination could fall wholly within these aims **with either of two radically different approaches**:

- **the first approach involves significantly reducing vehicle energy demand**; in outline, this route could be followed either by **drastically decreasing the weight** of multi-usage private vehicles (as opposed to urban vehicles) or by **developing small-size urban vehicles**;
- **the second approach increasing fuel flexibility** by developing **new motor-propulsion systems** (e.g. electric, plug in hybrid vehicles) and using **new fuels** (e.g. hydrogen), whose production is based on processes emitting little or no GHG.

These two approaches are considered by group members to be the **strategic options** open to the car and fuel production sectors in response to French and European energy security and GHG emission reduction objectives. These two options may be complementary, but may also turn out to be alternatives.

Whilst choosing between these two approaches will be based on the **relative performance level achieved by each** (cf. table below), the group of experts agrees on the following facts.

- The fall in **vehicle energy demand will play a discriminating role** and thus, if decreases in unit consumption and emissions achieved by lowering vehicle weight are significant, interest in motor-propulsion system alternatives to the IC engine will be less attractive because savings will have been achieved by reducing private vehicle energy demand;
- **Development and implementation of these different approaches will not be linear**: given the investments required, for example to revise vehicle design models or develop new fuel distribution infrastructure, the group of

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<sup>7</sup> Implementation of this assumption would imply in particular that decision-makers have access to full information on technology performance, direct (e.g. variation in vehicle unit consumptions and emissions) and indirect (e.g. variation in mobility behaviours) impacts of options available to them, which is, in reality, far from being the case.

experts effectively considers that **a rapid swing will occur**<sup>8</sup> at the point in time when most stakeholders (e.g. car and parts manufacturers, public authorities) reckon that one of the options on the supply or demand side has achieved a sufficiently high performance level with respect to “factor 2” and “factor 4” objectives.

- **These two approaches are not exclusive (cf. table on page 8):** for example, a strong reduction in vehicle energy demand could facilitate emergence of electric vehicles because of fewer constraints affecting storage systems.

#### 4. Four visions until 2050

**In line** with the **two long-term aims of energy policies** (reduction of GHG emissions and energy security) and the **two response strategies identified for the car sector** (reduction in energy demand or promotion of an alternative energy supply), the group of experts has developed 4 visions for the private vehicle – fuel combination, which appear to be compatible with both “factor 2” and “factor 4” objectives.

Two of these visions (low vehicle energy demand and vehicle pool segmentation) are based on **demand-dominated responses**. The other two visions (hydrogen, fuel-cell vehicles and rechargeable hybrid vehicles) are based on **supply-dominated responses**.

##### a) Two visions: an energy demand-based response

###### Low vehicle energy demand

Decrease in vehicle energy demand through weight reduction well beyond incremental technologies would allow French and worldwide vehicle pools to meet “factor 4” and “factor 2” objectives respectively. Under these circumstances, **pressure on usage changes remains limited** to the extent that virtually all savings would be achieved through **lowering the vehicle’s energy demand**. Nevertheless, there remains heavy **pressure on the way in which the fuels used are extracted, produced, transformed and transported**.

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<sup>8</sup> This assumption is atypical with respect to conventional results of forecasting models, none of which make an exclusive choice between the different possible technological options.

### Interactions between demand reduction and supply diversification

	<b>Reducing vehicle energy demand</b>		<b>Diversifying energy offer</b>
<b>Incremental developments</b>	<p>Reduced rolling and frictional resistances by pursuing underlying developments in tire technology and aerodynamic drag.</p>		<p>1<sup>st</sup> and 2<sup>nd</sup> generation biofuels are produced with good environmental and GHG balances.</p> <p>Batteries allow autonomies of the order of 200 - 300 km to be reached and hybrid vehicles are developed.</p>
<b>Breakthrough</b>	<p>Significant urban vehicle demand appears. Usage conditions (e.g. speed limited in urban areas) enable design constraints to be curtailed, especially because of safety regulations. Size reduction and safety standard revision for this vehicle type combine to offer major reductions in vehicle energy demand.</p>	<p>Forward leap in vehicle design methods. This advance results in very significant reductions in vehicle energy demand (divided by 2 or 3) and curtails the scope of MP units alternative to the IC engine. Also allows multi-usage vehicles to be maintained (as opposed to urban vehicles)</p>	<p>Considerable progress made in:</p> <ul style="list-style-type: none"> <li>• <b>on-board storage</b> of electricity or hydrogen,</li> <li>• <b>generation</b> of these two energy vectors from renewable resources and/or processes emitting little or no GHG.</li> </ul> <p>In order of magnitude terms, these advances allow autonomy levels between 500 and 600 km to be reached for electric vehicles and between 90 and 110 km for plug in hybrid vehicles.</p>

Their production and transformation methods should effectively be studied to **limit the GHG emissions they induce to a minimum.**

On the engine side, **IC engines**, possibly hybrid, continue to dominate the market because savings in terms of vehicle energy demand offer no incentive for developing new motor propulsion systems (e.g. plug in hybrids, hydrogen vehicles).

In this vision, the significantly larger relative proportion of biofuels<sup>9</sup> is not linked to higher production or imports **but to a greater reduction in private vehicle energy demand than in the other scenarios.**

### **Vehicle pool segmentation**

**Strong actions on vehicle usage are initiated** (e.g. all cities with more than a certain number of inhabitants prohibit vehicles emitting more than 20 gCO<sub>2</sub>/km in 2050 and more than 50 gCO<sub>2</sub>/km in 2020). These actions lead to the emergence of **significant demand in favour of small-size, limited autonomy vehicles** (around 300 km), which emit little or no GHG. This is the “**battery-powered electric vehicle**” solution, favoured along with **electricity generation processes emitting little or no CO<sub>2</sub>.**

Totally flexible, hybrid or plug in hybrid vehicles are marketed for usages, which cannot be fulfilled by urban vehicles (e.g. journeys exceeding 300 km). Consumption of these vehicles is equivalent for biofuels, synthetic (LPF, LPG) and conventional fuels. Here again, special attention is given to fuel production methods to ensure they generate as little GHG as possible.

From the standpoint of users' relations with their vehicles and car sector development, we see large-scale emergence of **mobility service companies**, which will be prime movers in rapid distribution of small vehicles and development the service offer for non-urban journeys.

## **b) Two visions: an energy supply-based response**

### **Hydrogen and fuel-cells**

Hydrogen and fuel-cell vehicles will represent **60 - 70% of the world vehicle pool by 2050.** This scenario is based on **resorting heavily to CO<sub>2</sub> sequestration**, due to hydrogen production being based partly on fossil energy, and resorting to synthetic fuel. We assume that the 30 - 40% of the world vehicle pool not operating on hydrogen comprises a **multi-usage, totally flexible vehicle pool**, which can be supplied on an equivalent basis by biofuels (1<sup>st</sup> and 2<sup>nd</sup> generation) or synthetic fuels

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<sup>9</sup> cf. table on page 10, which shows, for information, the pool energy balance for the different outlooks and orders of reduction level magnitude, which vehicle energy demand should achieve.

(LPF and LPG). Flexibility provides both a response to national energy security concerns and a reduction in the risks affecting manufacturers.

The non-hydrogen vehicle pool comprises vehicles, which have achieved energy demand reductions of around 30% in 2050 compared with the current position.

**Electricity and rechargeable hybrid**

Electric and plug in hybrid vehicles will represent **80 - 100% of the world vehicle pool by 2050**. The remaining 0 - 20% will consist of totally flexible, IC vehicles (possibly hybrid) capable of operating on biofuels, synthetic fuels and petroleum.

As in the case of the “hydrogen and fuel-cell” outlook, we assume that **most of the electricity** used by private cars **is generated without GHG emissions**.

Identical to the previous visions, the non-electric or non-rechargeable hybrid pool comprises vehicles, which have achieved energy demand reductions of around **30%** in 2050 compared with the present position.

**Energy balances for different visions for worldwide vehicle pool by 2050<sup>10</sup> (fuel relative proportion)**

	<b>Low energy demand</b>	<b>Pool segmentation</b>	<b>Hydrogen and fuel-cell</b>	<b>Electricity and plug in</b>
<b>Hydrogen without CO<sub>2</sub></b>	0%	0%	60 - 70%	0%
<b>Electricity without CO<sub>2</sub></b>	0%	50%	0%	80%
<b>Biofuels (incl. LPB)</b>	40%	20%	20%	0 - 20%
<b>Synthetic fuels (LPF, LPG) without CO<sub>2</sub> and without CH<sub>4</sub> at production stage</b>	30%	15%	0 - 25%	0 - 20%
<b>Conventional and non-conventional petroleum</b>	30%	15%	0%	0%

<sup>10</sup> Data included in this table are only orders of magnitude suggested by participants.

**Energy demand reduction levels to achieve factor 4<sup>11</sup> in different visions compared with current position**

	Low energy demand	Pool segmentation	Hydrogen and fuel-cell	Electricity and plug in
Vehicle energy demand	-65%	-33%	-8%	0%

## 5. Imperatives

Beyond consistency with long-term aims of energy policies and response strategies offered by the car sector, the 4 visions for the private vehicle – fuel combination proposed by the group of experts are based on **4 imperative factors, impacting the type of research topics considered priority by the participants.**

### a) Necessary flexibility of IC engines

Expert group members consider that flexibility effectively meets the **growing concerns for energy security**, which most countries will experience over the next 40 years. Technological options in terms of flexibility will be directed by two parameters: the decision of major or all countries to **use biofuels in a blend or not** and the decision or lack thereof of major emerging countries (China, India, Brazil and South Africa) to set out to produce LPF and LPB on a extensive scale.

### b) Omnipresence of CO<sub>2</sub> sequestration and 2<sup>nd</sup> generation biofuels

Geological sequestration of CO<sub>2</sub> and 2<sup>nd</sup> generation biofuel production are systematically identified as components of the energy mix (biofuel case) or as a process permitting production of energy vectors (electricity and hydrogen) and/or synthetic fuels (LPF and LPG) with “little” CO<sub>2</sub> emissions.

- **2<sup>nd</sup> generation biofuels** must be massively available from 2020 onwards to complement 1<sup>st</sup> generation biofuel production, thereby alleviating the constraints (competition with food usages, environmental impacts) that production beyond identified sources (fallow land and agricultural surpluses) could create.
- **CO<sub>2</sub> sequestration** is used either to produce hydrogen from fossil energies with little CO<sub>2</sub> emission or to widen the range of possible solutions in terms of

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<sup>11</sup> These values are simply orders of magnitude, but they allow us to see by how much vehicle energy demand will have to be reduced for each vision’s energy balance to be compatible with “factor 2” and “factor 4” objectives.

generating low CO<sub>2</sub> content electricity or to curtail CO<sub>2</sub> emissions associated with synthetic fuel production, which some nations could be tempted to launch for energy security reasons. This option must also be available at **competitive cost and under acceptable environmental and social conditions from 2020 onwards.**

### c) Car sector developments

The different outlooks proposed reflect implicitly **the participants' uncertainties regarding car industry sector development.** In outline, the industrial model of the car sector is today characterised by **production and usage of a unique private vehicle model** in virtually every country of the world. This vehicle is powered by an **IC engine** and is **designed to fulfil many different usages** (e.g. urban area, interurban and long-distance movements).

In relation to this initial situation, two major changes appear to be looming today, even though it is difficult to accurately and fully assess their consequences.

- The first change is that, in the industrialised countries, **the car market is now moving away from an offer-based market towards a demand-based market.** The latter market induces consumer behaviours, which differ widely from those to which the car sector is accustomed: **in brief, the customer takes the initiative in the customer – supplier relationship.** In practice, this will be reflected by **extensive diversification of the offer proposed by manufacturers.** This creates opportunities in the energy field to the extent that the **demand will lay stress on the environmental, durability qualities of its products. This will therefore allow new technologies suited to reinforcing these qualities to be introduced much quicker than usual.** The second consequence, which will reinforce the first, is that **the product renewal cycle will become significantly shorter** and will therefore offer fresh opportunities for introducing new technologies;
- The second change arises from a mutation, which we already observe in embryonic form for some time, which would transform manufacturers **from product – car – suppliers to mobility service providers.** Within this framework the product becomes secondary because the commercial offer is now mobility. This offer will not be restricted to just cars, but will be extended to **all forms of mobility**, especially those, which **will best meet user requirements** in terms of **costs**, practicality and **environmental qualities.** This will allow the question of car alternatives to be answered and emergence of transport means better suited to certain specific usages, such as urban area movements. Here again, the car product will have to adapt to user requirements because it is no longer an object itself, but a means of mobility and will therefore have to evolve sufficiently rapidly.

Visions for the private vehicle – fuel combination proposed by participants integrate imperfectly these developments because of the great uncertainty surrounding them. Nevertheless, regular road map revisions will give special attention to this question.

#### **d) A transition period**

A transition period has been positioned in time at 2020 to take simultaneous account of **private vehicle pool turnover rate**, **European energy policy objectives** expected that time and both **public and private R&D programme life cycles** in energy and transport terms. This transition stage shows that, from the perspective of the group members, research **programming logic, which must be followed from 2010 to 2020, is not the same as that which must be followed from 2020 to 2050.**

The participants considered that, from 2010 to 2020, the technologies (e.g. plug in hybrid, low energy demand vehicles) and organisational options (e.g. mobility services, industrial organisation compatible with producing small urban vehicles) **would not be at a sufficiently mature stage of development** to allow different operators to make exclusive choices. The logic of this first programming phase is therefore **exploratory**, above all. During this period, R&D players must therefore be encouraged to conduct **demonstration activities in all areas related to the 4 outlooks proposed.**

**Beyond 2020**, operators, consumers and controllers will have confirmed the potential (e.g. cost, performance, industrial profitability) of each technology or organisation, which will have been tested and **be subjected to clear strategic decisions** in terms of industrialisation and organisation.

**Energy balance of the world vehicle pool at transition stage<sup>12</sup>**

<b>Energy or energy vector type</b>	<b>2020 transition stage</b>
Hydrogen without CO <sub>2</sub>	0 - 10%
Electricity without CO <sub>2</sub>	0 - 10%
Biofuels (incl. LPB)	20%
Synthetic fuels (LPF, LPG) without CO <sub>2</sub> and without CH <sub>4</sub> at production stage	15%
Conventional and non-conventional petroleum	55%

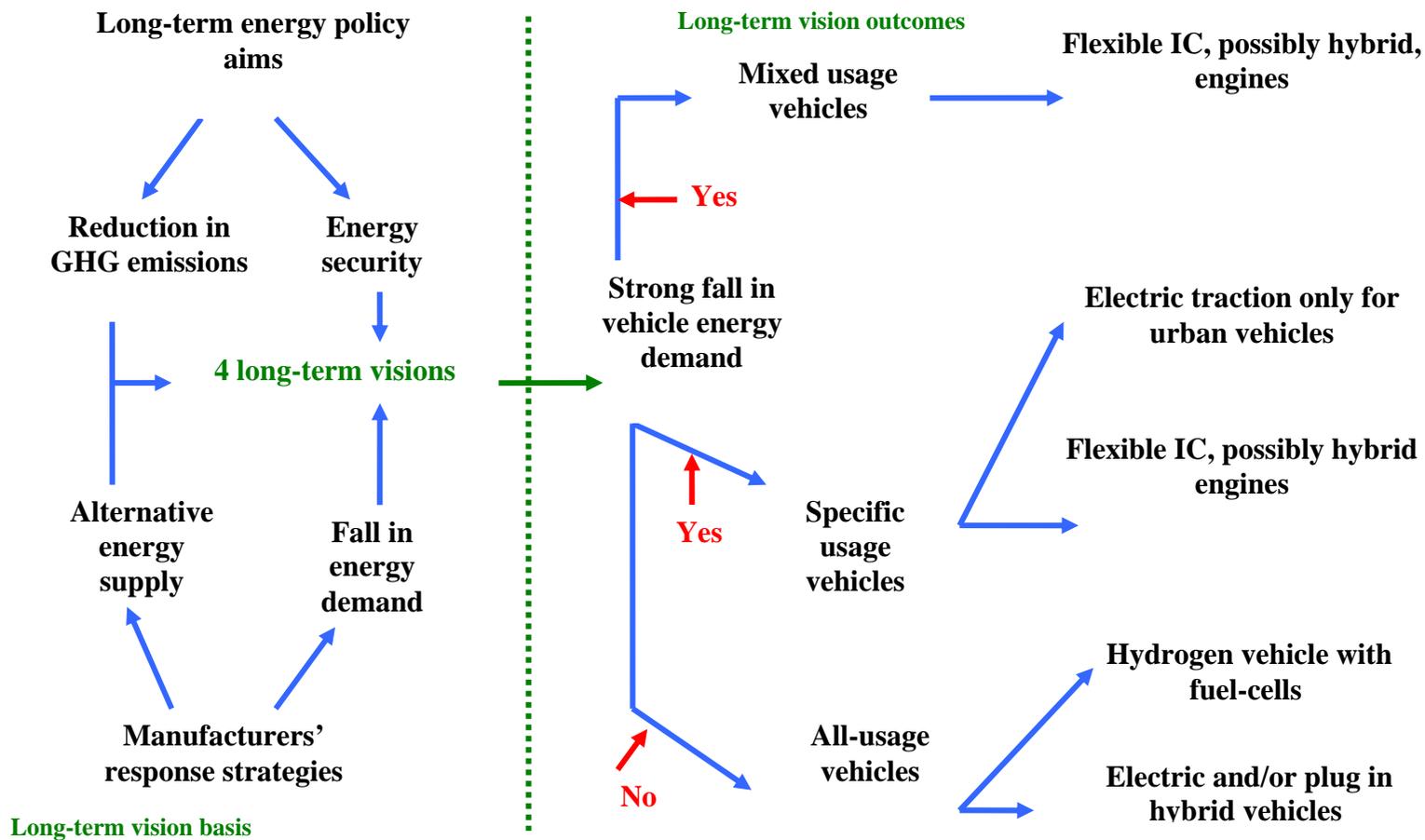
**Energy demand reduction level to be achieved at transition stage**

	<b>Reduction level achieved in 2020</b>	<b>Manufacturers' response strategy</b>
<b>Vehicle energy demand</b>	< 20%	Trend towards "alternative energy offer"-type response
	> 20%	Trend towards "energy demand reduction"-type response

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<sup>12</sup>Data included these two tables are only orders of magnitude suggested by participants. At this stage, they have been subjected to no estimate based on models confirmed by extended expert communities.

Summary diagram of logics behind the private vehicle – fuel road map



## 6. Eleven research priorities

Based on these four scenarios, participants identified three families of topics, which then formed the subject of R&D “prioritisation”.

- **The “motor propulsion system” family**, which combines topics aimed at improving performance characteristics (diesel uniform and petrol stratified combustion for conventional converters, downsizing technologies, hybrid and dedicated motor propulsion systems), developing new fuels (e.g. 2<sup>nd</sup> generation biofuels, carbon- and natural gas-based synthetic fuels) and designing vehicles considered as alternatives (e.g.: hydrogen, plug in vehicles);
- **The “reduced vehicle energy demand” family**, which combines research areas involving improved energy efficiency or carbon efficiency of auxiliaries (e.g. CO<sub>2</sub> air-conditioning), reduced friction (e.g. active aerodynamics), lower vehicle weight (e.g. aluminium and magnesium mechanical components, assemblies of lightweight parts for vehicle structural materials) and energy recovery (e.g. recovery of vehicle kinetic and motor propulsion system thermal energies).
- **The “market, produced and purchased vehicle pool segmentation” family**, which includes research topics involving usage enhancement and understanding, study of industrial models compatible with urban vehicle emergence and a technological component focusing on urban vehicle-dedicated MPU developments.

Out of the 39 topics subjected to “prioritisation”, **11 were considered high-priority by participants.**

Three other topics, considered medium-priority, have been added to these 11 high-priority topics. These three additional topics consist of **analysing private vehicle ownership and usage conditions, developing regulation systems to prompt changes in usage and analysing industrial production and organisation systems compatible with mass-production of urban and small-size vehicles.**

Unlike most other research topics considered priority, these 3 latter topics are not of technological nature. However, the research issues they raise are major, especially **with respect to questions involving development of the car sector industrial model**, which was one of the main uncertainties raised by participants.

### Priority topics by family

Topic family	Topics considered high-priority
<b>Motor propulsion system</b>	<ul style="list-style-type: none"> <li>• <b>Diesel uniform and petrol stratified combustion</b> for current converters</li> <li>• “Downsizing” technologies: variable distribution, oversupply, etc.</li> <li>• <b>Hybrid and dedicated MPUs</b></li> <li>• <b>2<sup>nd</sup> generation biofuel development</b> using thermochemical or biological processes</li> <li>• <b>Power electronics</b> for optimising battery – engine coupling</li> <li>• <b>Electric vehicle developments</b> powered by lithium-ion or nickel-metal batteries</li> <li>• Fuel-cell research</li> </ul>
<b>Reduced vehicle energy demand</b>	<ul style="list-style-type: none"> <li>• <b>Redefinition of vehicle structural design models</b></li> <li>• <b>Active aerodynamics</b></li> <li>• <b>Kinetic and thermal energy recovery</b></li> <li>• Development of <b>lightweight materials for vehicle structural parts</b></li> <li>• Development of <b>lightweight materials for ground connection parts</b></li> <li>• Development of <b>aluminium and magnesium engine components</b></li> <li>• Development of <b>new assembly methods</b> for these new materials</li> </ul>
<b>Vehicle pool and usage segmentation</b>	<ul style="list-style-type: none"> <li>• Private and urban utility vehicle <b>weight reduction</b> (topic closely linked to “energy efficiency” group)</li> <li>• Development of <b>new motorisations</b> for private and urban utility vehicles (topic closely linked to the “MPU” group).</li> </ul>

**Summary table of R&D timeframes for development available technologies in different scenarios**

<i>Technological or organisational building blocks</i>	<i>Scenarios</i>	<i>R&amp;D</i>	<i>Demonstration</i>	<i>Deployment</i>	<i>Maturity</i>
1 <sup>st</sup> generation biofuels	V1 V2 V3 V4			<b>2007-2020</b>	<b>2020-2040</b>
2 <sup>nd</sup> generation biofuels	V1 V2 V3 V4	<b>2007-2013</b>	<b>2013-2020</b>	<b>2020-2030</b>	<b>2040 + beyond</b>
Fossil energy-based synthetic fuels (LPF, LPG)	V1 V2 V3 V4		<b>2007-2013</b>	<b>2015-2030</b>	<b>2040 + beyond</b>
Lightweight vehicles with low energy demand	V1	<b>2010-2020</b>	<b>2015-2020</b>	<b>2020-2040</b>	<b>2040-2050</b>
Small-size electric urban vehicles	V2	<b>2010-2020</b>	<b>2015-2020</b>	<b>2020-2040</b>	<b>2030 + beyond</b>
Hydrogen vehicles	V3	<b>2007-2020</b>	<b>2015-2025</b>	<b>2025-2045</b>	<b>2045 + beyond</b>
Plug in vehicles	V4	<b>2010-2020</b>	<b>2018-2025</b>	<b>2025-2045</b>	<b>2045 and beyond</b>

## 7. Research prospects

At this stage, several lines of research should be pursued to provide further input and to strengthen this road map.

- **1<sup>st</sup> line of research.** Share and validate **technological potentials** (e.g. performance characteristics, costs, usable potentials, date of availability, penetration level), outlined for different technologies or organisations identified as pivotal in this road map, with **extended expert communities** (e.g. Club CO<sub>2</sub>, biofuel specialists, material specialists) and/or scientific literature review.
- **2<sup>nd</sup> line of research.** Subject scenarios developed in this road map to a **quantification exercise for the GHG emission they induce** to confirm on a quantitative level their compatibility with the national objective of dividing GHG emissions by 4 and the worldwide objective of dividing them by 2. This quantification exercise will be all the more interesting if the visions proposed by participants correspond to **radical changes in the private vehicle – fuel combination** (e.g. 60 - 70% hydrogen vehicles, 80 - 100% rechargeable hybrid of low-consumption vehicles). Such radical changes are **very far removed from what is currently modelled within the scope of WETO\*-type forecasting exercises**, which result in scenarios representing “soft” transitions in the technological portfolio, in which virtually all technologies remain present until 2050. Visions developed within the scope of the road map could therefore be used to **accompany modelling work aimed at simulating breakthrough scenarios**. One feasible approach would be to examine what set of assumptions would need introduction into the model (e.g. POLES) for the outcomes to be compatible with perspectives identified within the scope of the road map and to validate their consistency.
- **3<sup>rd</sup> line of research.** Develop **linkages between research topics of technological nature and those of societal and organisational nature**. In particular, linkage development could be undertaken within the framework of a road map for **the development of urban areas and energy networks**, which would be based on visions for the private vehicle – fuel combination proposed in the present road map, amongst other information.

\* “World Energy Technology Outlook” European Commission, Research GD