Alliance Nationale de Coordination de la Recherche pour l'Énergie

Decarbonization Wedges Exercise

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HYBRID & ELECTRIC VEHICLE

1. State of the art and current development in different world regions

Electrification of vehicle drivetrains is implemented at different levels of power and energy in various architectures, corresponding to a wide range of features and vehicle performances. One can distinguish 6 types of progressive electrification levels, ranging from the conventional vehicle to the electric vehicle, as detailed hereafter.

Technologies 1, 2&3: Micro to mild hybrids
Stop&Start systems are mature technologies. Most simple technologies implement reinforced starter and a separate alternator, most sophisticated uses a unique belt driven alternator-starter. Sophistication trends are toward optimized energy recovery and increase in power thus increasing the features (early fuel cutoff, creeping, and boost). The continuous improvement in the implemented technologies and performances lead to a continuum of solutions from the Micro, to the Soft (Micro-Mild) then to Mild hybrids.

The fuel consumption gains ranges from 5 to 25% depending on the technology implemented. They are very sensitive to the vehicle type of use and will be maximum in dense urban areas.

Technology 4: Full hybrids
These drivetrains will enable the vehicle to be operated in full electric mode on short distances (1 to 3 km) and under the control of the drivetrain energy management. The high power of the electric drivetrain will enable to greatly optimize the engine working condition and to recover a maximum of the available energy during braking.

Technology 5: Plug-in hybrids (PHEVs)
Such vehicles are equipped with a larger battery (5 to 16 kWh total) which will enable the vehicle to be operated on a specific range in all electric mode under the control of the driver (ZEV –Zero Emission Vehicle–-range 15 to 60 km) and to be charged from the grid. Some PHEVs may be operated in blended mode, some have their full dynamic capabilities in electric mode but very limited dynamic performances if the battery becomes fully discharged, etc.

Technology 6: Electric vehicles (EVs)
Light duty electric vehicles have been developed since the mid-60s, using the existing technologies and on the basis on conventional car conversion. EVs marketed these years use dedicated body for the major part but some are still converted from existing models. Due to progress in lithium batteries and in electric drivetrains, EVs present good or even excellent dynamic performances, with ranges from 100 to 250 km, or even more. EVs are however still expensive, depend on the charging grid and need some further improvement in their A/C systems. The development of new types of use, such as car sharing or 'last kilometer' deliveries in city centers will be favorable to this new type of vehicle. In parallel, the development of the charging infrastructure will be necessary to the market expansion of EVs, even though battery improvements could allow a significant range autonomy increase at short / mid-term.

2. Maturity level and technological perspectives

Maturity of elementary technologies associated with hybrid and electric vehicles

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
Micro and micro-mild hybrid	4	5	5	5	5
Mild hybrid	4	4	4	4	4
Full hybrid	4	4	4-5	5	5
Plug-in hybrid	4	4	4	4-5	5
Electric vehicle	4	4	4	4-5	5

HEVs will continue to be improved with better integration of components and decrease in costs. The less sophisticated – and more economic solutions (micro and micro-mild) will progressively become the main stream. The HEVs solutions will remain the more expensive ones but thanks to their cost decrease they will be available on a large amount of the manufacturer's range. After 2030, progress in battery and electric components may enable the most sophisticated HEVs to progressively benefit from PHEVs features.

EVs will progressively leave the status of converted cars to be dedicated ones with all the possible synergies in components location, efficiency and cost. The major drivers of the EVs mass production will be the battery costs reduction, the enhanced charging infrastructure development and local policies promoting their use, especially in urban and peri-urban areas.

Potential development of technologies associated with hybrid and electric vehicles

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

	2020	2030	2040	2050
Micro et micro-mild hybrids	3	3	3	2
Mild hybrids	1	2	2	1
Full hybrids	1	4	4	3
Plug-in hybrides	2	4	4	4
Electric vehicles	1	4	4	4

Stop&Start systems represent almost 50 % of new cars sold in Europe (less than 15 % worldwide). The Stop&Start system and its evolutions in micro-mild hybrids are expected to be the main stream on the market in Europe, Japan, Korea and US by 2020, on a worldwide basis, they will at that term represent more than 40 % of the passenger cars market. Concerning micro hybrid and micro-mild hybrid, fuel consumption and CO2 gain of 5 to 15 % can be expected compared to conventional vehicle.

Full hybrid technology is still expensive due to high power electric components and on board storage system. On a worldwide basis, the 2020 HEVs market share is estimated between 4 to 9 %. PHEVs development expectation is limited to a few percentages (2 to 5 %) of the WW market in 2020. However it is worth noting the rapid growth of this young market. EV market penetration is expected to stay low in 2020, between 1 and 2 % of the WW market. Full hybrid and Plug-in Hybrid vehicles represent, compared to conventional vehicles, CO_2 emissions gains of respectively 25 to 40 % and 55 to 85 % from tank to wheel.

These assumptions should be considered carefully as they are defined for a specific scenario (based on Blue Map scenario of IEA) and are linked to factors such as energy price evolution and also dependent on more subjective criterions such as population consciousness-raising in different parts of the world regarding local pollution health effects in large conurbation together with GHG consequences on their behavior.

3. Technological, economic and social bottlenecks

Methodological information:

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.
It must be stressed that the ranking of such different factors must be considered with caution; as an expert's judgement, not a quantitative assessment.

Technology		Research & technological bottlenecks	Economy and Financial bottlenecks (investment, risks)	Regulation & institutional environment	Resources & environmental impacts (including scarcity of raw materials, water, land, climate)	Safety & security (impacts on health, people and security assets)	Socio-technical feasibility
Micro	Rank	1	2	5	6	4	3
	Key-words	Dedicated low cost energy storage	Components ageing	No ZEV (Zero Emission Vehicle) operation	Low impact on CO2 and local nuisances	Noise Vibration Harshness	Mainstream solution
Micro-mild	Rank	2	3	5	6	1	4
	Key-words	Dedicated low cost energy storage	Components ageing	No ZEV operation	Moderate impact on CO2 and local nuisances		High potential development
Mild	Rank	2	3	4	5	1	6
	Key-words	Component integration	Industrialization at automotive costs	No ZEV operation	Moderate impact on CO2 and local nuisances		
Full	Rank	3	5	6	2	1	4
	Key-words	Battery safety, power density, industrialization, standardization, recycling Bat/Supercap coupling Asymmetric Supercaps	Industrialization at automotive costs Components ageing	No ZEV range	Good impact on CO2 and local nuisances Sensitive materials, Recycling		TCO (Total Cost of Ownership)
Plug-in	Rank	5	6	3	2	1	4
	Key-words	Battery safety, power/energy density, management, industrialization, standardization integration, recycling	Battery industrialization at automotive costs	Initial incentives Clean vehicle dedicated circulation and access, Evaluation protocol representativeness	Urban use with no local nuisances Low carbon renewable electricity generation, Sensitive materials, Recycling		Specific uses for TCO decrease and for optimum environmental performance
Electric	Rank	4	6	3	1	2	5
	Key-words	Battery, safety, energy density, lifetime, cost, management, industrialization, standardization, integration, recycling Efficient cabin thermal control	Charging infrastructure Battery industrialization at automotive costs Battery pack rental business	Initial incentives Clean vehicle dedicated circulation and access, Evaluation protocol representativeness	No local nuisances Low carbon, renewable electricity generation, Sensitive materials, Recycling	Battery safety in use	Specific uses for TCO decrease

Per bottleneck

Technological Research and Economy and financial investments: For those criteria, the expected occurrence of bottleneck eventuality increases with the complexity of the involved technology: from Micro hybrids to PHEVs for the technology criteria, and from micro hybrids to EVs for the financial criteria.

Resources and Environmental impact: The growing complexity of the solutions leads to a decrease in petroleum consumption and CO_2 emissions. The consequence is a progressive decrease in the level of possible bottlenecks for this criteria. The influence of other parameters such as raw materials' topic has been considered as being of a lesser extent.
Socio-technical feasibility: This bottleneck is supposed to increase with technology complexity and TCO –Total Cost of Ownership– constraints, except for the mild hybrid case.

<u>**Per technology**</u>

Technologies1 & 2 –Micro Hybrid and Micro-Mild Hybrid: These are the simplest solutions (low risks on Research and Finance), but with very low to low impact on vehicle CO_2 emissions (limited gain for environment) and potentially NVH (Noise, Vibration, Harshness) nuisances.
Technology 3 –Mild Hybrid: More complex technologies, with a limited cost to CO_2 gain ratio and suffering for an impossible evolution towards full hybrid or PHEV technologies;
Technology 4 –Full Hybrid : Limited amount of research needed (mainly for batteries: safety, power density, lifetime, cost) for these well-known technologies with a good environmental impact, but still a high financial amount necessary to establish them as a main stream worldwide, especially in areas where diesel solution is well established.
Technology 5 –Plug-in Hybrid : These solutions involve a high power - high energy battery, an adapted IC Engine and after treatment together with a dedicated management, demanding a high level of research still to be carried out and a rather high financial risk.
Technology 6 –Electric Vehicle: Still research needed on the energy storage (high energy by mass and volume, cost, safety, ageing …) together with high financial investments for the vehicle industrialization and for the charging infrastructure. Socio-Technological risks may be encountered due to the high purchase cost and the low charging infrastructure density.

4. Potential radical and incremental innovations

<u>Methodological information:</u>

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		**Research & technological innovations**	**Economy and Financial innovations** (investment, risk)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
Micro	I or R	I	I	I	I	I	I
	Key-words	Low cost energy storage Low cost DC/DC converter			Recycling		
Micro-mild	I or R	I	I	I	I	I	I
	Key-words	Low cost energy storage, Low cost DC/DC converter			Recycling		
Mild	I or R	I	I	I	I	I	I
	Key-words				Recycling		
Full	I or R	I	I	I	I	I	I
	Key-words	Low cost, long life energy storage	Industrialization		Recycling		
Plug-in	I or R	I	R	R	I	I	R
	Key-words	Low cost, long life energy storage Inductive charging	Industrialization Charging infrastructure Vehicle sharing Vehicle lease Battery lease	Incentives, Charging interoperability (roaming)	Clean electricity generation Recycling		Buying services (km) rather than vehicles

Electric	I or R	R	R	R	I	I	R
	Key-words	Low cost, long life energy storage Inductive charging	Industrialization Charging infrastructure Vehicle sharing Vehicle lease Battery lease	Incentives Charging interoperability (roaming)	Clean electricity generation Recycling		Buying services (km) rather than vehicles

Micro to EVs technologies will continue to be improved with better integration of components (machine, and electronics, cooling loops), advanced batteries, decrease in costs, lower fuel consumption thanks to better component efficiencies and use of ICT (Information and Communication Technologies).

As far as battery is concerned, new materials and chemistries are currently developed to increase the energy density of lithium battery-powered vehicles. In a very long term vision, numerous research teams are conducting studies on the metal/air technologies. The zinc/air, aluminium/air or Li/air technologies are the most well-known and the most promising. Although many challenges are still to be faced there is much at stake since energy densities of between 500 and 1000 Wh/kg could be obtained.

In parallel battery rental could be a solution to decrease initial cost together with customers' risks. The vehicle owner may still not be the mainstream use in the future and the customers may only buy driven kilometers rather than buying the object itself (car-sharing…).

New models for distribution and marketing may be implemented by car manufacturers, especially new incomers, such as e-retailing. Local incentives may possibly change the game as well as vehicle to grid (V2G) and vehicle to home (V2H) emerging models in relation with the development of diffuse electricity production and stationary storage issues.

LCA (Life Cycle Analyses) will have to be carried out on their entire life with the aim to i) reduce their footprint to the minimum and ii) involve the minimum, or even no, potentially sensitive materials such as rare earths or lithium…; LCA will have to be carried out with the aim of reducing the footprint and involving the minimum potentially sensitive materials such as rare earths or lithium…