Analysis of Adverse Effects on Vehicle Performance Due to Hybrid Vehicle Battery Deterioration

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Abstract
This paper presents the results of analysis into the adverse effects on vehicle performance caused by the deterioration in capacity and increase in resistance of lithium-ion batteries installed in hybrid electric vehicles (HEVs). Detailed evaluations were conducted based on simulations to determine the adverse effects on HEV performance. It was concluded that the battery resistance at which the CO2 emissions rate and the Fuel Consumption reaches 120% of the level of a new vehicle is approximately 350% of the initial battery resistance value.

Keywords: environment, HEV (hybrid electric vehicle), internal resistance, lithium battery, vehicle performance

1 Introduction
In recent years, the electrification of the automobile has been vigorously promoted from the standpoint of addressing environmental and energy problems. This paper summarizes the results of research into the permissible deterioration of the battery, which is considered the heart of an electrically powered automobile.

Battery power deterioration naturally has an adverse effect on the power and environmental performance of the vehicle. However, the specifics and extent of this effect on vehicle performance differ greatly depending on the type of vehicle system. For example, the effects on vehicle performance are completely different if batteries with the same power deterioration characteristics are installed in a battery electric vehicle (BEV) or a hybrid electric vehicle (HEV). Consequently, it is important to determine the permissible battery deterioration for each type of vehicle system separately, based on the characteristics of the effects.

Consequently, this study examines the effects of battery deterioration on vehicle performance using an HEV equipped with a lithium-ion battery as the test vehicle. First, the study analyzed in detail the effect on vehicle performance as the battery deteriorated. Here, the research studied deterioration in battery capacity as well as deterioration in internal resistance. Subsequently, this battery deterioration data was utilized to determine the permissible deterioration of the HEV lithium-ion battery, with a particular focus on the effect on CO2 emissions and fuel consumption.

2 Details of Simulation

2.1 Outline of Test HEV and Simulation
Table 1 shows the specifications of the vehicle, which is a passenger vehicle installed with a series-parallel hybrid system. The simulation model reproduces the power split device, which links the
motor, engine, and generator, as well as phenomena such as engine cranking (Fig. 1) [1], [2], [3].

Table 1: Vehicle Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Curb Weight</td>
<td>1,310 kg</td>
</tr>
<tr>
<td>Engine Max Power</td>
<td>73 kW@5,200 rpm</td>
</tr>
<tr>
<td>Motor Max Power</td>
<td>60 kW</td>
</tr>
<tr>
<td>Generator Max Power</td>
<td>30 kW</td>
</tr>
<tr>
<td>Battery Voltage/ Weight</td>
<td>345 V/ 22.4 kg</td>
</tr>
<tr>
<td>Number of Cells</td>
<td>92</td>
</tr>
<tr>
<td>Capacity</td>
<td>6.5 Ah</td>
</tr>
</tbody>
</table>

![HEV Simulation Model](image)

Figure 1: HEV Simulation Model

2.2 Engine ON Conditions

Table 2 shows the conditions under which the engine is switched on. The following three elements are used as the triggers: 1) required drive power, 2) vehicle speed, and 3) the state of charge (SOC) of the battery. These three elements are further divided into controls for high and low SOCs, and values were set independently for these two categories. When the vehicle is started, the engine is operated following the operating curve.

Table 2: Engine on Conditions

<table>
<thead>
<tr>
<th>Control (SOC)</th>
<th>Low (Under 32.5%)</th>
<th>High (Above 32.5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Power</td>
<td>10 kW or Over</td>
<td>15 kW or Over</td>
</tr>
<tr>
<td>Vehicle Speed</td>
<td>25 km/h or Over</td>
<td>55 km/h or Over</td>
</tr>
<tr>
<td>SOC</td>
<td>Under 30%</td>
<td>(Engine OFF) SOC : Above 35%</td>
</tr>
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</table>

2.3 Test Battery

Figure 2 shows the SOC dependency of the open-circuit voltage and the internal resistance of the test lithium-ion battery. In this study, the upper limit of the terminal voltage is 4.3 V and the lower limit is 2.5 V for both the new and the deteriorated batteries. In addition, a maximum discharge rate of 20C and a maximum charge rate of 10C were also set as limitations.

This paper defines capacity retention ($C_s$ [%]) as the capacity of a new battery compared to the capacity of the battery after deterioration. Internal resistance increase ($R_s$ [%]) is defined in the same way. The criteria for battery SOC are the capacity when the battery is new and the capacity of the battery after deterioration. Furthermore, battery capacity deterioration is assumed to have no effect on the SOC dependency of the open-circuit voltage.

![Characteristics of Internal Resistance and Open-circuit Voltage of the Lithium-ion Battery (Single Cell)](image)

Figure 2: Characteristics of Internal Resistance and Open-circuit Voltage of the Lithium-ion Battery (Single Cell)

2.4 SOC Correction and Hot/Cold Start Correction for HEV

An evaluation of the fuel economy of an HEV must be performed under conditions where there is no difference in SOC before and after the vehicle is driven. Therefore, the fuel economy when $\Delta$SOC=0 is estimated based on the results of a fuel consumption simulation with various initial SOC levels. The evaluation then uses this data as the corrected fuel economy.

Furthermore, this research performed a test cycle under both cold and warm start conditions. The fuel economy value was then calculated based on the following proportions: cold start = 25% and hot start = 75%. This made it possible to obtain results that considered the effect of warming up on fuel economy.
3 Effects of Deterioration in Capacity and Internal Resistance on Vehicle Performance

This section analyzes and evaluates the effects of lithium-ion battery capacity and internal resistance deterioration on vehicle performance, and describes the results of the tests. To make it easier to identify the effects on vehicle performance, the study first assumed that each of the following types of battery deterioration advanced independently.

3.1 Effects of Battery Capacity Deterioration

Table 3 and Fig. 3 show the simulation results for the effect of decreases in battery capacity on vehicle performance. These results confirmed that fuel economy (i.e., km driven per liter of fuel) worsened slightly when the capacity retention was 40%. This is because the SOC is more susceptible to fluctuation when the battery capacity decreases (Fig. 4), which increases the frequency at which a SOC of 35% is reached. Since the signal to switch the engine off is transmitted when the SOC reaches 35%, the number of times that the engine is turned ON and OFF also increases. This also leads to an increase in engine cranking, which involves large current flows, and causes an increase in internal resistance loss. However, the results also show that battery capacity deterioration has a very minor effect on vehicle performance.

Table 3: Relationship between Capacity Retention (Cs) and Fuel Economy

<table>
<thead>
<tr>
<th>Cs [%]</th>
<th>Warm up conditions</th>
<th>Initial SOC [%]</th>
<th>Final SOC [%]</th>
<th>ΔSOC [%]</th>
<th>Fuel Economy [km/l]</th>
<th>Corrected fuel Economy [km/l]</th>
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Figure 3: Relationship between Capacity Retention (Cs) and Fuel Economy

Figure 4: Change in SOC at Different Capacity Retention Values
3.2 Effects of Internal Resistance Increase

Table 4 and Fig. 5 show the simulation results for the effect of increases in internal resistance on vehicle performance. As shown in these results, an increase in internal resistance has a significantly greater effect on fuel economy than a reduction in battery capacity. This section evaluates the following performance values to consider the reason for this result.

Table 4: Relationship between Internal Resistance Increase (Rs) and Fuel Economy

<table>
<thead>
<tr>
<th>Rs [%]</th>
<th>Warm up conditions</th>
<th>Initial SOC [%]</th>
<th>Final SOC [%]</th>
<th>ΔSOC [%]</th>
<th>Fuel Economy [km/l]</th>
<th>Corrected fuel Economy [km/l]</th>
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</table>

Figure 5: Increase in Battery Resistance and Fuel Economy Performance

- Charge and discharge efficiency

The discharge efficiency (η<sub>dis</sub>) and charge efficiency (η<sub>chg</sub>) are derived via the following equations.

\[
\eta_{\text{dis}} = \frac{\int (V_{\text{o}} - I_{\text{dis}}R) \, dt}{\int V_{\text{o}} \, dt} \times 100 \tag{1}
\]

\[
\eta_{\text{chg}} = \frac{\int (V_{\text{chg}} - I_{\text{chg}}R) \, dt}{\int V_{\text{chg}} \, dt} \times 100 \tag{2}
\]

- \( V_{\text{o}} \): Open-circuit voltage [V]
- \( V_{\text{chg}} \): Terminal voltage during charging [V]
- \( I_{\text{dis}} \): Discharge current [A]
- \( I_{\text{chg}} \): Charge current [A]
- \( R \): Internal resistance [Ω]
Permissible recovery rate

The permissible recovery rate is an index that expresses how much the battery can be charged from the available power (through regenerative braking etc.) from the standpoint of input performance (determined by the upper limit voltage and maximum charge rate). See Equation 3.

Permissible recovery rate [%]

\[
\text{Permissible recovery rate} = \frac{\text{Amount of power actually charged [kJ]}}{\text{Amount of power supplied to battery [kJ]}} \times 100
\]

Fuel economy declines due to an increase in internal resistance for the following reasons. The first reason is that both the charge and discharge efficiency of the battery decline. Figure 6 shows the efficiency values derived using Equations 1 and 2 above. In particular, the decrease in the discharge efficiency is quite pronounced. To clarify this effect, Fig. 7 shows the total battery energy and internal resistance loss per increase in internal resistance. The increase in internal resistance during discharge makes it more likely that the lower limit voltage will be reached, thereby limiting and reducing the current. The engine then must compensate for the insufficient battery power. As a result, the total battery discharge greatly reduces as the internal resistance rises. In contrast, during charging, the internal resistance can increase to 200% without reaching the upper limit voltage limit so the total energy input will rise in this range. However, when the internal resistance increase exceeds 300%, the upper limit voltage limit is reached and the energy input from charging then decreases. Nonetheless, this decrease is smaller than the total output. The loss increases for both energy input and output. Consequently, in the case of Equations 1 and 2 above, the increase in internal resistance has a larger adverse effect on discharge efficiency compared to charge efficiency.

The second reason is that when the internal resistance increase reaches 300% or higher, the power for charging the battery when the vehicle decelerates is limited. Figure 8 shows the charge efficiency (derived from Equation 2) and the permissible recovery rate of regenerated power (derived from Equation 3) per increase in internal resistance. It is possible to recover all regenerated power when the battery is new, but the permissible recovery rate is greatly reduced when the internal resistance increases. This results in a reduction in fuel economy.

Finally, the third reason for the reduction in fuel economy is that the engine ON time increases. Figure 9 shows the engine running time and increase as the internal resistance rises. This graph indicates that the engine running time increases in accordance with the internal resistance, which has an adverse effect on fuel economy. Furthermore, increased engine cranking also reduces fuel economy. However, compared to the three reasons described above, the adverse effect of additional engine cranking is only minor.

![Figure 6: Charge and Discharge Efficiency when Internal Resistance Increases](image)

![Figure 7: Total Battery Energy and Total Internal Resistance Loss during Charge and Discharge when Internal Resistance Increases](image)

![Figure 8: Charge Efficiency and Permissible Recovery Rate of Regenerated Power per Internal Resistance Increase](image)
4 Effects of Simultaneous Deterioration in Capacity and Internal Resistance on Vehicle Performance

This section describes the results of an evaluation of simultaneous deterioration in battery capacity and internal resistance deterioration to reproduce actual usage conditions more closely. Table 5 compares these two types of battery deterioration. This table was created by referring to the results of a lithium-ion battery storage capacity loss test and then adopted in this analysis [4]. Figure 10 shows the relationship between the internal resistance increase $Rs$ (with simultaneous deterioration in battery capacity) and fuel economy, fuel consumption. These results confirmed that simultaneous deterioration has a larger adverse effect on vehicle performance than the independent deterioration described in the previous sections. This can be explained by a combination of the previous results and observations of the adverse effects of these two battery deterioration phenomena.

Table 5: Relationship between $Cs$ and $Rs$ of Deteriorated Lithium-ion Batteries (Mn-type LIB)

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<td>235%</td>
<td>370%</td>
</tr>
</tbody>
</table>

5 Study of Permissible Battery Deterioration

This section examines the permissible battery deterioration, with a focus on well-to-wheel CO2 emissions [5] and fuel consumption. The results of the analysis are summarized in Fig. 11. Battery deterioration that results in a 20% reduction in vehicle performance compared to a vehicle with a new battery can be defined as the permissible deterioration [6]. As shown in the figure, a 350% increase in internal resistance does not present any problems (when the battery capacity has deteriorated to approximately 60% of the initial value).
6 Conclusion

1. It was confirmed that deterioration in the battery capacity has only a minor adverse effect on the fuel economy and CO₂ emissions of an HEV.

2. In contrast, deterioration in the battery internal resistance has a large adverse effect on the fuel economy and CO₂ emissions of an HEV. Test results and analysis showed that this is directly caused by reductions in the charge and discharge efficiency, an increase in the engine running time due to greater limitations on battery discharge, and a decrease in the permissible recovery rate (an index that expresses how much the battery can be charged from the available power (through regeneration and the like) from the standpoint of input performance).

3. CO₂ emissions and fuel consumption were evaluated as indices of the effect on vehicle performance to examine the permissible battery deterioration. This research determined the permissible vehicle performance reduction to be 20%. It was confirmed that a 350% increase in internal resistance (with capacity retention of approximately 60% compared to a new battery) results in a 20% reduction in vehicle performance. Therefore, it is proposed that 350% internal resistance increase can be used to determine the permissible deterioration of lithium-ion batteries in an HEV.

References


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Electric Future for Transport

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IDTechEx has offices across the world
It provides events, consultancy and publications on electric vehicles, energy harvesting, printed electronics and allied subjects
www.idtechex.com
5 kWh/100km/person fully loaded

Fastest in congestion
Greatest choice of destination
Causes most congestion & accidents

Fastest where there is no congestion
Poorest choice of destination
Causes least congestion & accidents

Bike Scooter Mbike Microcar Midcar Largecar Smallbus Midbus Largebus
Peak car

Car registrations have peaked in many cities
Sydney becomes car free by 2020
New Zealand gave 2000 postmen ebikes
“Young people cannot use a mobile phone while driving”
Other challenges

• China can never build enough roads and parking for cars. It must prioritise subways, trains and buses
• Malaysia and parts of China banning e-bikes because of accidents and congestion
• Government support could be suddenly withdrawn and destroy the electric car industry – it happened in Japan, UK and Spain with solar panels on houses
What EVs are successful

Most attention is given to electric cars but

• More than half the market value is – and will remain - in other electric vehicles

• Increasingly, the same companies make many types of hybrid and pure electric EV.

• The world’s largest electric vehicle business is $23 billion in Toyota - electric forklifts, buses, cars etc and shares the knowhow

• In ten years, most buses will be EVs but no more than 10% of cars will be EVs
Electric vehicles EVs can be pure electric or hybrid

Pure electric EVs drive the wheels/propellers with electricity all the time, usually from a battery.

Hybrid EVs have another source of traction power on board –

First generation HEV has a conventional internal combustion engine – diesel or gasoline.

Second generation HEV has a smaller, simpler piston ICE designed to purpose.

Third generation HEV has a non ICE “range extender” that is better/cheaper eg mini gas turbine or fuel cell.
Hybrid electric vehicles will gradually become more like pure electric vehicles.
Replacing diesel and gasoline
Replacing kerosene and diesel in aircraft
EVs replace oil with

Electricity from sunshine on the vehicle

Hydrogen for fuel cells

Wide choice of liquid fuels for mini turbines
Challenges

Traction batteries – Cost (up to 50% of cost), energy storage = range – 160-240 km today - safety, life
Traction motors – move to no magnets, some in-wheel
Electronic controls including battery management
Systems BMS – move to printed electronics
Range extenders – cost, life, performance, start up time
Energy harvesting – photovoltaic, thermoelectric, electrodynamic, piezoelectric – cost, life, performance

Electrodynamics includes: regenerative braking, shock absorbers, active suspension, plane soaring/descending/landing, boat sailing – propeller in reverse or hydroturbine
Lower upfront cost than ICE version  

Higher cost than ICE but less fuel & maintenance gives payback over life  

Robot bats, birds, insects  

Golf, Microcar, Bike, Disabled  

Forklift, UAV, Bus, Car, Supercar, AUV, Plane, Commercial  

1000 EV Cost $K  

100  

10  

0.1  

0.01  

100 kWh  

1000  

CHEAPER BATTERIES WILL MAKE MORE EVS CHEAPER TO BUY THAN ALTERNATIVES
When will EVs meaningfully take over?  
Global market penetration in numbers %

<table>
<thead>
<tr>
<th>TYPE</th>
<th>2011</th>
<th>2021</th>
<th>2031</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Industrial indoor</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Heavy industrial outdoor</td>
<td>&lt;1</td>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>Light Industrial/Commercial</td>
<td>&lt;1</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>Buses</td>
<td>10</td>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>Two Wheel</td>
<td>20</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Disabled</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Car</td>
<td>3</td>
<td>15</td>
<td>50 90 at best</td>
</tr>
<tr>
<td>Golf Car</td>
<td>70</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Marine</td>
<td>&lt;1 (100 for underwater)</td>
<td>15</td>
<td>30 50 at best</td>
</tr>
<tr>
<td>Aircraft</td>
<td>&lt;1</td>
<td>20</td>
<td>80</td>
</tr>
</tbody>
</table>
For more ..... Choose from 18 IDTechEx reports on EVs and their key components eg “Electric Buses and Taxis 2011-2021” “Electric Vehicle Industry Profitability 2012: Where, Why, What Next?” Read the free Attend “Electric Vehicles Land, Sea, Air” San Jose California March 27-28
Next leap forward of Power Module Interconnection technology to address the demands on reliability and cost targets of the electric drive train (SiPLIT)

Carsten Schmidt, Sales and Marketing Manager, Inside e-Car, Siemens AG
Uwe Gunreben, Product Manager Power Electronics, Inside e-Car, Siemens AG
Motivation

Extended reliability and environmental requirements for the automotive applications.

Current situation: widely spread usage of wire bonding technology for power module components.

Limits of wire bonding technology:
- ruggedness: sensitive to overloads and EMC; silicone required
- reliability: increased failure rates with high temperatures
- performance: inefficient utilization of contact area

→ paradigm shift in chip technology leads to demand on new interconnect technologies
Planar Interconnect Technology-Platform for Power Module Packaging

Advantages

- reduced conduction losses and thermal resistance
- higher power density
- reduced stray inductance
- higher power cycling capability
- improved surge current robustness
- optimized/double side cooling
- integration of sensors enabled

Wire bond technology

Cu-lead
Chip
Cu-metallization
Direct Copper Bonded (DCB) ceramic
Cu metallization

Planar Interconnect

insulation film
Process Flow Example: Semiconductor switch

Original chip on DCB

Isolation by lamination

Laser-Structuring

Metallization

5x7 inch DCB substrate

Photo structuring & Electroplating

Resist Stripping

Difference Etching/Finish

Semiconductor switch

Original chip on DCB

5x7 inch DCB substrate

Photo structuring & Electroplating

Resist Stripping

Difference Etching/Finish
### Innovative Applications in Industrial Electronics

<table>
<thead>
<tr>
<th>IGBT-module for motor inverter</th>
<th>Semiconductor relay</th>
<th>SiC-module for motor inverter</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Inverter power module (3 phase)" /></td>
<td><img src="image" alt="Semiconductor relay: E-Switch module" /></td>
<td><img src="image" alt="SiC-module" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feature</th>
<th>IGBT-module</th>
<th>Semiconductor relay</th>
<th>SiC-module for motor inverter</th>
</tr>
</thead>
<tbody>
<tr>
<td>+400% power cycling robustness</td>
<td></td>
<td></td>
<td>high temperature up to 200°C</td>
</tr>
<tr>
<td>integration of passives</td>
<td></td>
<td></td>
<td>laser welded customer contacts</td>
</tr>
<tr>
<td>customer-specific power module</td>
<td></td>
<td></td>
<td>integration of line and motor filter into inverter housing</td>
</tr>
<tr>
<td>silicone-free</td>
<td></td>
<td></td>
<td>SiC chip technology</td>
</tr>
<tr>
<td>explosion-free</td>
<td></td>
<td></td>
<td>150kHz switching frequency</td>
</tr>
</tbody>
</table>

- +15% surge current robustness
- -7% thermal resistance
- -8% conduction losses
- +32% I²t robustness
- silicone-free
- explosion-free
- -50% substrate height
Reduced conduction losses

Experimental result:
3-phase MOSFET motor inverter

→ 30% higher current rating

Technology Innovations:
- almost 100% chip area contacted
- optimized interconnect thickness
- flexible layout
Improved thermal resistance

Experimental result:
Semiconductor relay (thyristor)

- 15% higher current rating
- 30% higher $I^2t$ robustness

Technology Innovations:

- heat spreading by thick copper lead
- heat buffer for overload conditions
- increased contact robustness

Wire bond

Planar interconnect
Innovation cooling concept

Experimental result:
Energy transfer gate

→ 450 A switched current

Technology Innovations:
- double side cooling
- reduced assembly volume
Stray inductance reduction

**Experimental result:**
Test structure for inductance measurement

→ 50% reduced stray inductance

**Technology Innovations:**
- EMC optimized layout
- planar interconnect
- higher module performance
- integration of components at interconnect level
Concluding remarks

Achievements

Comprehensive reliability tests passed, e.g.

- 150°C for 20,000h lifetime, up to Tj 200°C
- potential for operation > 200°C
- up to 6.5 kV chip blocking voltage
- RF performance up to 77 GHz demonstrated

Technology readily developed for series production
ELECTRIC VEHICLE, WHY SPAIN?

INVEST IN SPAIN
February 2012
Electric Vehicle, why Spain?

I. Introduction
II. Business Identification
III. Excellent environment
IV. Business Analysis
V. State Aid
VI. Integral Plan for Electric Vehicles (Ministry of Industry)
VII. Project Movele (IDAE)
VIII. Spanish Electric Vehicle Forum (FOREVE)
IX. Project CENIT VERDE
X. Green eMotion (European Commission)
XI. Cooperation and Leadership Opportunities
XII. Conclusions
I. Introduction

The **Government of Spain** keeps the bet on the electric vehicle. The policy of development of the electric vehicles is one of the priorities of the Ministry of Industry, Energy and Tourism. This kind of vehicle will be a reference in the Sustainable Economy, and an example of a new model of growth for the Spanish economy.

Their combination of energy and environmental efficiency make electric vehicles the clearest example of the move towards a more sustainable and rational mode of transport deemed necessary and desirable by today's societies.

Spain is especially well placed to meet all the technical and business needs of this sector, coupled with the political will to socially consolidate the use of electric vehicles.
I. Introduction

Various initiatives arise from the intention to win for the Spanish industry the projects which are coming up in this field, as well inside as outside our borders:

✓ 2011: Granting of **168,5 million Euros for the implementation and development of the electric vehicle. Line of guarantees of 500 million Euros** for the development and industrialization of the EV.

✓ 2011: Within the framework of the general call of **support** to strategic industrial sectors the **Automotive** sector will be protagonist with a specific call of **215 million Euros**. The projects related with the hybrid and electric vehicles have special preference.

✓ The **Project Verde**, through the Centre for the Development of Industrial Technology (CDTI), expects to help the proposals for the development in Spain of the technology and manufacturing of the electric vehicle.

✓ **FOREVE**, a forum which brings together important companies whose target is to promote in Spain the development and use of this kind of propulsion.

✓ **Integral Plan for the Electric Vehicle in Spain.**
II. Business Identification

Business Definition

Although sales in Spain cannot yet be defined as high, the gradual electrification of the motor vehicles in use is an inevitable reality.
II. Business Identification

Value Chain

DEMAND

Vehicle on the road

Vehicle availability

Network availability

Import

Domestic production

Charging R&D

Infrastructure

Export

New

Existing

R&D

Investment

R&D Centres

Companies

Technological Centres

Components

Production Technology

Specialized staff

Urban planning

Investment
## II. Business Identification

### Description of the Technology

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hybrid Vehicle (HV)</strong></td>
<td>Combining a thermal engine of medium/big size with an electric motor as support when moving off and accelerating. The vehicle is able to work indistinctly with one, with the other, or with both at the same time.</td>
</tr>
<tr>
<td><strong>Plug-in Hybrid Vehicle (PEHV)</strong></td>
<td>Vehicles powered exclusively by electric motors, and whose batteries are charged from the network or using a small internal combustion engine which spins constantly.</td>
</tr>
<tr>
<td><strong>Vehicle with fuel cells</strong></td>
<td>Vehicle with an electric motor whose energy is provided by a chemical reaction inside a fuel cell.</td>
</tr>
<tr>
<td><strong>Pure Electric Vehicle (EV)</strong></td>
<td>Driven exclusively by one or several electric motors. The charging of the batteries is done from the network or the batteries are being replaced.</td>
</tr>
</tbody>
</table>
III. Excellent environment

The characteristics of the Spanish vehicle production, specialized in low range and with models similar to the electric proposals, make it more compatible as in other countries.

In favor of Spain acts the fact to be specialized in medium and low ranges, precisely where the electric cars are included.

Excellent geostrategic situation of Spain, with direct, fast and economic access to:

✓ The other main European automobile markets (Germany, France, Italy and United Kingdom)

✓ The new emerging markets in North Africa.
III. Excellent environment

The **high development in Spain of the wind energy** makes our country an **ideal destination for the introduction of the electric vehicle on a large scale**.

If the electric vehicle is charged during the night, it is possible to use much better the wind energy produced in night hours (off-peak hours). (Sometimes the wind generators have to be disconnected during the night, as there is not enough demand of electricity.)
III. Excellent environment

Spain has an extensive experience in the automotive sector, as well related to vehicle production, as to having an important sector of automotive parts and accessories.

Our vehicle production plants are between the most competitive at European and world level, and at the same time they have shown that they are very flexible, what entitles them to adapt fast to new market niches.
III. Excellent environment

Final manufacturing cost is lower

In many plants in countries with higher labor costs than in Spain, the labor cost is twice as much as in Spain.

- The transport of a vehicle from a Spanish plant to central Europe can be 60% of the distance from a plant in Romania, or 45% of the distance from a plant in Turkey or in Ukraine.

- The final manufacturing costs in plants in East Europe are above the ones in our plants. That’s why the labor cost is a absolutely irrelevant measure. Training, employee turnover, inflexibility, difficulty for outsourcing, stocks, logistics, interruptions, bureaucracy, at the end increase the costs in an as important as unforeseeable way.

- The plants in Spain have nowadays very reasonable costs. Labor costs that can be the half than in central Europe. Important flexibility levels. High potential of outsourcing. Close suppliers with high levels of real just-in-time. Logistic and connecting infrastructures comparable with the French, German or Italian. Trade unions capable to understand the reality. Therefore, this are plants with future for who worries about the shareholders on long term.
III. Excellent environment

Factors favoring the initiative

*Spain is an important world car manufacturer, with production focused on models in segments with the greatest electrification potential.*

- Second largest vehicle manufacturer in Europe
- First European industrial vehicle manufacturer
- Worlds eight largest manufacturer
III. Excellent environment

Factors favoring the initiative

Spain has a large and competitive auto parts industry, with companies committed to R&D in projects related to electric vehicles.

Spain enjoys a consolidated network of technology centers with highly skilled staff that are breaking new ground in the development of electric vehicles.

Research and development activities enjoy tax breaks
III. Excellent environment

Factors favoring the initiative

In Spain there are 12 companies registered as manufacturers or distributors of batteries, but only two have manufacturing in Spain.

The two main competitive advantages which present Spain refer to:

1.- The high weight and dangerousness of the batteries mean great logistic costs. That’s why the proximity of the manufacturers is a fundamental competitive factor.

2.- A relevant factor in the development of the lithium batteries is the electronic of control of the batteries. The lithium batteries, specific for electric vehicles, require a complex electronic for its more effective use.
III. Excellent environment

Factors favoring the initiative

*Spain is located in the top five electricity producing countries of the European Union, making it one of the most attractive places for the development of electric vehicles.*

| Producción total neta de energía eléctrica de los países de la Unión Europea miembros de la UCTE (TWh) |
|----------------------------------|----------|----------|--------|
|  | 2007    | 2008    | % 08/07 |
| Alemania | 584,0    | 587,3    | 0,6    |
| Austria  | 63,9     | 66,8     | 4,4    |
| Bélgica  | 89,1     | 89,6     | -0,5   |
| Bulgaria | 38,2     | 40,6     | 6,2    |
| Estiónia | 26,1     | 27,4     | 5,0    |
| Eslovenia| 13,1     | 14,3     | 9,7    |
| España (1)| 271,6   | 278,3    | 2,5    |
| Francia  | 544,7    | 549,1    | 0,8    |
| Grecia   | 52,5     | 51,9     | -1,1   |
| Holanda  | 91,3     | 104,4    | 5,1    |
| Hungría  | 37,3     | 35,0     | -6,1   |
| Italia   | 301,4    | 305,2    | 1,2    |
| Luxemburgo| 3,9     | 3,8      | -11,7  |
| Polonia  | 148,4    | 144,4    | -2,7   |
| Portugal | 44,6     | 43,4     | -2,8   |
| República Checa| 81,4 | 77,1    | -5,3   |
| Rumania  | 56,4     | 57,9     | 2,6    |

Total   | 2,451,9  | 2,449,0  | 0,7    |

(1) Sistema particular. Fuente: UCTE. Incluye adquisiciones al régimen especial.
III. Excellent environment

Factors favoring the initiative

In addition, Spain offers lower energy transport costs than its competitors, as can be seen in the following graph.

Source: REE Data 31/12/2008
III. Excellent environment

Factors favoring the initiative

92.5% of the increase in power output was provided mainly by renewable sources. Wind power meets 11% of the total demand.

Source: REE Data 31/12/2008
III. Excellent environment

Factors favoring the initiative

Main projects currently being developed in Spain

- REVE
- URBANcar
- CITYELEC
- TECMUSA
- CENIT VERDE
- HIRIKO
III. Excellent environment

**Project Hiriko**

Initiative promoted by AFYPAIDA, DENOKINN, EPSILON EUSKADI with the collaboration of the MIT for the development of a new solution for the new urban mobility as conceptualized under the “Citycar” concept. This corporate Project will transform the initial concept of the “Citycar” and turn it into an innovating industrial Project consisting of the development of the initial prototype and its industrialization by means of an innovating production and distribution model. This project is born with a clear vision of transforming and regenerating the industrial grid in both Alava and the Basque Country, and for this purpose it counts on the participation of companies from the automotive sector that are in charge of manufacturing and developing each one of the modules that compose the “Citycar” concept.

Launching in 2012. Price is estimated at 9.000€. It will be collapsible to facilitate parking, with a battery charging time of 12 minutes, 50 km/h of maximum speed and 120 km of range.
IV. Business Analysis

Current Business Situation in Spain

Domestic and foreign manufacturers such as RENAULT, MERCEDES-BENZ, PEUGEOT, CITROËN, FORD and SEAT have already made firm decisions to produce electric powered vehicles in Spain.

The main domestic and foreign parts companies with plants in Spain are already working on specific components and systems for electric and hybrid vehicles.
IV. Business Analysis

Current Business Situation in Spain

Based on imagination and research the bus Tempus has been conceived and built by Castrosua in collaboration with other companies, universities and technological centers. Tempus is an electric vehicle, able to run with zero pollutant emissions and low noise in those more sensitive areas of the city, with a range up to 300km.

With an electrically powered and diesel engine to help charge the batteries, this hybrid concept is an effective and ecological for city buses.
IV. Business Analysis

Current Business Situation in Spain

The operator responsible for managing electricity in Spain, REE, is considering and assessing the integration and development of electric vehicles in Spain.

In addition, large energy companies such as Cepsa, Repsol, Endesa, Iberdrola, Gas Natural and Acciona are taking part in projects to develop the necessary charging infrastructure for electric and plug-in hybrid vehicles.
IV. Business Analysis

Progression Forecasts

The electrification of the automobiles in use is a reality. In the next years the number of hybrid and electric vehicles will increase in a nearly exponential way.

**Ambitious target: 1 million hybrid and electric vehicles in 2014**

The consumer perception when purchasing a vehicle will change substantially towards values as energy efficiency and sustainability. That’s why the prospects for the electric powered vehicles are very favorable.
IV. Business Analysis

Interest in and purchase consideration of electric and hybrid vehicles

<table>
<thead>
<tr>
<th>Country</th>
<th>Interest in Electric or Hybrid Vehicles</th>
<th>Purchase Consideration of Electric or Hybrid Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>32%</td>
<td>30%</td>
</tr>
<tr>
<td>Germany</td>
<td>27%</td>
<td>21%</td>
</tr>
<tr>
<td>Italy</td>
<td>29%</td>
<td>17%</td>
</tr>
<tr>
<td>Spain</td>
<td>32%</td>
<td>22%</td>
</tr>
<tr>
<td>UK</td>
<td>19%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Base: 5,253 interviews conducted in France (1,102), Germany (1,029), Italy (1,060), Spain (1,006) and UK (1,056)

Note: Question asked: “Which of the following actions have you ever undertaken in relation to electric or hybrid cars?”; participants could choose all applicable activities from a list of answers for interest (“researched facts and figures”, “obtained pricing”, “obtained technical info”, “test drove”) and purchase consideration (“considered buying in more than 2 years”, “considered buying in 1-2 years”)

Source: EurotaxGlass’s & Harris Interactive Consumer Survey (2010)
IV. Business Analysis

Purchase Intention of Electric and Hybrid Vehicles

Source: EurotaxGlass’s & Harris Interactive Consumer Survey (2010)
IV. Business Analysis

Progression Forecasts

Spain is one of the European countries that is most committed to electric powered transport, both in the development of vehicles and supply infrastructure.

**IMPULSO DEL VEHICULO ELÉCTRICO EN ESPAÑA**

<table>
<thead>
<tr>
<th>Iniciativa</th>
<th>Objetivo</th>
<th>Al final de ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corto Plazo: MOVELE (1)</td>
<td>2.000</td>
<td>2010</td>
</tr>
<tr>
<td>Medio Plazo: EEIVE (2)</td>
<td>250.000</td>
<td>2014</td>
</tr>
<tr>
<td>Largo Plazo: Directiva EE.RR. (3)</td>
<td>2.500.000</td>
<td>2020</td>
</tr>
</tbody>
</table>

(1) Proyecto Piloto gestionado por IDAE (casi 100% BEV).
(2) Estrategia Español de Impulso del VE (2010-2014)
(3) Directiva 2009/28/CE: Art. 3.4. Objetivo 2020: 10% de fuentes renovables en el transporte. (Biocombustibles y electricidad renovable en VE. - 38,5% EERR en el mix eléctrico)

Legislación nacional: PANER (2011-2020): 342 ktep/a en 2020 (Consumo estimado - 20% Full electric; 80% PHEV; 12.500 km/a; 0,19/0,09 kWh/km).
V. State aid

Incentives from the Ministry of Industry

2011: Budget allocation for the implementation and development of the electric vehicle.

The budget stipulates a total of 81 million to subsidize de acquisition of electric vehicles.

Furthermore other actions are planned, as a support plan for the development and industrialization of the electric vehicle (70 million) and a support plan for the communication technologies between the electric grid and the electric vehicle (17.5 million).

Likewise a new line of guarantees of an amount of 500 million for the development and industrialization of the EV is planned.
V. State aid

Competitiveness Plan of the Automotive Sector

Provision of financial support to the automobile sector specially for the development of projects concerning electric vehicles.

Designated to the realization of investments aimed at the manufacturing of more environmental friendly products.

Financing projects which consist of the production of green cars and car components which contribute to the realization of green cars and thereby significantly improve environmental protection.

Call 2011: **215 million Euros**

http://www.mityc.es/PortalAyudas/Automocion/Descripción/Paginas/Objetivos.aspx
VI. Integral Plan for the Electric Vehicle in Spain

The quantitative target of the Integral Plan for the Electric Vehicle in Spain is to facilitate the introduction of electric and plug-in hybrid vehicles, to reach in 2014 the presence of 250,000 units of this kind of vehicles in Spain*.

To reach this target, the boost of the electric vehicle has to overcome the barriers on its introduction in the market, through four action lines or fields:

- Boost of demand and promotion of use of EV.
- Encourage its industrialization and the specific R&D+I for the EV.
- Development of charging infrastructure and energy management.
- A group of horizontal measures which group aspects common to the before mentioned strategic lines, or which are not specific of one of them.

* This number of vehicles added to the number of hybrid vehicles reaches de total quantity of one million vehicles.
VI. Integral Plan for the Electric Vehicle in Spain

**Targets 2014:**

- new registrations of EV will reach 110,000 units (aprox 7% of the market in 2008)
- 250,000 electric vehicles in use in Spain (1% of vehicles in use 2008).
- 340,000 charging spots
VI. Integral Plan for the Electric Vehicle in Spain

Public support of 590 million Euros in 2011-2012:

• **Incentive for acquisition:** 25% of vehicle price (max. 6,000€)

• **Support for industrialization and R&D+i.** Inside the support to the strategic industrial sectors and to the reindustrialization the business plans focused on the electric vehicle will have priority. It is planned to assign **140 million Euros in 2011 y 2012**.

• **Support for the development of communication technologies between electric grid and electric vehicles.** Through the Plan Avanza a line will enunciate to favor the development of technologies on communication systems for charging optimization. It is planned to assign **35 million Euros in two years**.

• **Priority lines of R&D+i for electric vehicles.** This initiative expects to identify and analyze the key technologies, and its spreading in business and research fields, as well as its fostering. For this the estimation is a contribution of **173 million Euros**.

• **Strategic Marketing and institutional communication.** Identification of the barriers of habits and opinion which present the electric vehicle. Definition and realization of a marketing plan to overcome this barriers. In total the cost estimation of this actions is of **2 million Euros**.
The Project Movele is an initiative meant to show the technical, economic and energy feasibility of electric vehicles through the introduction, in a timeframe of two years, of 2000 electric vehicles.

For this it counts with a total amount of 8 million € for direct incentives between 750 and 20000 €, depending on the type of vehicle, and which in case of cars can be up to 7000€.

In parallel, and to guarantee the logistic feasibility of this project, the city councils from Madrid, Barcelona and Seville will collaborate with the Government through the implementation and put in operation of a pilot network of public charging stations for electric vehicles. Specifically, and thanks to the agreements signed with this three big cities, 546 public charging spots will be installed -280 in Madrid, 191 in Barcelona and 75 in Seville- between 2009 and 2010. The investment associated to this infrastructures add up to 2.5 million €.
VIII. Spanish Electric Vehicle Forum (FORĒVE)

The Spanish Forum of the Electric Vehicle (FORĒVE) starts with the target to boost the manufacturing, use and energy use of this mean of transport. FORĒVE is a private initiative promoted by FITSA (Foundation Technological Institute for the Safety of the Automobile) and by IDAE (Institute for the Diversification and Saving of Energy).

FORĒVE will concentrate on carrying out and promoting useful actions for the following fields:

- The industry and the technology
- Boost of the demand
- The technological solution for a sustainable mobility
- The energy services required by the vehicle, as well as by the electric energy supply management.
- Support services for the public initiatives that promote the use of electric vehicles.
IX. Project CENIT VERDE

The aim of the project is the research and development of technologies which allow a fast, economic and reliable market penetration of the plug-in hybrid and electric vehicles, manufactured mostly in Spain. It is structured in seven principal activities:

ACTIVIDAD 1: Estudio e integración de tecnologías mecánicas y eléctricas en el vehículo eléctrico

ACTIVIDAD 2: Sistemas de almacenamiento de energía

ACTIVIDAD 3: Sistemas de tracción eléctrica

ACTIVIDAD 4: Convertidores de carga y descarga de baterías

ACTIVIDAD 5: Infraestructuras para la recarga de energía

ACTIVIDAD 6: Integración de la carga del vehículo eléctrico en el sistema eléctrico

ACTIVIDAD 7: Integración y validación de las tecnologías desarrolladas: balances energéticos y medioambientales

Endesa and Iberdrola co-lead the activity 6

(1) Proyecto CENIT (Consorcios Estratégicos Nacionales en Investigación Técnica) dentro del Programa Ingenio 2010 del CDTI (Centro para el Desarrollo Tecnológico Industrial), dependiente del Ministerio de Ciencia e Innovación. Participantes: SEAT, CEGASA, SIEMENS, LEAR, COBRA, ENDESA, IBERDROLA y REE.
X. Green eMotion (European Commission)

Green eMotion Initiative to prepare the mass market for electromobility in Europe

The 42 partners in the initiative comprising industrial companies and automobile manufacturers, utilities, municipalities, universities, and technology & research institutions are to input, exchange and expand their know-how and experience in selected regions within Europe:

- **Industries:**
  - Alstom, Better Place, Bosch, IRM, SAP, Siemens
- **Utilities:**
  - Danish Energy Association, EDF, Endesa, Enel, ESB, Eurelectric, Iberdrola, RWE, PPC
- **Electric vehicle manufacturers:**
  - BMW, Daimler, Micro-Vetti, Nissan, Renault
- **Municipalities:**
  - Barcelona, Berlin, Bornholm, Copenhagen, Cork, Dublin, Malaga, Malmö, Rome
- **Research institutions and universities:**
  - Cartif, Cidaut, CTL, DTU, ECN, Imperial, IREC, RSE, TCD, Tecnalia
- **EV technology institutions:**
  - DTI, FKA, TÜV Nord
X. Green eMotion (European Commission)

EU-wide demonstration features: Consumer label / EU clearing house / standards and interoperability / cross-border rally

- Strasbourg
  Special features: Plug-in hybrid vehicles, cross-border connection with Karlsruhe / Stuttgart

- Ireland (Dublin, Cork)
  Special features: DC charging stations, kWh billing system, supplier choice

- Madrid
  Special features: Advanced RES integration studies, smart grid integration etc.

- Malaga
  Special features: Embedment in smart city concept, V2G, B2G, DC charging stations

- Karlsruhe/Stuttgart
  Special features: Smart Grid features, optimised bi-directional charging, cross-border connection with Strasbourg

- Copenhagen, Bornholm, Malmö
  Special features: Battery swopping, cross-border

- Berlin
  Special features: Largest integrated project worldwide testing business models and consumer behavior

- Barcelona
  Special features: Electric mobility service citizen office, large e-motorbike demonstration, EVS27

- Italy (Rome, Pisa)
  Special features: System approach enabling innovative services and user interfaces, kWh billing system, alternative business models testing

- Existing demonstration region
- Replication region
- Municipalities involved in Green eMotion
XI. Cooperation and Leadership Opportunities

- 2009: Spain was the second European vehicle manufacturer
- 11 vehicle manufacturer in Spain
- Opportunity of attraction of R&D+I activities to Spain
- Opportunity of cooperation and synergies with the big European automotive groups present in Spain.

- Spain: world leader country in renewable energies (TOP-5 in installed capacity and world leading companies)
- Spain must solve soon the problem of squander of the renewable energy in off-peak hours (night hours), being the EV an excellent opportunity.
- Capacity of Spanish leadership in technologies of integration and management of the demand.

- Spain has companies that are reference at international level on electronic measurement and tarification systems
- In Spain there are companies with capacity for the development if the communications between vehicle and charging spot
- Spain counts with leading companies in infrastructure and civil works
- Leadership capacity in development and management of charging systems for EV
The electric vehicle is a reality in Spain, currently there are projects for its development.

Public administrations and private companies are boosting this initiative.

Spain has outstanding competitive advantages, as the business infrastructure of very developed and specialized technological and industrial centers.
SPAIN WILL HOST ELECTRIC VEHICLE SYMPOSIUM 2013

EVS27
Barcelona 2013

Barcelona: voted to host EVS27, June 2013.
Preparation of Spanish candidacy was led by:
• Barcelona City Council
• IDAE: Institute for Energy Diversification and Saving (Ministry of Industry).
• AVELE: Spanish Association of EV

Ajuntament de Barcelona
avele
IDAE
Thank You Very Much