Fuel Consumption Potential of Different Plug-in Hybrid Vehicle Architectures in the European and American Contexts

A. Da Costa, N. Kim, F. Le Berr, N. Marc, F. Badin, A. Rousseau

IFP Energies nouvelles / Argonne National Laboratory
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- Sizing Results
- Simulation Results
- Conclusion
Objectives

The objective is to assess the impact of driving behavior and standard test procedures on the true benefits of PHEVs for Europe and the US market.

- Increasing pressure on GHG emissions
- EEC / USA
  - different markets
  - different standards procedures
  - different tax systems
- By 2020, which car for which country?
Approach

- Simulation of different HEV/PHEV architectures
- Several AER considered
- Both EEC and USA contexts
- Identical program of demand for all the vehicles
  - maximum speed
  - hill capability
  - acceleration
Methodology

- Each Lab used its own simulation tools
  - ANL : Autonomie
  - IFPEN : AMESim
- We made sure results were consistent
- Dedicated tools were shared
  - ANL : Battery sizing
  - IFPEN : Electric motor sizing

Comparison of fuel consumption between AMESim and Autonomie

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Conventional [L/100km]</th>
<th>Parallel HEV [L/100km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEDC</td>
<td>Autonomie 5.75</td>
<td>3.52</td>
</tr>
<tr>
<td></td>
<td>AMESim 5.64</td>
<td>3.51</td>
</tr>
<tr>
<td>Artemis Urban</td>
<td>Autonomie 8.42</td>
<td>3.97</td>
</tr>
<tr>
<td></td>
<td>AMESim 8.27</td>
<td>3.74</td>
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<tr>
<td>Artemis Road</td>
<td>Autonomie 4.88</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td>AMESim 4.78</td>
<td>3.67</td>
</tr>
<tr>
<td>Artemis Highway</td>
<td>Autonomie 6.44</td>
<td>5.93</td>
</tr>
<tr>
<td></td>
<td>AMESim 6.3</td>
<td>6.1</td>
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<tr>
<td>UDDS</td>
<td>Autonomie 5.56</td>
<td>3.52</td>
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<tr>
<td></td>
<td>AMESim 5.51</td>
<td>3.6</td>
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<tr>
<td>HWFET</td>
<td>Autonomie 4.2</td>
<td>4.13</td>
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<tr>
<td></td>
<td>AMESim 4.16</td>
<td>4.18</td>
</tr>
</tbody>
</table>
Component Data

- Internal Combustion Engine (ICE)
  - 1800cc spark ignition engine developed at IFPEN
- Electric Machine - IFPEN in-house software (EMTool)
- Battery - reference provided by Argonne, Idaho National Laboratory, and major battery suppliers

Efficiency map of electric motor (experimental data from Oak Ridge laboratory)

Efficiency map of electric motor (simulation results coming from the EMTool)

Absolute error map between experimental results and simulation results
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Component Sizing

- All the vehicles have been sized to meet the same requirements:
  - Initial vehicle movement (IVM) to 100kph in 9 sec ±0.1 sec,
  - Maximum grade of 5% at 110kph at gross vehicle weight (GVW)
  - Maximum vehicle speed >150kph with ICE power only, and
  - All electric Range (AER) on UDDS (for US) or Artemis Urban (for Europe)

### Specification of the compact-size sedan

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body and chassis mass</td>
<td>800 kg</td>
</tr>
<tr>
<td>Frontal area</td>
<td>2.18 m²</td>
</tr>
<tr>
<td>Drag coefficient</td>
<td>0.3</td>
</tr>
<tr>
<td>Wheel radius</td>
<td>0.317 m</td>
</tr>
</tbody>
</table>
| Final drive ratio      | Conv. AU : 4.44, Conv. MT : 4.29  
                         | Parallel HEV&PHEV : 4.29, Split HEV&PHEV : 4.059  
                         | Series PHEV : 11.36, GM Voltec : 3.02, BEV : 4.44  |
| Gear ratio             | Conv. AU : 2.67, 1.53, 1.02, 0.72, 0.53  
                         | Conv. MT : 3.14, 1.87, 1.24, 0.95, 0.73  
                         | Parallel HEV&PHEV : 3.14, 1.87, 1.24, 0.95, 0.73  
                         | Split HEV&PHEV : 2.6 (Zr/Zs), Series PHEV: -  
                         | GM Voltec : 2.24 (Zr/Zs), BEV : 1.86, 1  |
Sizing Results

- Power demands close for US and EEC vehicles
- Parallel hybrid leads to the lowest total embedded power
Sizing Results

Battery sizing results

- Par. - EU
- Par. - US
- Series - EU
- Series - US
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Fuel Consumption results
Charge Sustaining

- Results are comparable for all architectures, except Series
- NEDC leads to high Fuel Savings
Fuel Consumption results
Charge Sustaining

- Results are comparable for all architectures, except Series
- NEDC leads to high Fuel Savings
- EEC procedure always tends to higher electric consumption
- Overall energy consumption is lower on the EEC test procedure
CO2 emissions

- 3 daily trips scenarios have been simulated
  - 40, 75, 100km

- 3 electricity mix have been considered
  - 100, 450, 650 g CO2/kW.h$_{el}$
CO2 emissions

Total CO2 emissions on mission profile 3
Conv. AU : 173, MT : 163

CO2 emissions [g/km]

Total Battery energy [kW.h]
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Conclusions

- Graph Fuel saving vs Batt energy EEC/USA → easier to cut standards FC in EEC

![Graph showing Fuel Consumption gain on standard procedure - EEC & US](image-url)
Conclusions

• On an overall CO2 point of vue, PHEV and BEV make more sense in Europe or France

• On an economic point of vue: go see Dr Bernd Propfe (DLR) presentation! (dialogue session 2, board #11E)
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Contact / Website

Anthony Da Costa, anthony.da-costa@ifpen.fr, François Badin, francois.badin@ifpen.fr
IFP Energies Nouvelles 1 à 4, Avenue de Bois-Préau 92500 Rueil-Malmaison, France

Namdo Kim, nkim@anl.gov, Aymeric Rousseau, arousseau@anl.gov (http://www.autonomie.net/)
Argonne National Laboratory, 9700 South Cass, Argonne IL 60439, USA