Hybrid4All:
A low voltage, low cost, mass-market hybrid solution

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Agenda

1 Market Analysis
2 Main issues of Hybrid / Electric vehicles
3 Simulation approach
4 Valeo Components
5 Conclusions
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1. Market Analysis
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Regulation is the main driver of Powertrain evolution

Consensus on regulation target

- **2020**
  - 5 l/100 km (117g) for P Cars
  - 4.5 l/100 km (106g) for P Cars

- **2025**
  - 54.5 mpg
  - 93g CO₂/km eq
  - NEDC for P Cars
  - 3.9 l/100 km

- **2020 (cars only)**
  - 95g CO₂/km
  - 4.0 l/100 km

US Speeding up, China have set up the rules
All catching up on Europe

*China's target reflects gasoline vehicles only. The target may be lower as all vehicles are considered.*

October 2013
To reach 95g, ICE and transmissions efficiency is not enough. Hybrids and EVs will be necessary.
There are a lot of Hybrids

*From simple Start-Stop to ZEV mode*

Micro Hybrid

Mild Hybrid

Full Hybrid

Plug In Hybrid

Range Battery EV

Fuel Cell EV

Smart

Buick LaCrosse

Honda Insight

Toyota Prius3

GM Volt

Nissan Leaf

+ Electric drive

+ Electric take off

+ Engine Torque assistance

+ Kinetic Energy recovery

Stop & Start

October 2013 | 6
There are a lot of Hybrids

By definition, an Hybrid has 2 DNAs; combustion and electric engines

- Electric motor on Combustion Engine (Buick LaCrosse)
- Electric motor in transmission (Toyota PRIUS)
- Electric motor on rear axle (PSA 3008 HY4)

October 2013
Electrification Forecast: Worldwide

**Vehicles <6T, Oil barrel $120 2020, Li-Ion Battery 300 €/kWh 2020**

Source: 2013 Valeo Powertrain Forecast

**Internal Combustion Engine**

- **Growth of Stop-Start**
- **FULL as niche, then growth**
- **MILD take-off**
- **Emergence of PHEV**
- **Stop-Start**

**Trends**

- **BEV/FCEV**: only 1.6% in 2023, still a limited market (lower segments), urban usage or image product
- **EREV**: not confirmed
- **FULL / PHEV**: faster growth than in last forecast, growing weight of PHEV from 2018 – 2019
- **MILD**: market take off delay, rather in 2018
- **Stop-Start**: getting mainstream with regular growth from now – still 23% CONV, mainly in BRICS

October 2013 | 8
**Electrification Forecast: Europe**

*Vehicles <6T, Oil barrel $120 2020, Li-Ion Battery 300 €/kWh 2020*

- **Fast growth of Stop-Start**
- **Emergence of Electric**
- **Growth of MILD / FULL**

**Trends**

- **BEV/FCEV:** lower forecast than in the past (A / B / C + LCV), EREV remaining a niche
- **FULL / PHEV:** growing significance, with higher weight of PHEV in sales
- **MILD:** somewhat postponed – take off expected in 2018
- **Stop-Start:** becoming standard within the next 6 years, almost 0% conventional engines in 2023
- **Significant Hybrid growth expected before 2020 to reach 95 g (expected 103g 2020, 88 g 2023)**

*Source: 2013 Valeo Powertrain Forecast*
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Main issue of Hybrid/Electric: COST!

- Cost of powertrain (£): 68% for GASOLINE STOPSTART, 29% for DIESEL STOPSTART.

Market Share 2012:
- Diesel: 1%
- Gasoline Stopstart: 2%
- Gasoline Mild Hybrid: 0%
- Gasoline Full Hybrid: 0%
- Gasoline PHEV: 0%
- BEV: 0%

Diesel today just represents the upper limit customers are ready to pay for. Hybrids won’t develop in mass market without a clear cost breakthrough.
Main issue of Hybrid/Electric: COST!

Main reason of high cost is battery voltage. The higher the voltage, the higher the cost.
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Optimized hybrid: simulation approach

**Architecture study**
- (e-Machine location)

**Electric motor & battery**
- (Technology, Power, Voltage, Capacity)

**Mission profile**
- (NEDC, WLTC, Artemis Urban)

**Vehicle platform**
- (Engine displacement, segment)

**HEV simulation platform**
- Supervisor model
- Vehicle & driver model
- Traction model

**Energy Management**
- Voltage and current curves
- Operating modes
- Energy storage

**Fuel consumption**
- CO2 saving
- Cost / gCO2

**Optimized system**
Architecture study

**Electric Motor directly on the crankshaft of the engine**
- Single Electric Machine
- Easy integration in case of belt driven system
- Low global efficiency due to engine losses
- Engine losses compensation by EM

**Electric Motor between engine and gearbox with an additional clutch**
- No engine losses to compensate
- Original clutch to be controlled & additional clutch required
- Integration issue on transversal engine
- Potential additional starter / alternator
- Torque control during engine start

**Electric Motor behind the gearbox through a disconnect clutch**
- No engine nor gearbox losses to compensate
- Torque continuity during gear change
- Original clutch to be controlled & additional clutch required
- Additional starter / alternator
- Speed range issue for electric motor efficiency

First conclusion: Easiest / cheapest system is with belt-driven machine
Operation modes

- Extended Stop / Start (even with manual gearbox), coasting
- Electric mode: running and take off (even with belt driven system)
- Generation mode & regenerative braking
- Torque assist / Overboost
Battery capacity sizing

Simulation results on B segment vehicle

**NEDC results**

- **EDLC max. storable energy [kJ]**
  - NEDC - MH1
  - NEDC - MH2
  - NEDC - MH3

- **Electric energy stored in EDLC during regenerative braking [kJ]**
  - ~50 kJ
  - ~75 kJ
  - ~75-105 kJ

**Artemis urban results**

- **EDLC max. storable energy [kJ]**
  - NEDC - MH1
  - NEDC - MH2
  - NEDC - MH3

- **Electric energy stored in EDLC during regenerative braking [kJ]**
  - 40-75 kJ
  - 40-75 kJ
  - 75-105 kJ

Second conclusion: Best value usable energy capacity < 100 kJ
Battery capacity sizing

- 100 kJ is the optimal usable level of energy

- However, to size the storage pack, need to apply SOC and safety factors
  - Using ultracapacitors, the only limit in SOC is voltage drop. To keep voltage at nominal level, we have then considered a maximum 50% depletion in use:
    - *We then considered the size of UCAPs pack at ~200kJ*
  - Using Li-Ion batteries, it is necessary to limit the SOC swing in order to have a good lifetime (ex: 30%). Also, the peak currents (12kW under 48V gives 250Amps) might seriously damage the battery. Hence, in accordance with battery makers, we have applied an additional safety factor of 2 to 3.
    - *We then considered the size of the Li-ion pack at ~600-900 kJ (~180-270Wh) – therefore, a Li-ion cell around 6Ah*

**Third conclusion:** Small storage capacity is enough (<900 kJ)
Fourth conclusion: best cost to value with a 6-8 kW BSG motor
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Valeo i-BSG Product Definition

**E-machine description**

- **Claw poles number**: 8pp
- **Interpolar magnets type**: Low Dy rate
- **Stator type**: U pins
- **Stator length**: 42mm
- **Phases number**: 2 x 3
- **Stator thermal sensor
- **Cooling**: Forced air convection
- **Electronics**: Integrated inverter
- **Protection level**: IP25
- **Weight**: 9,5kg

* Bracket diameter
** Without pulley
Valeo i-BSG Product Definition

E-machine Mappings

I-BSG double star machine + Inverter total efficiency at 44 Volt DC
(machine copper $T^c=100^\circ C$, MOS $T^c=100^\circ C$, 2 MOS Fairchild 30mm$^2$)

Machine torque (Nm)

Rotor speed (rpm)

(% efficiency)
### Valeo DC/DC Converter Definition

#### Prototype – Specifications

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic</td>
<td>Reversible buck (pre-charge and/or boost feature) &lt;br&gt;Uninsulated chopper with embedded EMC filters in LV side</td>
</tr>
<tr>
<td>Output Voltage Range</td>
<td>Buck/Boost: 8 – 14 – 16V &lt;br&gt;Derating between 8 and 10V</td>
</tr>
<tr>
<td>Max Rated Power</td>
<td>2,5kW @ 14,5V</td>
</tr>
<tr>
<td>Efficiency</td>
<td>96% @ 500W &lt;br&gt;93,5% @ 2500W</td>
</tr>
<tr>
<td>Weight</td>
<td>&lt; 3,1kg</td>
</tr>
<tr>
<td>Cooling</td>
<td>Air cooled with minimal air velocity 2m/s</td>
</tr>
<tr>
<td>Full Temperature Range</td>
<td>-30 to +75°C &lt;br&gt;Derating between 75 and 105°C</td>
</tr>
<tr>
<td>Protection class</td>
<td>IP67, IPX9X</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>Full compliance with Li-Ion battery (bidirectional power flow when Vin &gt; Vout)</td>
</tr>
</tbody>
</table>

- Bi-directional power flow → Can supply the energy storage unit with power
- High safety class (ASIL C), high power (2,5kW)
Valeo DC/DC Converter Definition

Prototype – Packaging

Dimensions

- Length: 218mm
- Width: 152mm
- Height: 78mm
- Volume: 2.6l

Estimated weight: 3kg

Control Board

Power Board Scalable Design
4 Cells
Demonstrator: BSG implementation on 1.6l Turbo GDI M/T: i-BSG integration scheduled.
Fuel economy results

Simulation results on NEDC cycle B segment vehicle

Extended stop start
Up to 5.5%

Regen and boost
Up to 5%

Electric modes
Up to 3-4%

13-15% Fuel economy can be achieved
Vehicle assessment

- **Stop Start extended function**
  - Faster starting with BSG machine than starter / starter generator
  - Very low vibration level and silent cranking
  - Capability of Reflex start & coasting up to 70kph
  - Excellent Engine stop assistance: -70% stop time & oscillation

- **Torque assist**
  - Transparent to the driver,
  - Turbolag compensation at low revs

- **Electric mode in running & take Off conditions**
  - Transparent switch from thermal to electric mode even in take off
  - Up to 30kph electric drive possible in steady state conditions, up to 20% driving time in city conditions

Overall excellent driveability
Cost estimate

- Total system cost estimate (Machine, Inverter, Battery, DCDC and ancillaries) in €
- Production volume sensitivity with projection up to 1 Mu/yr.

The value equation turns very positive with mass production volumes, in the 40€/g CO₂ range
Conclusion

- A 48V mild hybrid system can deliver 13 - 15% fuel economy

- A 48V system allows, through rightsizing of the storage element, to cut cost of current mild hybrids by half

- This is why we believe mild hybrids could go to mass-market and reach a 10-12% WW market shares in 2020.

Thank you