APEC 2015
EV-HEV Market and Technology Trends
EV/HEV Market
EV/HEV market development: why and how?

Why developing electrified vehicles?
CO2 and pollution reduction

The strengthening CO\(_2\) regulation is the key driver for the development of electrified vehicles.

Source: Mov’eo
Different options to electrify vehicles

Definition of different electrified vehicles (1/2)

- **SSV + µHEV**: 5 – 10%
- **Mild HEV**: 10 – 25%
- **Full HEV**: 25 – 40%
- **Plug in HEV (with EREV)**: 50 – 100%
- **EV (BEV or FCV)**: 100%

Different levels of electrification exist to answer CO2 reduction targets.

Cars examples (not exhaustive list):
- Toyota Prius
- Honda Civic
- Mitsubishi Outlander
- Nissan Leaf

Source: Yole Développement
### EV/HEV market development: why and how?

**Different options to develop electrified vehicles**

**Definition of different electrified vehicles (2/2)**

<table>
<thead>
<tr>
<th>Functions</th>
<th>SSV + µHEV</th>
<th>Mild HEV</th>
<th>Full HEV</th>
<th>PHEV (with EREV)</th>
<th>EV (BEV or FCV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start/stop: stop engine idle when a vehicle slows down and comes to a stop</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Regenerate braking</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Additional power for a few seconds (electric motor)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Additional power for mid distance (city traffic)</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Power for long distance (10 to 40 miles)</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>recharge battery on the grid or with a generator</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Energy savings</td>
<td>5-10%</td>
<td>10-25%</td>
<td>25-50%</td>
<td>50-100%</td>
<td>100%</td>
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<tr>
<td>(up to 25% in city traffic)</td>
<td></td>
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<tr>
<td>Electric power</td>
<td>3-8 kW</td>
<td>4-20 kW</td>
<td>30-75 kW</td>
<td>70-100 kW</td>
<td>70-100 kW</td>
</tr>
<tr>
<td>Car example</td>
<td>PSA C2</td>
<td>Honda civic</td>
<td>Toyota Prius</td>
<td>GM Volt</td>
<td>Nissan leaf</td>
</tr>
</tbody>
</table>

*Source: Yole Développement*
EV/HEV market development: why and how?

EV sales worldwide in 2013 and S1 2014
Split by car models

For the first semester 2014, the Nissan Leaf was still leader with more than 50% of 2013 sales. The Mitsubishi Outlander (PHEV) is second, but its sales for 2014 represent more than 75% of 2013 sales, which is very encouraging.

Kandi EV cars are mainly used for car-sharing in Hangzhou city.
EV/HEV market development: why and how?

*What slows down electrification*

- Electrified vehicles market still has to overcome some difficulties to know a full development

- **Price** of electrified vehicles is often prohibitive for users; with technology continuous improvement and volumes increase, electrified vehicles should quickly reach thermic ones in terms of price

- **Battery cost and autonomy** is still a big obstacle to market advancement. Many projects have been launched to increase battery capacity worldwide and so to decrease battery cost. Moreover, many progress have been done on power density to reduce battery volume. In the coming years we expect battery cost to drop strongly and autonomy to increase greatly for a reasonable price

- With **regulations** coming from Governments, charging solutions should quickly come to a standard and infrastructure should develop a lot

- All those points that have to be improved for electric vehicles open a clear path for plug-in hybrid vehicles development
From 2010 to 2015 Electrified Vehicles will remain with modest growth except for Stop-Start Vehicles:
- Stop-Starts already enter most of generalist carmaker fleet. In next years, we expect SSVs to take a huge part of the overall car market
- Stop-Starts are easy to implement and correspond to the lower amount of $ that a carmaker has to pay to reduce 1% of CO2 emission

After 2015, 48V mild hybrid and plug In Hybrid will catch up market:
- Many 48V mild hybrid and PHEV project will reach SOP (Start Of Production)
- Plug In Hybrid seems to meet every needed requirements:
  - High level of CO2 Reduction for carmakers
  - Money saving from modest oil needs for consumers
  - Any lack of autonomy for consumers

Full Cell Vehicles remain at a R&D level from now and will need a specific H2 infrastructure
- We do not expect FCV to enter the market for mass production before 2023
EV/HEV market forecasts

**EV sales worldwide forecasts**

Split by type of vehicles

As an affordable solution, Stop Start Vehicles are expected to catch around 65% of the overall 2023 car market.
Supply chain description
Supply Chain description

HEV/EV Industrial supply-chain and typical market prices from module to power train

**Si devices**
- Toyota (JP)
- Mitsubishi (JP)
- Infineon (DE)
- ST (FR)
- Fuji (JP)
- Toshiba (JP)
- Hitachi (JP)

**Power module Manufacturers**
- Toyota (JP)
- Mitsubishi (JP)
- Infineon (DE)
- Semikron (DE)
- Danfoss (DE)
- Delphi (US)
- Denso (JP)
- BYD (CN)
- Fuji Electric (JP)
- Hitachi (JP)

**Tier one suppliers**
- Europe: Valeo (FR), Continental (DE), Bosch (DE), Siemens (DE)
- USA: Delphi
- Asia: Toyota (JP), Hitachi (JP), Denso (JP), Mitsubishi Electric (JP), BYD (CN)

**Car Manufacturers**
- Europe: PSA, BMW, Daimler Chrysler, Volvo, Renault
- USA: Ford, GM, Tesla motors
- Japan: Toyota, Honda, Nissan
- China: BYD, Chery, Geely

Supply chain description
Supply Chain description

Business Models trends

Evolution of business models: 3 major remaining business models

1. Discret Component
   - Chip makers
2. Power Module
   - Tier 1 and module makers
3. Power Assembly
   - Car manufacturers
4. Vehicles
   - Car manufacturers

Supply chain description
Despite a relative low market share today, the “Hyundai” business model 2 seems to more and more attract other manufacturers such as Renault or Nissan, who are developing internal competencies to make their own inverters, using external sources of semiconductor chips and power modules from the same supplier.

These manufacturers will probably not manufacture their own chips and power modules and will prefer buying off-the-shelf, but will get very involved in inverter design and packaging.

The main driver for such a move is the creation of a strong differentiation factor from the competition. If using the same inverter, every car maker would have almost the same performance. Making their own inverters will allow promoting different value-propositions for each of them.

Power modules manufacturer landscape will change: they are working on inverters that could be sold to car manufacturers that are not involved in inverter manufacturing.

Toyota will most likely keep on its business model of a fully-integrated value chain.
TECHNOLOGY TRENDS
Vehicle Architectures

*Power electronics used in electrified vehicles*

Key elements for power assembly evolution

- **$/kW**
- **kW/kg**
- **kW/l**

### Technical Breakthrough

**Power Assembly Architecture**
- Converter Topologies (mainly for LV-HV DC/DC and AC/DC)
- Inverter has to be developed according to the electric motor

**Passive Elements (Cooling, capacitors, busbars, etc...)**
- High Temperature Capacitors, Laminated Busbars
- Enhanced cooling of the power converter

**Power Packaging**
- Low stray inductance packaging
- High Temperature and reliable assemblies

**Wide Band gap Semiconductors**
- High Temperature operation
- More compact inverters
Power assembly

Competitive assembly technology
Roadmap of Power assembly technology toward higher integration and power density

- Improved cooling
- Higher power density
- Mechatronic improvement

Direct Cooling

Co-integration motor + inverter:
- Increase power density
- Inverter mechatronic design to fit with motor aspect ratio

Double side cooling

Converters co-intergration
- DC/DC Boost + Inverter + Generator
- Inverter + LV-HV DC/DC
- On board DC/DC + LV-HV DC/DC
Power module packaging

Competitive packaging technology

Roadmap of Power module technology toward higher integration and power density

- Improved cooling
- Higher integration
- High freq. compatible

Toyota 2010
- Standard packaging
- Ribbon bonding
- Direct substrate cooling

Honda 2010
- Epoxy packaging
- Cu lead bonding
- Direct substrate cooling

Delphi 2010
- Single IGBT/diode packaging
- Flip-chip soldering
- Direct substrate cooling

Mitsubishi 2014
- Six Pack IGBT/Diode Package
- Cooling fin
- Thick Copper layer for thermal spreading
- Direct substrate cooling

Bosch 2013
- Molded package
- Die on Leadframe
- Thick Copper layer for thermal spreading
- Direct substrate cooling

Denso 2008/Lexus LS
- Single IGBT/diode packaging
- Flip-chip soldering
- Double side cooling
- Too expensive
Semiconductor innovation

Wide band-gap semiconductors: SiC and GaN

Reasons for WBG Added Value

- **Intrinsic properties**
  - High Junction T°
  - High electron mobility
  - No recovery time during switching
  - Low losses
    - less energy to dissipate
  - Less cooling needs
  - System size and weight reduction
  - High switching frequency
  - Smaller filters and passives

- **Impact on operation**
- **Impact on power module**
- **Impact on power system**
Semiconductor innovation

Wide band-gap semiconductors: SiC and GaN

Case Study: Toyota

- Toyota exhibited the SiC technology at the 2014 Automotive Engineering Exposition, to be held from May 21 to May 23 at the Pacifico Yokohama convention center in Yokohama
- The demonstrator was produce with Denso
- Major achievements:
  - 40% size reduction
  - 10% improve in Fuel efficiency

Boost + Inverter + Generator With Si device

Boost + Inverter + Generator With SiC device
Conclusion
As a conclusion to this 2014 report, the EV and HEV market will definitely grow in the next ten years. Even if market is mainly pulled at first by highly restrictive regulation, the whole supply chain has developed technical solutions to overcome EV/HEV adoption breaks:

- Vehicle/Battery Cost
- Vehicle autonomy
- Ability to recharge easily

In 2023, 18%+ of vehicles sold will be mild HEV, HEV, PHEV or BEV thanks to a large adoption of PHEV and 48V mild HEV vehicles. We expect China to become the bigger market for electrified vehicles by 2018.

With such a market volume, power converters will reach 16B$+ and impact the whole power electronic market. New development from supplier (Tier 1, Tier 2, etc..) will fit automotive drivers and specifications

- Power Density
- Reliability
- Cost
Conclusion
Supply Chain

- Car maker know-how has been built on combustion engines: transition to electric engines must go with transition of this specific know-how. Electric conversion in automotive application can now be addressed by many players. All over the supply chain, landscape is moving fast
  - Historical suppliers want to keep automotive market for them
  - New entrant want to be part of these new business opportunities
  - We see many vertical integration within the supply chain to gain market shares and increase profitability

- Also, car makers need to differentiate compare to the competition by being intrusive (at hardware and software level) in motor or converters development. Some of them are producing their own inverter (and even their own power module) to reduce supplier margin

- All these business models will coexist in the next years and then consolidate with the market ramp up (around 2018)
• Large R&D expenses for innovation have been invested to enter this promising market with tough competition zone. EV/HEV is now facing huge technical breakthrough in many fields.

• The whole power conversion architecture will drastically be impacted in the next ten years. Needs in power density will lead to improvement in thermal management, passive elements volumes and mechatronics. Power modules will fit with automotive drivers (cost, reliability) and lead innovation for all power electronic applications.

• Wide Band Gap semiconductor will reach electrified vehicle market with:
  – Opportunities on vehicle architecture:
    • Using hot water cooling system from ICE to cool power converters (for HEV and PHEV)
    • Using Air cooling for electric motor and power converters (for BEV)
  – Power converter volume may be shrunk by 40% to help mechanical integration
  – Losses reduction will allow better fuel efficiency and autonomy

• Fuel Cell Vehicles penetration rate will clearly depends on its cost and H₂ charging infrastructure