Energy-power spectrum across applications

Propulsion systems are tailored to specific power and energy demands, based on their use case and duty cycle. The graph below presents an outline of principle mass market products.

The 2020 roadmap provides values for
(1) Cost effective, high volume indicators.
Values for (2) Power dense, high performance and
(3) High power, ultra-high efficiency applications will be developed with industry due course.

1 Cost effective, high volume orientated:
Achieving economies of scale at a low cost is paramount for these products. Applications include high volume passenger car and delivery vans (majority 400V).

2 Power dense, high performance orientated
High power densities are required with cost a less decisive factor. Applications include performance passenger cars, buses and some medium duty vehicles (800V prevalent).

3 High power, ultra high efficiency orientated
High power densities and reliability are needed for these applications but efficiency is key to maximise energy use. Applications include 44 tonne trucks and large, off-highway vehicles (700-1,200V).
Technology indicators for cost effective, high volume applications

Technology indicators that industry is likely to achieve in a mass-market competitive environment. All the cost and performance metrics are ambitious, but relate to the same technology.

### Inverter Indicators Spec

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power</td>
<td>100kW</td>
<td>100kW</td>
<td>100kW</td>
</tr>
<tr>
<td>Continuous Power</td>
<td>50kW</td>
<td>50kW</td>
<td>70kW</td>
</tr>
<tr>
<td>Input voltage (mini)</td>
<td>250V</td>
<td>250V</td>
<td>500V</td>
</tr>
<tr>
<td>Input voltage (nominal)</td>
<td>400V</td>
<td>400V</td>
<td>800V</td>
</tr>
<tr>
<td>Output current (max)</td>
<td>450A rms</td>
<td>450A rms</td>
<td>225A rms</td>
</tr>
<tr>
<td>Coolant inlet temperature</td>
<td>65°C</td>
<td>65°C</td>
<td>65°C</td>
</tr>
<tr>
<td>Production volume</td>
<td>&gt;100k</td>
<td>&gt;100k</td>
<td>&gt;200k</td>
</tr>
</tbody>
</table>

### DC-DC Converter Indicators

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power</td>
<td>3kW</td>
<td>3kW</td>
<td>4kW</td>
</tr>
<tr>
<td>Continuous Power</td>
<td>3kW</td>
<td>3kW</td>
<td>4kW</td>
</tr>
<tr>
<td>Input / output voltage (nominal)</td>
<td>400V</td>
<td>400V</td>
<td>800V</td>
</tr>
<tr>
<td>Output / input voltage (nominal)</td>
<td>12V</td>
<td>12V</td>
<td>12V</td>
</tr>
<tr>
<td>Coolant inlet temperature</td>
<td>65°C</td>
<td>65°C</td>
<td>65°C</td>
</tr>
<tr>
<td>Production volume</td>
<td>&gt;100k</td>
<td>&gt;100k</td>
<td>&gt;200k</td>
</tr>
</tbody>
</table>

### Single Phase, On-Board Charger Indicators

<table>
<thead>
<tr>
<th>Year</th>
<th>2020</th>
<th>2025</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power</td>
<td>6.6kW</td>
<td>6.6kW</td>
<td>6.6kW</td>
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<tr>
<td>Continuous Power</td>
<td>6.6kW</td>
<td>6.6kW</td>
<td>6.6kW</td>
</tr>
<tr>
<td>Input / output voltage (nominal)</td>
<td>400V</td>
<td>400V</td>
<td>800V</td>
</tr>
<tr>
<td>Output / input voltage (nominal)</td>
<td>12V</td>
<td>12V</td>
<td>12V</td>
</tr>
<tr>
<td>Coolant inlet temperature</td>
<td>65°C</td>
<td>65°C</td>
<td>65°C</td>
</tr>
<tr>
<td>Production volume</td>
<td>&gt;100k</td>
<td>&gt;100k</td>
<td>&gt;200k</td>
</tr>
</tbody>
</table>

### Cost ($/kW)

- Inverter Indicators: 1.7
- DC-DC Converter Indicators: 1.5
- Single Phase, On-Board Charger Indicators: 1.5

### Volumetric Power Density (kW/l)

- Inverter Indicators: 25
- DC-DC Converter Indicators: 1.75
- Single Phase, On-Board Charger Indicators: 1.75

### Gravimetric Power Density (kW/kg)

- Inverter Indicators: 13
- DC-DC Converter Indicators: 2.5
- Single Phase, On-Board Charger Indicators: 2.5

### WLTP Average Efficiency

- Inverter Indicators: 97%
- DC-DC Converter Indicators: 97%
- Single Phase, On-Board Charger Indicators: 97%

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1. Unidirectional power flow and galvanic isolation assumed
2. Assumes increasing MaaS / infotainment functionality
3. Bidirectional power flow and galvanic isolation assumed
This roadmap represents a snapshot-in-time view of the global automotive industry propulsion technology forecast for mass market adoption. Specific application-tailored technologies will vary from region to region.

**Semiconductors**
- Optimised Si semiconductor devices
  - 6" based SiC devices
  - 8" based SiC devices
  - 12" based SiC devices
  - GaN on Si semiconductor devices
  - GaN on GaN / SiC semiconductor devices
- "Ultra" WBG materials (e.g., Ga203, Diamond)

**Components**
- New package designs tailored for WBG materials
  - 1st phase integration (i.e., sensors in package)
  - Sophisticated device integration (multiple sub-components in-package)
- WBG power module standardisation for scale up
- PCB embedded dies and components
- Converter in-package devices

**Passives, Sensors, and PCBs**
- Lighter, smaller and more thermally robust passives
- Lower loss, high temp. and smaller sensors
- Integrated, multi-functional sensors with in-built health management
- Higher current and temperature capable PCBs
- New PCB materials and manufacturing processes

**Design**
- Optimised Si architectures for high volume applications
- WBG drop in Si-based architectures
- Converters optimised for WBG (i.e., soft switching, multi-level)
- Converters designed for "ultra" WBG materials

**Control**
- Enhanced fault resilient systems (i.e., sensorless, self-diagnostics)
- Control designed for functional safety (i.e., HV and dynamic)
- Safe and secure self learning, optimized software (i.e., efficiency, performance)
- Functionally integrated drives (i.e., shared cooling, housing, embedded electronics, high speed gearbox)

**Integration**
- Multifunctional converters
- Converters with enhanced features (e.g., V2G, wireless charging)
- Dedicated HDV converter (i.e., pantograph, ultra-fast charging)
- High volume, modular converters for multiple vehicle platforms

**Life Cycle**
- Pilot recycling methods for automotive PE
- High volume automotive PE recycling
- Circular economy established for automotive PE
- Reduce carbon intensity of PE value chain
- Full life cycle impact compliant PE value chain

**Roadmap 2020**
- Technology Roadmap
- Technology indicators for 2020-2035 can be seen on page 2

**Transition:**
- Transitions do not mean a phase out from market but a change of R&D emphasis

**Dotted line bar:**
- Market Mature – technology has reached maturity. Likely to remain in mass market until it fades out where it's superseded

**Dark bar:**
- Technology is in a mass market application. Significant innovation is expected in this time frame

**This roadmap represents a snapshot-in-time view of the global automotive industry propulsion technology forecast for mass market adoption. Specific application-tailored technologies will vary from region to region.**