CHALLENGES OF THE PRODUCTION OF ELECTRIC POWERTRAINS FROM THE PERSPECTIVE OF A PREMIUM CARMAKER.
## CONTENTS

<table>
<thead>
<tr>
<th></th>
<th>Motivation and History of Electrification at BMW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The new Brand BMW i and its Vehicles i3 and i8</td>
</tr>
<tr>
<td>3</td>
<td>The Electric Drive Components: E-Motor and High Voltage Battery</td>
</tr>
<tr>
<td>4</td>
<td>The Challenges of the Production of those Components</td>
</tr>
<tr>
<td>5</td>
<td>Summary</td>
</tr>
</tbody>
</table>
IN A CHANGING WORLD, E-MOBILITY IS AN INTERESTING APPROACH.

**Environment**
Climate change its knock-on effects

**Urbanisation**
By 2030, over 60% of the world’s population will live in cities

**Customer Expectations**
Changing values

**DRIVING FACTORS**

**Culture**
Sustainable mobility as part of a modern urban lifestyle; taking social responsibility

**Economics**
Dwindling resources, rising fossil fuel prices

**Politics and Regulations**
CO$_2$ and fleet regulations, import restrictions

AMAA Berlin; Dr. Frank Möbius; BMW Group; 17.06.2013
BMW GROUP EFFICIENT DYNAMICS.
THE ROAD TO EMISSION-FREE MOBILITY.

BMW EfficientDynamics

Optimizing:
- Efficiency
- Aerodynamics
- Lightweight
- Energy Management
- Road Resistance

ActiveHybrid
- ActiveHybrid X6
- ActiveHybrid 7
- ActiveHybrid 5
- Active Hybrid 3

PEV / BMW i
Plug-in Vehicles / i3 & i8

Hydrogen
FCEV
Long Range ZEV Mobility

AMAA Berlin; Dr. Frank Möbius; BMW Group; 17.06.2013
HISTORY OF ELECTRIFICATION AT BMW.

Electric vehicles (BEV)
- 1972 BMW 1602, Lead Acid Battery
- 1987 BMW 325, NaS-Batt.
- 1991 BMW E1, NaNiCl-Batt.
- 1992 BMW 325, NaNiCl-Batt.
- 1994 518i Parallel-Hybrid, NiCd-Battery
- 1995 316i Serial Hybrid, Super Caps
- 1996 BMW 325, Li-Ion-Batt.
- 1998 BMW 325, NaNiCl-Batt.
- 1999 BMW Z3 Roadster, NiCd-Battery
- 2000 BMW Z4 Roadster, NiCd-Battery
- 2001 BMW Z3 Coupe, Li-Ion-Batt.
- 2003 X5 Active Hybrid, Ni-MH Battery
- 2008 MINI E, Li-Ionen-Batterie
- 2009 Active Hybrid 7, Li-Ion Battery
- 2009 MINI E, Li-Ionen-Batterie
- 2011 BMW ActiveE, Li-Ionen-Batterie
- 2012 BMW i3, Li-Ionen-Batterie
- 2014 BMW i8, Li-Ionen-Batterie
- 2014 BMW i3, Li-Ionen-Batterie

Hybrid vehicles (HEV/PHEV)
- 1995 BMW ActiveHybrid, Ni-MH Battery
- 2008 BMW ActiveHybrid, Ni-MH Battery
- 2009 BMW ActiveHybrid 7, Li-Ion Battery
- 2011 BMW ActiveE, Li-Ionen-Batterie
COMPARISON OF CO₂ FLEET REDUCTIONS IN EUROPE. BMW HAS ALREADY ACHIEVED A GREAT DEAL. TOUGH TARGETS TO COME.

BMW Group has more than fulfilled its contribution to the ACEA commitment to reduce fuel consumption by 25% from 1995 to 2008.

*Manufacturers get individual targets, which may be above or below the value of the Ø EU Com fleet emissions, depending of their individual Ø weight.

EU COM target = Ø fleet emissions (EU-27)

2015 = 130 g/km*

2020 = 95 g/km*
SHARE OF PHEV/BEV POWERTRAIN TECHNOLOGIES EUROPE IN 2020 – VERY DIFFERENT SCENARIOS.

- **Low scenario**
  - 2013: <0.1%
  - 2015: 1.7%
  - 2016: 4.2%
  - 2018: 11%
  - 2020: 17.6%

- **High scenario**
  - 2013: <0.1%
  - 2015: 3.1%
  - 2016: 11%
  - 2018: 14.1%
  - 2020: 23.3%

- **Expected scenario**
  - 2013: <0.1%
  - 2015: 5.9%
  - 2016: 14.1%
  - 2018: 23.3%
  - 2020: 23.3%
CLASSIFICATION OF ELECTRIFIED VEHICLES.

Increasing CO₂-Potential

100% Combustion Engine

100% Fuel

100% Battery

Start Stop, Recuperation

Mild HEV

Full HEV

PHEV

Range Extender

BEV

100% E-Machine

AMAA Berlin; Dr. Frank Möbius; BMW Group; 17.06.2013
ARCHITECTURE OF A PLUG IN HYBRID (PHEV).
ARCHITECTURE OF A PURE ELECTRIC VEHICLE (BEV).
## CONTENTS

1. Motivation and History of Electrification at BMW
2. The new Brand BMW i and its Vehicles i3 and i8
3. The Electric Drive Components: E-Motor and High Voltage Battery
4. The Challenges of the Production of those Components
5. Summary
BMW i is a new value proposition.

- Thrilling Performance
- Unrivaled Experience
- Striking Technology
- Dynamic Performance
- Aesthetic Design
- Innovative Technologies
- Visionary Mobility
- Inspiring Design
- Next Premium
RESPONSIVENESS FROM STANDSTILL.

Individual measurements for i3, M3 Coupé and 118dA compared.
PURE ELECTRIC DRIVING AT BMW: FROM THE MINI E TO THE BMW i3.

2009
MINI E

2011
BMW ActiveE

2013
BMW i3
BMW i3 CONCEPT – SOME TECHNICAL DATA.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>3,85m</td>
</tr>
<tr>
<td>Weight</td>
<td>1250kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Driving Performance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>125kW/250Nm</td>
</tr>
<tr>
<td>Acceleration 0-100 km/h</td>
<td>7,9s</td>
</tr>
<tr>
<td>Maximum Speed</td>
<td>150 km/h</td>
</tr>
<tr>
<td>Range (NEDC)</td>
<td>225 km</td>
</tr>
<tr>
<td>Range (Customer)</td>
<td>130 - 160 km</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recharging</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging time (standard)</td>
<td>6h (100%)</td>
</tr>
<tr>
<td>Charging time (optional)</td>
<td>&lt; 30 min (80%)</td>
</tr>
</tbody>
</table>
BMW i3: PRESS FEEDBACK.

„This car is a revolution“ (Auto Bild 1/3/2013).

Conclusion

The i3 does everything differently and much better. It is as quiet as a cat on the mantel, structurally strong as cast iron, tracks properly such as a rack railway and weighs without a battery even not 1000 kilograms. All this makes it an automotive revolution.

„The BMW i3 is a real BMW.“

„Its (BMW i3) carbon fiber body is wrapped in layers of electronic services and smartphone apps designed to make life simpler and save time for the owner. ”

„BMW’s pioneering i3 electric car is one of the most exciting cars of 2013.“

Auto Bild, 1/3/2013

Auto, 27/2/2013

FORTUNE

AMAA Berlin; Dr. Frank Möbius; BMW Group; 17.06.2013
BMW i3 CONCEPT – POWERTRAIN.

<table>
<thead>
<tr>
<th>System output</th>
<th>125kW/250Nm</th>
</tr>
</thead>
</table>
| Electric range      | Everyday range: 130-160 km / 80-100 miles
                    | FTP72 cycle: 225 km / 140 miles |
| Battery charge time | Standard: 6 h for 100 %
                    | Optional: <30min for 80 % charge |
BMW i8 CONCEPT – SOME TECHNICAL DATA.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>4,63m</td>
</tr>
<tr>
<td>Weight</td>
<td>1480kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Driving Performance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance (System)</td>
<td>260kW/550Nm</td>
</tr>
<tr>
<td>Performance (Otto)</td>
<td>164 kW/300Nm</td>
</tr>
<tr>
<td>Performance (electric)</td>
<td>96kW/250Nm</td>
</tr>
<tr>
<td>Acceleration 0-100 km/h</td>
<td>4,6s</td>
</tr>
<tr>
<td>Consumption</td>
<td>2,7l, 66g CO$_2$</td>
</tr>
<tr>
<td>Range (electric)</td>
<td>35 km</td>
</tr>
<tr>
<td>Charging time</td>
<td>1:45h (100%)</td>
</tr>
</tbody>
</table>
BMW i8: PRESS FEEDBACK.

„Captain Future“ (Auto Zeitung 27/2/2013).

„... we now know that the BMW i8 is not only spectacularly futuristic in terms of appearance but also engagingly fast, eminently usable and comfortable enough to be used every day."

„The i8 with its performance of more than 350 hp can in icy curves be steered with four fingers. It drives manageable through the corners, with only slight oversteer. The track width, the favorable weight distribution by the two motors and the low center of gravity - thanks to the wide underlying battery - makes this possible."

„A mixture of Tesla Roadster and Porsche 911 - and yet so much more. The BMW i8 is a gamble, but it thrilles."

Auto Express, 06Mar13
## BMW i8 CONCEPT – POWERTRAIN.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System output</strong></td>
<td>260 kW/ 550 Nm</td>
</tr>
<tr>
<td><strong>Petrol engine</strong></td>
<td>164 kW/ 300 Nm</td>
</tr>
<tr>
<td><strong>Electric motor</strong></td>
<td>96 kW/ 250 Nm</td>
</tr>
<tr>
<td><strong>Electric range</strong></td>
<td>approx. 35 km / 20 miles</td>
</tr>
<tr>
<td><strong>Battery charge time</strong></td>
<td>Standard: 1:45 h for 100 % charge</td>
</tr>
</tbody>
</table>
## CONTENTS

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motivation and History of Electrification at BMW</td>
</tr>
<tr>
<td>2</td>
<td>The new Brand BMW i and its Vehicles i3 and i8</td>
</tr>
<tr>
<td>3</td>
<td>The Electric Drive Components: E-Motor and High Voltage Battery</td>
</tr>
<tr>
<td>4</td>
<td>The Challenges of the Production of those Components</td>
</tr>
<tr>
<td>5</td>
<td>Summary</td>
</tr>
</tbody>
</table>
THE ELECTRIC MOTOR.

- Optimum ratio of power vs. weight
- Maximum torque during start-up
- High degree of efficiency over a wide operating range.
THE HIGH VOLTAGE BATTERY.

- Efficient and compact design
- High power and energy density
- High automotive life time robustness
- High level of automotive safety
## CONTENTS

1. Motivation and History of Electrification at BMW
2. The new Brand BMW i and its Vehicles i3 and i8
3. The Electric Drive Components: E-Motor and High Voltage Battery
4. The Challenges of the Production of those Components
5. Summary
PRODUCTION STEPS OF THE ELECTRIC MOTOR.

- **Stator**
  - Impregnate winding
  - Wire and check winding
  - Form winding head
  - Insulate lamination stack
  - Stator shrunk into inner housing
  - Joining rotor with outer housing
  - Assembly stator in inside housing with rotor in external housing
  - Assembly position sensor
  - End of line test without and commissioning with power electronics
  - Marking and packaging

- **Rotor**
  - Balance rotor
  - Shrink shaft
  - Join rotor segments
  - Attach magnets
  - Lamination stack
  - Slot insulation
  - Magnets
  - Lamination stack

- **Final Assembly**
  - Assembly position sensor
  - Assembly stator in inside housing with rotor in external housing
  - End of line test without and commissioning with power electronics
  - Marking and packaging
CHALLENGES IN PRODUCTION OF ELECTRIC MOTORS FOR THE AUTOMOTIVE INDUSTRY.

- High output **flexibility** of the production system required in case of rapid variations in demand.
- Optimized **manufacturing processes** to improve efficiency and power/weight ratio:
  - Winding → Slot filling factor.
  - Forming and connecting the winding head.
  - Minimize packaging space.
- Production-orientated design of **isolation concepts** in large series:
  Material of primary and secondary isolation, impregnation process, phase separation and –isolation.
- Reliable handling of **magnets**.
- **Measurement and testing** technologies: Standards and automation.
PRODUCTION STEPS OF THE HIGH VOLTAGE BATTERY.

Modules production:
- Cell-connector assembly
- Addition of floor plate
- Module assembly
- Insertion of cells
- Assemble module frame

Final Assembly:
- Mounting cooling system
- Assemble battery modules
- Electric connection modules
- Connect system control unit
- Mounting s-box
- Assemble housing
- End of line test

Battery cells
Module parts
CHALLENGES IN PRODUCTION OF HIGH VOLTAGE BATTERIES FOR THE AUTOMOTIVE INDUSTRY.

– No manufacturing of **cells** in Europe leads to a high effort in **logistic and quality** inspection before assembly.

– High output **flexibility** of the production system required in case of rapid variations in demand.

– New requirements of **joining processes**: transmission of high currents in welded joints, heat transfer and electrical isolation in adhesive layers, …

– **Automation** of assembly procedures: screwing, mounting of contacts, handling of filigree cooling systems, …

– **Safety** when using high voltage and technical cleanliness of manual assembly.

– **Measurement and testing** technologies: Standards und automation.
## CONTENTS

<table>
<thead>
<tr>
<th></th>
<th>Motivation and History of Electrification at BMW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The new Brand BMW i and its Vehicles i3 and i8</td>
</tr>
<tr>
<td>3</td>
<td>The Electric Drive Components: E-Motor and High Voltage Battery</td>
</tr>
<tr>
<td>4</td>
<td>The Challenges of the Production of those Components</td>
</tr>
<tr>
<td>5</td>
<td>Summary</td>
</tr>
</tbody>
</table>
Global increase of production capacities within all parts of the automotive industry expected (conventional and new drive technologies)

Unpredictable volumes regarding e-mobility, depending on lots of volatile parameters (legislation, markets, customer acceptance, …)

High variety and change rate of design, variants and derivatives expected

Flexibility, modularity, scalability of production necessary

Strong competition between OEMs and suppliers → “survival of the fittest”

High cost pressure, especially on e-drive components and systems
• High **speed of innovation** necessary (battery cells, ...) to optimize power, energy, durability, efficiency, size, weight, cost
• **New and rare qualifications** of engineers and workers required
• **Interdisciplinary work** required (mechanical, electrical, process, chemical, software engineering + economics + business administration)
• **Increase of automation** to reach high quality, safety and cost efficiency → depending on volumes!
• Manufacturing of **new and expensive materials**: high strength steel, light metals, fibre-reinforced plastics, ceramics, sandwich constructions, hybrid design, rare earth and complex material mixes
SUMMARY OF GENERAL CHALLENGES ON AUTOMOTIVE PRODUCTION FACING E-MOBILITY 3/3.

- New requirements on joining technologies necessary (hv electric current conduction, …)
- Assembly of highly integrated components (e-motor and power electronics…)
- Dealing with high voltage within the production → work safety!
- Demanding measuring and testing equipment
- High impact of energy efficiency and environmental restrictions
- Standardization of processes and tools (global versus local interests!)
- Cooperation and joined forces between OEMs, suppliers, engineering companies and research institutes needed
THANK YOU FOR YOUR ATTENTION.