INTRODUCTION
Conventional monopolar lithium batteries are limited in energy density due to the high share of inactive components and limited volume utilization on cell as well as on system level. The EMBATT bipolar battery concept (Fig. 1) reduces the amount of inactive components and leads to improved integration properties for automotive applications.

Main challenges which have been identified concern:
- Technological solutions for electrode and system manufacturing
- Material innovations for active material, electrolyte and current collector

Fraunhofer IKTS is addressing these topics in the projects EMBATT1.0 (manufacturing technology) and EMBATT2.0 (material innovations) as summarized in table 1.

WATER BASED ELECTRODES
Slurry development
Water based slurry recipes have been developed for LTO and LFP. Then, electrodes were manufactured on pilot scale coating equipment. A bipolar stack is coated on an Aluminum current collector.

Increasing electrode thickness
The slurry recipes and coating parameters were optimized with the goal of increasing electrode thickness. Plots 2 and 3 show the specific capacity and the normalized area specific capacity, respectively. An NMP based electrode is added for comparison.

SEPARATOR COATING
Replacement of additional separators
With the aim of omitting a conventional separator, which has to be placed in the cell during the manufacturing process, a technology was developed to apply a separator directly on the electrode.

In figure 2, an Al2O3 based separator was coated directly on the LFP cathode. By optimizing the coating process, thicknesses of approx. 30 µm could be achieved.

In EMBATT2.0, a solid polymeric electrolyte will be applied simultaneously.

CONCLUSIONS AND OUTLOOK
Several technological solutions for the manufacturing of large bipolar batteries have been developed in EMBATT1.0: water based processes for thick electrodes, bipolar electrodes, separators coated on the electrodes and electrolyte filling strategies.

In the recently started project EMBATT2.0 material innovations such as dedicated active materials, polymeric electrolytes and polymer based current collectors will increase energy densities up to 450 Wh/l on system level.

ACKNOWLEDGEMENT 1
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Table 1: Comparison of the generations of the EMBATT bipolar battery

<table>
<thead>
<tr>
<th>EMBATT1.0</th>
<th>EMBATT2.0</th>
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<tr>
<td>Materials</td>
<td>Commercial LFP and LTO</td>
</tr>
<tr>
<td>Electrolyte</td>
<td>Liquid electrolyte</td>
</tr>
<tr>
<td>Current collector</td>
<td>Al/Al current collector</td>
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<tr>
<td>Energy density</td>
<td>&gt; 200 Wh/l</td>
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</tbody>
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Figure 1: Schematic representation of the EMBATT concept.

Figure 2: Al2O3 layer coated on LFP based cathode.

Figure 3: Components of the bipolar stack. Cathode (left) with separator, electrolyte filling capillary and insulator and Anode (right). To form a bipolar test battery several of the shown components are stacked and the single cells are filled with electrolyte.

Figure 4: Cycling test for 5 coin cells, LTO/LFP, 1C/1C, 25 °C

Figure 5: Bipolar stack voltage and single cell voltages.

Figure 6: Bipolar cells and stacks

Figure 7: Material and process development for lithium bipolar batteries

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Batteries
Materials and process development for lithium bipolar batteries

EMBATT2.0
Material and process development for lithium bipolar batteries

EMBATT1.0
Water based processes for thick electrodes, bipolar electrodes, separators coated on the electrodes and electrolyte filling strategies.

EMBATT bipolar battery concept

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