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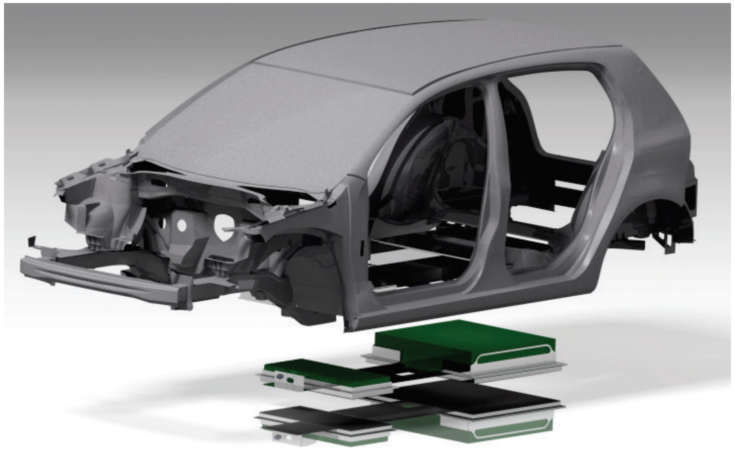
The 27th **INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION.**

Barcelona, Spain
17th-20th November 2013

Smart Batt



AIT AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

SmartBatt

Smart and Safe Integration of Batteries in Electric Vehicles

DI Hansjörg Kapeller
Mobility Department
Electric Drive Technologies
AIT Austrian Institute of Technology GmbH

Organized by: Fira Barcelona, avele
Hosted by: AVERE, neA, Ajuntament de Barcelona
In collaboration with: EVAAP, EDTA
Supported by: European Commission

Outlook

- Introduction of AIT Austrian Institute of Technology
- General presentation of the SmartBatt project
  - H. Kapeller: “Smart and Safe Integration of Batteries in EVs”
- Technical presentations
  - Dr. J. Bao: „Cell selection process and impact of future technology “
  - P. Luttenberger: „Crashworthy battery integration“
  - M. Hartmann: „Built-Up of the SmartBatt housing based on the proposed design”

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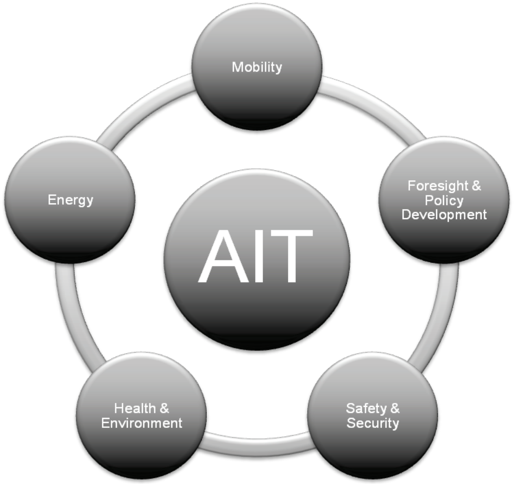
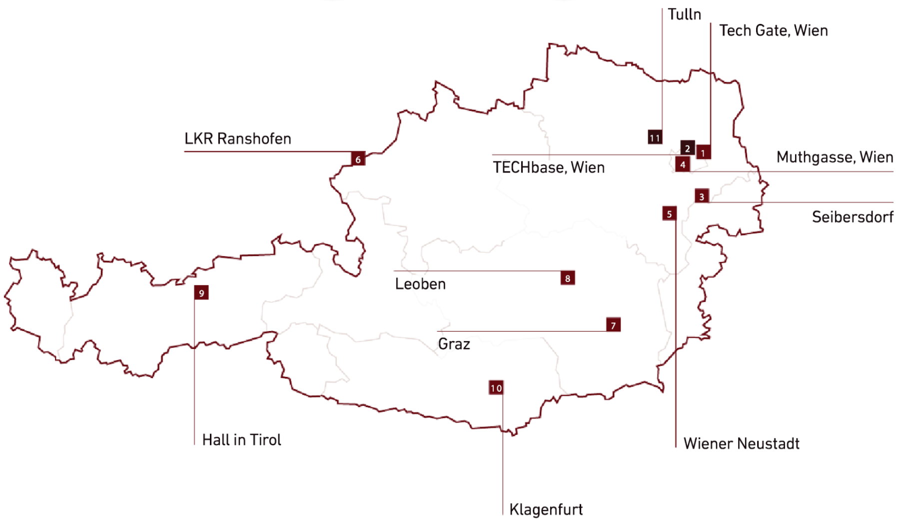


- **Owners**
  - 50.46% Republic of Austria **BMVIT** Federal Ministry for Transport, Innovation and Technology
  - 49.54% **Federation of Austrian Industries**
- **Employees:** 900 plus 200-250 on contract basis, thereof 95 PhD students
- **Financial Goal:** 30% Cooperative Research, 30% Contract Research, 40% Basic Funding



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AIT Strategic Research Areas and Research Fields

ENERGY

Electric Energy Infrastructure
- Smart Grids
- Photovoltaics

Energy for the built environment
- Energy in Cities
- Energy in Buildings
- Renewable Heating & Cooling

MOBILITY

Transportation and Infrastructure Solutions
- Sustainable Transportation Infrastructures
- Co-modal Transportation Dynamics
- Large Scale Mobility Information Acquisition and Modelling

Future Integrated Vehicle Concepts
- Virtual Design and Validation
- Electric Components for Future Vehicles
- Light Weight Metals for Components and Structures

SAFETY & SECURITY

Intelligent Vision Systems
- New Image Processing Algorithms and Concepts
- New Image Sensor Technologies

Future Networks and Services
- eHealth and Ambient Assisted Living (AAL)
- Next Generation Content Management Systems
- Secure Information Access in Distributed Systems

Highly Reliable Software and Systems
- Assessment and Testing of Autonomous and Safety-Critical Systems

HEALTH & ENVIRONMENT

Biomedical & Biomolecular Solutions
- Preclinical and Clinical Diagnostics
- Molecular Diagnostics
- AAL – Ambient Assisted Living
- Advanced Implant Solutions

Resource Exploitation & Management
- Exploitation of Biological Resources
- Microbial Detection
- Water Management & Purification
- Soil Remediation

FORESIGHT & POLICY DEVELOPMENT

Monitoring & Analysis Technology-Economy-Environment
- Models for complex social & natural systems
- Monitoring & Data Mining
- Development & application of methods & tools

Foresight Processes & Governance
- Foresight & policy strategies
- Governance of complex systems
- Innovation oriented sustainable Infrastructure Policy

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Hosted by: AVERE, nea, Ajuntament de Barcelona
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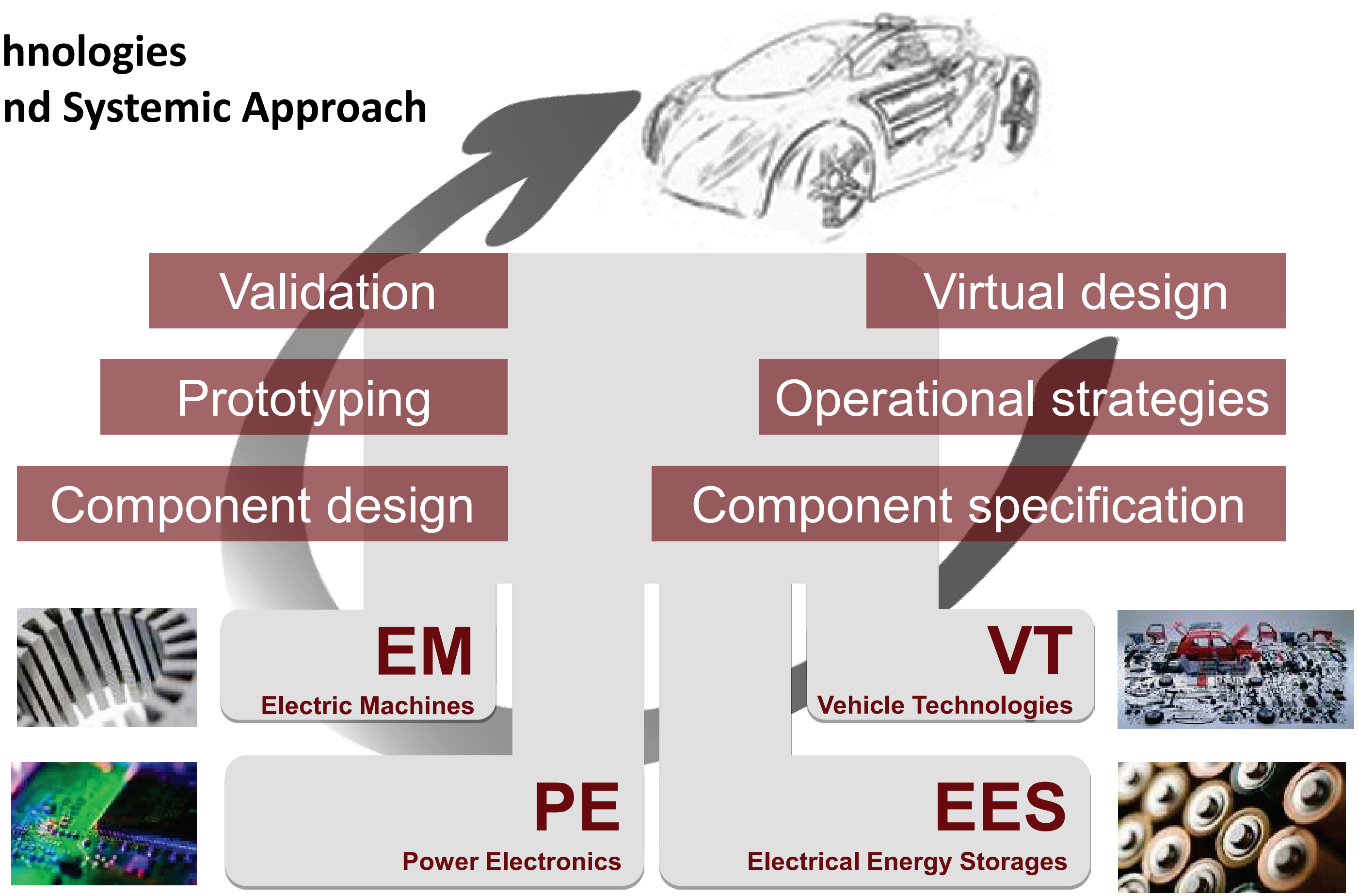
Electric Drive Technologies
Research Focus and Systemic Approach



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Smart Batt

SmartBatt

Smart and Safe Integration of Batteries in Electric Vehicles

An EU funded project

Organized by: Fira Barcelona, avele

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SmartBatt – Smart and Safe integration of batteries into electric vehicles

SmartBatt

EU funded under 7th Framework Programme

- **Objectives**

  Development of an electric vehicle battery focusing on
  - Minimization of weight
  - Optimization of safety
  - Minimization of costs
  - Design capable for series production
- **Realisation**
  - Battery for an A-class BEV with 100km NEDC Range
  - 15% lighter than SotA (75% weight ratio between system and cell)
  - Crash safety based on reference SLC (SuperLightCar) Body
  - Integrated BEV has same static and dynamic requirements as SLC

SmartBatt

EU funded under 7th Framework Programme

- **Budget**
  - 3 million EUR overall budget / 2.25 million EUR funded budget
- **Period**
  - January 2011 until December 2012
- **Consortium – 9 Partners from 5 European countries**

AIT Austrian Institute of Technology, LKR Ranshofen (AIT LKR), Johnson Matthey Battery Systems (formerly Axeon Technologies), Fraunhofer Gesellschaft, Impact Design Europe, Ricardo UK, SP Sweden, Technical University Graz, Volkswagen AG

Work Package Structure

- WP 1: Project Management
- WP 2: Specification Analysis / Requirements
- WP 3: Concept & Feasibility Study
- WP 4: Risk Assessment
- WP 5: Design & Development
- WP 6: Hardware Build-Up & final Validation
- WP 7: Assessment
- WP 8: Exploitation

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WP 1: Project Management

1 Project Management

2 Spec. / Requirements

What are the requirements for battery integration?

- Specification analysis
- Smart integration
- Safety
- Weight reduction
- Additional functions (monitoring)
- Electric, BMS, …

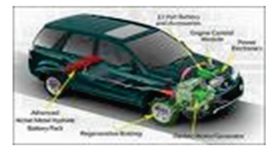
The integration has to fulfil …

Has to fulfill …, and the risk / scenarios are …

3 Concepts & feasibility study

How to fulfil the requirements and reduce the risks?

- Design concepts
- Material selection
- Functions
- Production



A smart battery integration should look like …

4 Risk Assessment

What are the risks on battery integration fulfilling the requirements?

- Electric shock
- Fire
- Gas
- Intrusions to passenger
- under which scenarios

5 Development

How is the detailed concept be working and looking?

- Detailed design
- Simulation
- Testing on small level
- Optimization

Prototype Design for Smart Battery integration

All relevant info from WPs

7 Assessment

What are the improvements / benefits?

- Identify/assess improvement of developed technology for EV market
- Quantify cost-benefit new developed technology vs. commercial solutions

6 Final validation

Does the design work?

- Prototyping
- Testing on full level

8 Exploitation

How to observe third party activities and exploit the integration?

- Papers / Conferences
- Other projects / experts
- Workshops
- Face to face meetings

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SmartBatt – Smart and Safe integration of batteries into electric vehicles

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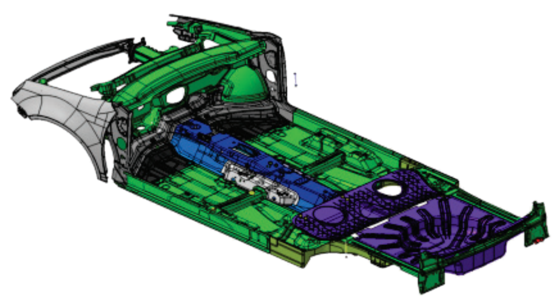
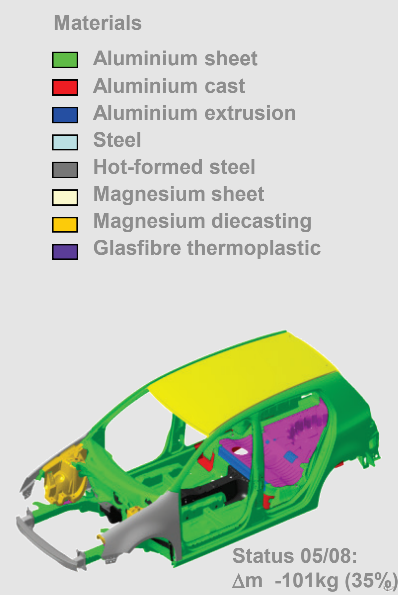
WP 2 - Specification Analysis and Requirements

- Definition / analysis of system constraints
  - Platform of SLC car used
    - Reference: http://www.superlightcar.com
  - ~20 kWh energy content
  - 15 % lighter than comparable systems
  - Same crashworthiness as SLC
- Identification of existing standards/regulation
  - IEC/ISO
  - FMVSS
  - SAE
  - ECE R100



SuperLightCar



EUCAR
EUROPEAN COUNCIL FOR AUTOMOTIVE R&D

Weight target calculation

State of the Art

- **Example for a 20 kWh Battery (~200 kg)**
  - Cells (60 - 70 %) = 120 kg - 140 kg
  - Components (10 - 15 %) = 20 kg - 30 kg
  - Housing (15 - 30 %) = 30 kg - 60 kg

➡ **“Reduction of pack weight by 10 % - 15 % due to housing components.”**
Aimed weight target 170 – 180 kg

SmartBatt

- Cells (68 - 80 %) = 120 kg - 140 kg (unchanged)
- Components (11,5 - 17 %) = 20 kg - 30 kg (almost unchanged)
- Housing (5,7 – 11,5 %) = 10 kg - 20 kg **(weight reduction of 66%)**

➡ **Function integration of “Body in white - floor” and housing to achieve this target**

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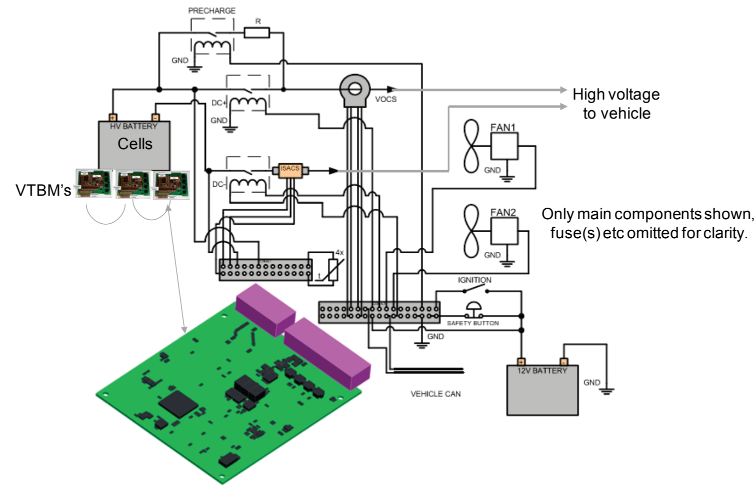
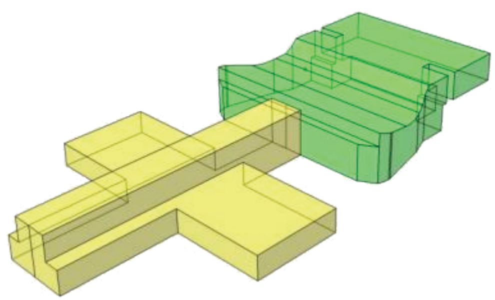
WP 3 - Concept & Feasibility Study

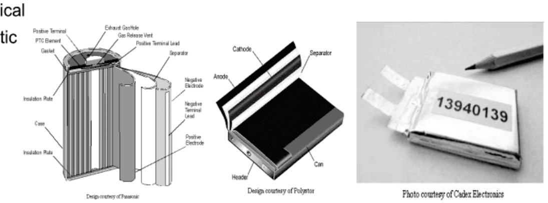
- Definition of interfaces
- Battery management system
- Cell selection
- Package room/battery housing





Source: Volkswagen, TUGraz, VSI

- Cells are available in a variety of packages :
  - Cylindrical
  - Prismatic
  - Pouch



	Cylinder	Prismatic	Pouch
Energy Density	Medium	High	Highest
Mechanical Stability	High	Medium	Low
Thermal Performance	High	Highest	Medium
Space Utilization	Low	High	Highest
Manufacturing cost	High	Medium	Low
Pressure Withstand	High	Medium	Low

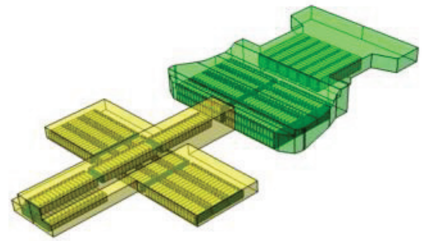
Key:
- Desirable
- Acceptable
- Undesirable

•Cell package selection is a trade-off, no one package is universally best

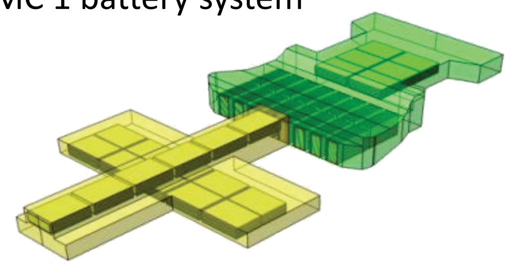
Source: Ricardo

Concepts

- Combining accident statistics with SLC CAD
- Possible structural solution of EV body
- Different investigated concepts (<u>M</u>etal <u>C</u>ase vs. <u>P</u>ouch) within the maximum package

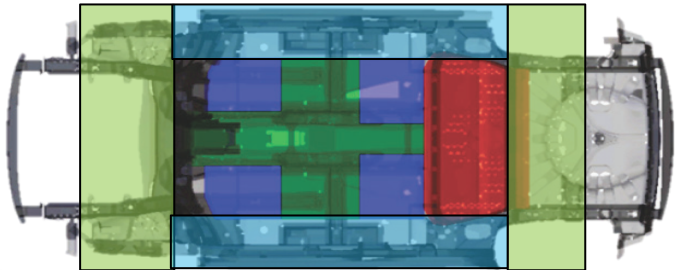


MC 1 battery system

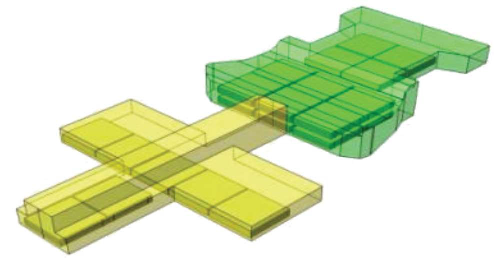


P1 battery system

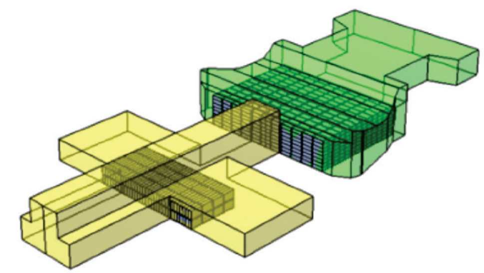
Source: Volkswagen, TUGraz, VSI



Reference:
Luttenberger et. al; Structural analysis of a body in white for battery integration using finite element and macro element; ECCOMAS, Vienna. 2012.
Adopted by ID



P3 battery systems



MC 2 battery System

SmartBatt – Smart and Safe integration of batteries into electric vehicles

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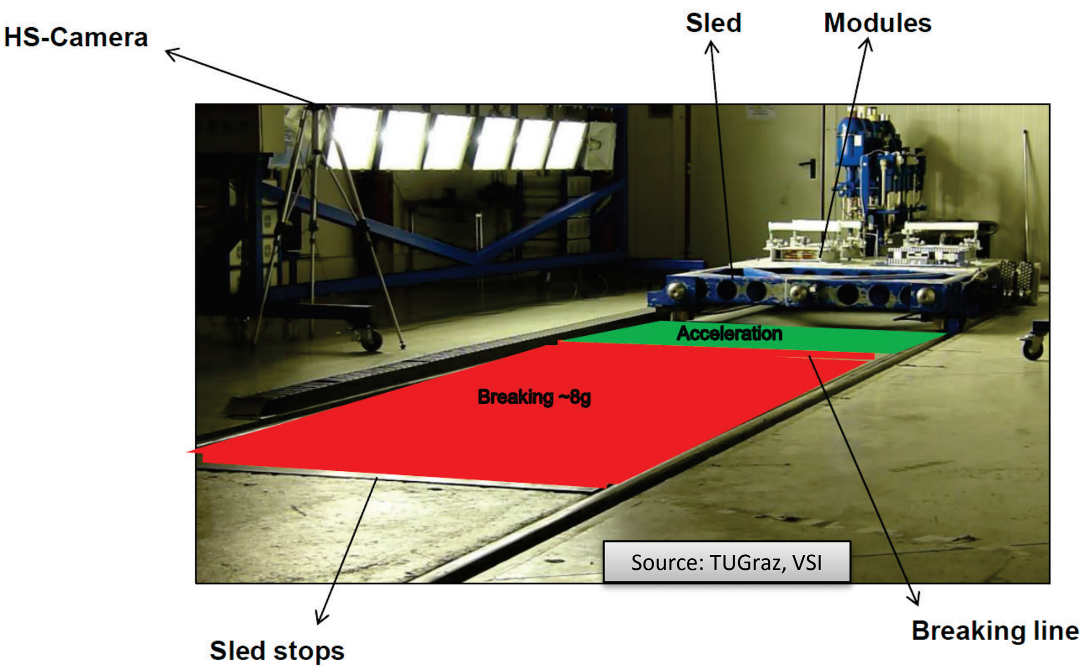
WP 4 - Risk Assessment

- Theoretical risk and failure analysis (e.g. FMEA)
- Experimental analysis (e.g. safety tests)



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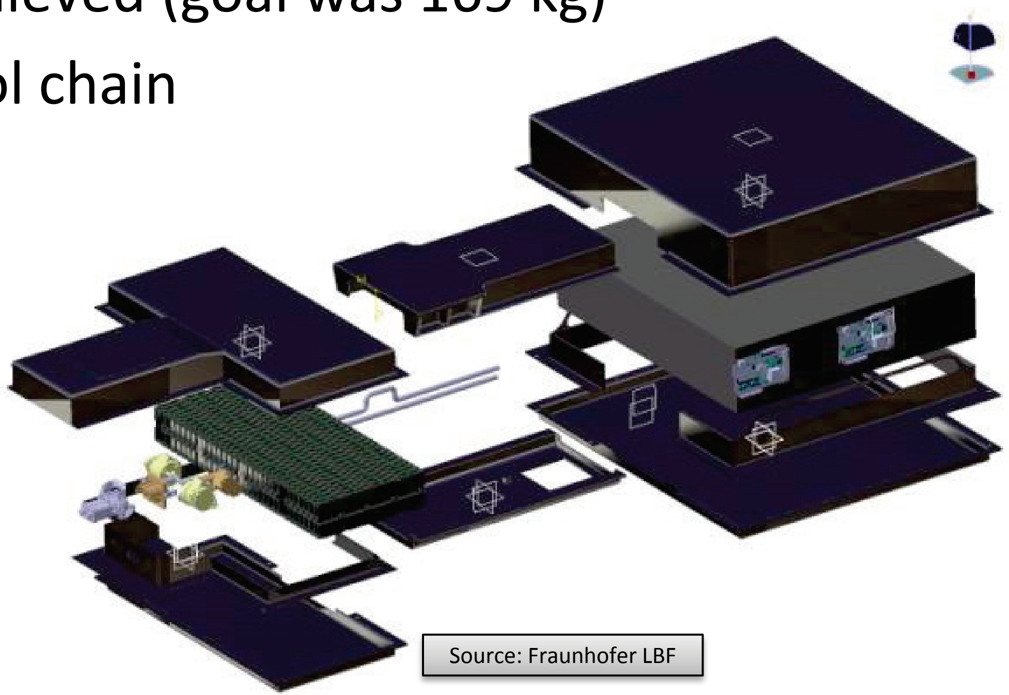
WP 5 - Design & Development

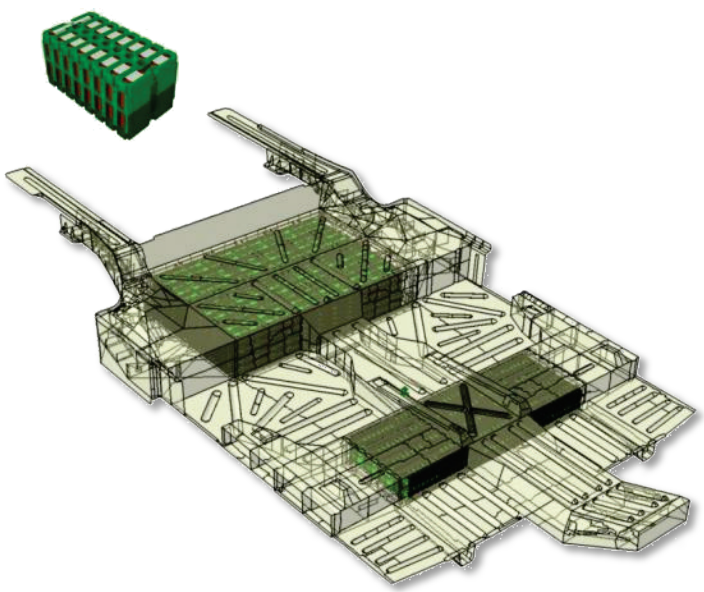
- Design of housing & mounting/simulation based optimization
- Design of modules
- Total weight of 155 kg achieved (goal was 169 kg)
- General workflow and tool chain for the design process

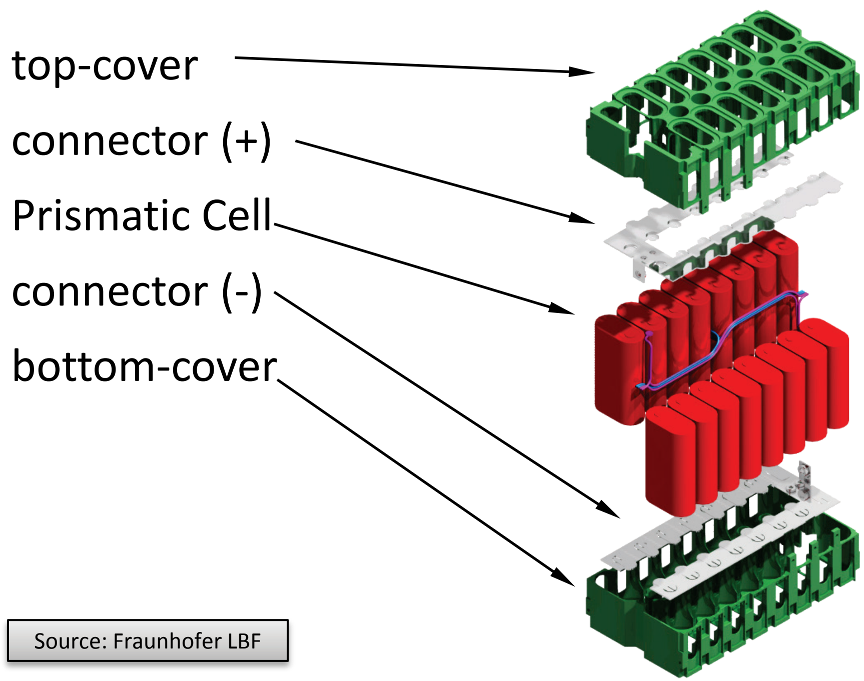


Source: Fraunhofer LBF

Prismatic vs. Pouch Cell

- Investigation of candidate chemistries, packaging and cost comparison has resulted selection in the prismatic concept
- No active cooling needed, the whole system is much lighter and easier to assemble (smart)

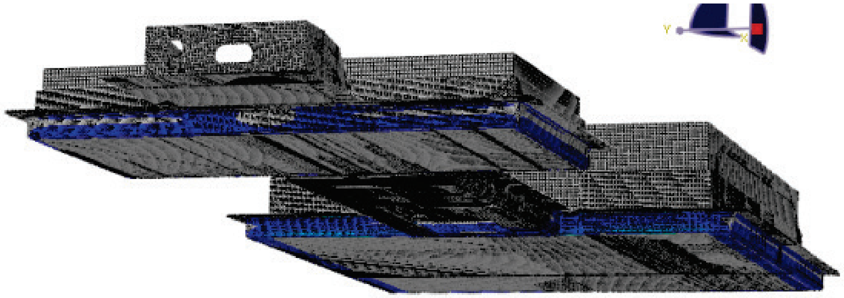


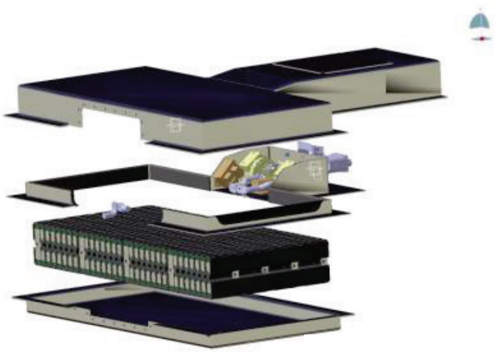


Source: Fraunhofer LBF

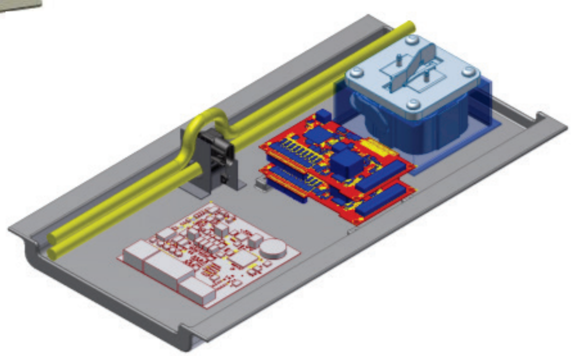
Technical Details

- Al hybrid foam sandwich structure
  - Maximum stiffness
  - Lightweight design
  - Ground protection
- Integrated „Plug balcony“
  - Easy to reach from inside
  - Fully integrated
- Aluminium die-cast tunnel
  - High grade of geometrical flexibility
  - Integrates electrical components





Source: Fraunhofer LBF



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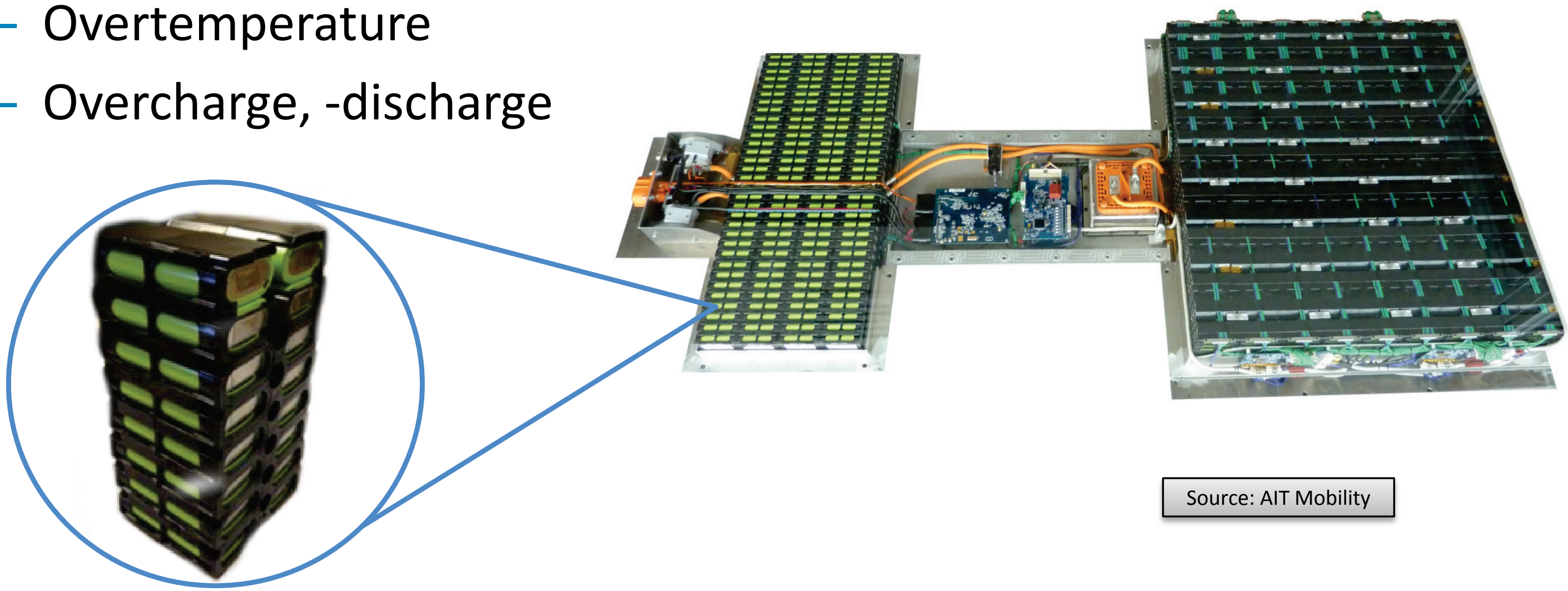
WP 6 - Hardware Build-Up & final Validation - AIT

- Build-up of a fully equipped evaluation model
- Build-up of an empty housing for test-reason
- Testing on pack level
  - Overtemperature
  - Overcharge, -discharge



Source: AIT Mobility

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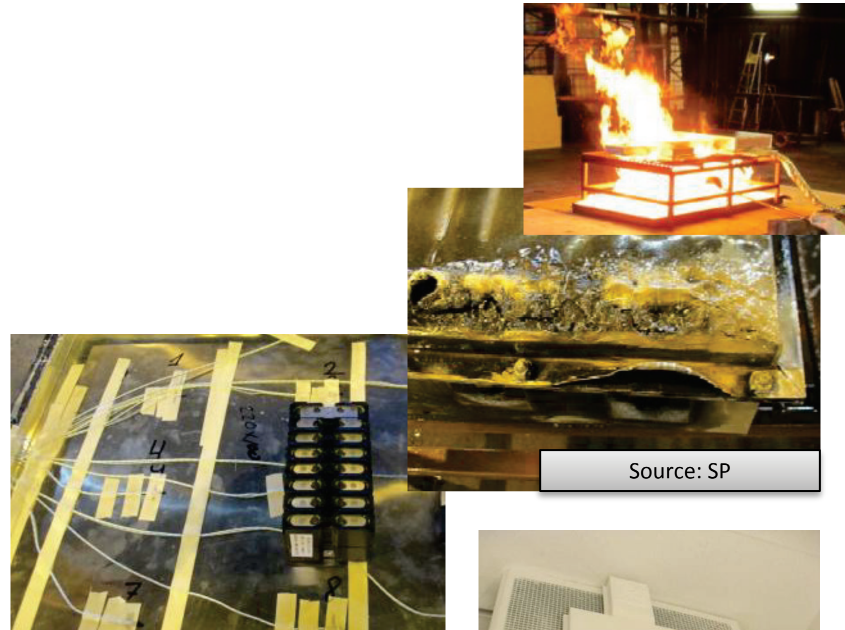
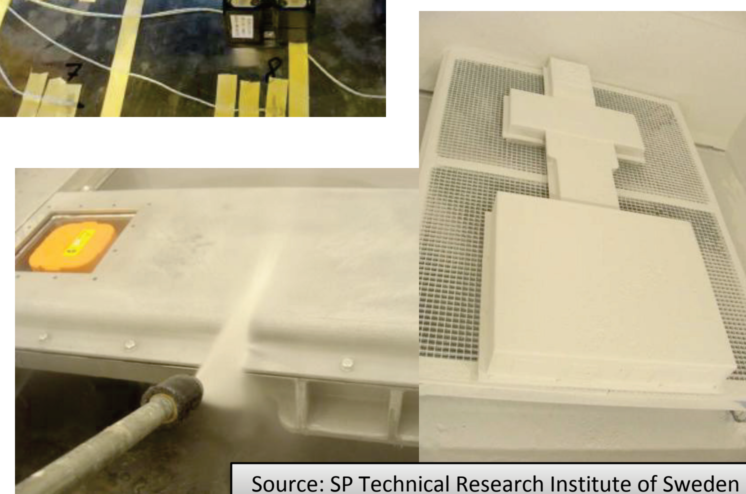
WP 6 - Hardware Build-Up & final Validation - SP

- Fire Test According to Future R100
  - Equipped with thermocouples, one battery module and bricks simulating thermal capacity
  - Placed on a grating table above fuel pan
  - Exposed to flames for a total of 130 s
  - Validating simulations
- IP Evaluation Test
  - Classification of degree of protection according to ISO 20653:2006, IP6K9K
  - Empty battery housing prototype
  - Exposed to test probe, dust and water



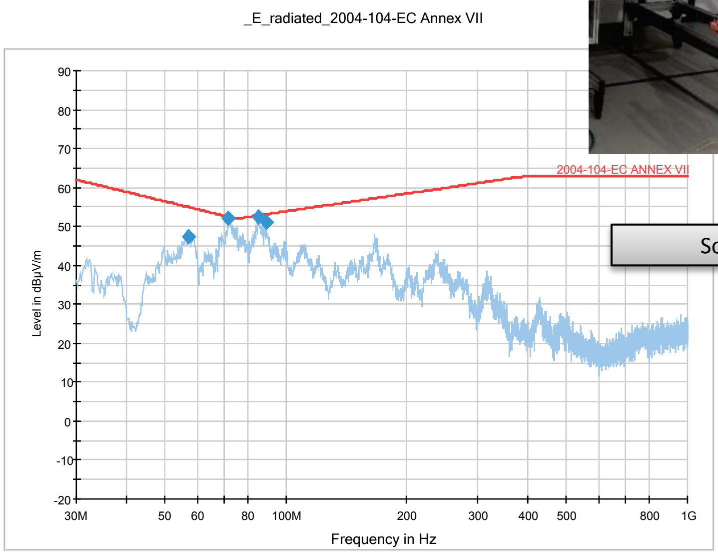
Source: SP



Source: SP Technical Research Institute of Sweden

WP 6 - Hardware Build-Up & final Validation - SP - TU Graz

- EMC Test (SP)
  - Radiated emission and radiation immunity
  - System running in normal operation with no load on HV outputs
  - Tested according to Functional Status Classification A
- Crash Test (TUG)
  - Complete floor structure assembled
  - Use of battery cell dummies
  - Validating simulations
  - Real crash test was similar to simulation after some improvements



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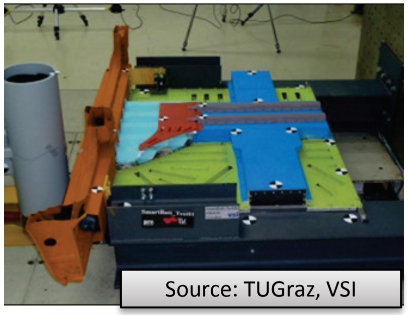
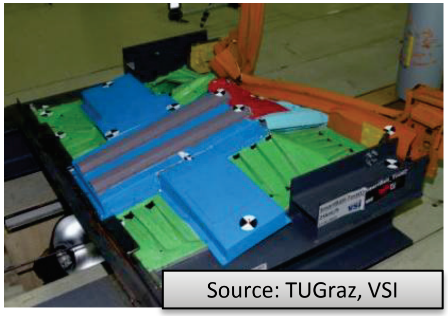


Source: TUGraz, VSI



Source: TUGraz, VSI

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WP 7 - Assessment

- Weight optimization
  - Performed analysis regarding energy consumption due to less weight of the battery system
  - Performed analysis on driving range improvements due to more battery capacity
  - Three different vehicle types were compared in standardized driving cycles and performance tests (NEDC, FTP 72 and Artemis cycle)
- Cost savings
  - The concept is suitable for the use in mass production
  - Cost outlook indicates potential in price reduction for cells
  - Components depending on volume sizes
- Impact on standardization
  - Standardization concerning EVs is performed within ISO/TC 22/SC21 and IEC/TC 69
  - UNECE/REESS amendment to R100 Battery Electric vehicle safety for Lithium Ion batteries developed and signed, interim from 1/3 2013, probably into force 1/3 2014
- Impact on replaceable-energy-storage-system concepts
  - Reviewed standardization of cells, modules, battery management system, electrical connectors and communications and battery enclosure
  - Imminently no standardization in sight

SmartBatt – Smart and Safe integration of batteries into electric vehicles

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WP 8 - Exploitation

- Knowledge Transfer
  - To electric vehicle community and broader public
  - Papers / Conferences
  - Other EU projects
- Promote Results
  - Website WP4/WP6
  - “Battery Integration Workshop” in May 2012 in Brussels
  - Fire fighter workshop in Austria
  - 5 papers in different conferences published
  - Exhibition of the demonstrator at the EEVC 2012 in Brussels
- Input for Regulations and Standards
  - ISO TC22/SC21 and UNECE R100 amendment

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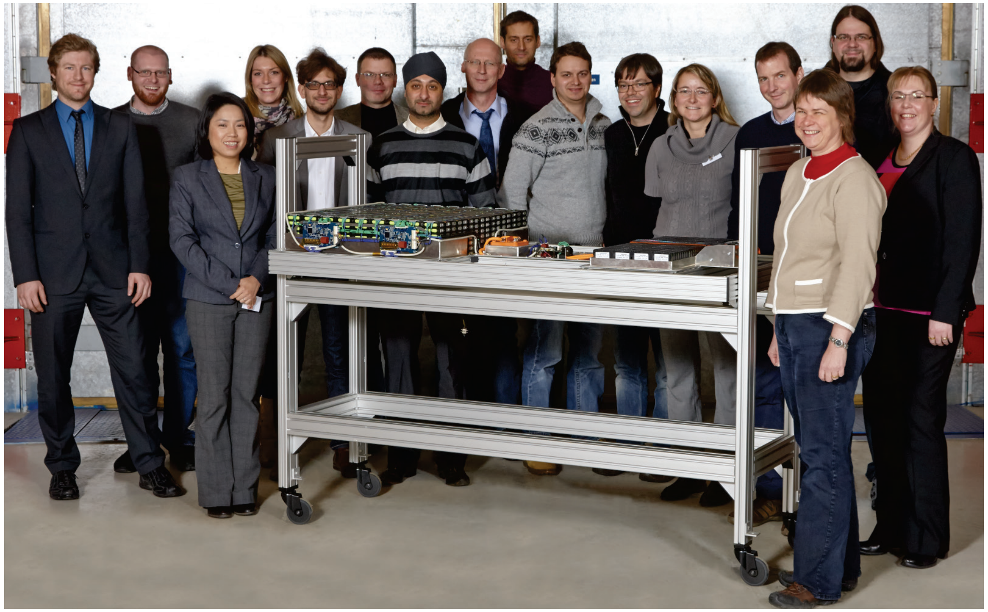
Summary and Highlights

- Complete assembled and fully functional battery SmartBatt prototype available.
- Total weight of 155 kg achieved (goal was 169 kg).
- 23 kWh with a total mass of 155 kg (reduction in housing mass to just 8.5 kg).
- Improved energy density of 148 Wh/kg (system level)
- The smart integration in the chassis improves the crash safety of the whole vehicle frame
- The concept is very suitable for mass production, with potential cost savings.



www.smartbatt.eu

Project Coordination

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http://www.ait.ac.at

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Thank you very much for your attention!

Outlook

- Technical Presentation 1 : „Cell selection process and impact of future technology“
- Technical Presentation 2: „Crashworthy battery integration“
- Technical Presentation 3: „Built-Up of the SmartBatt housing based on the proposed design”

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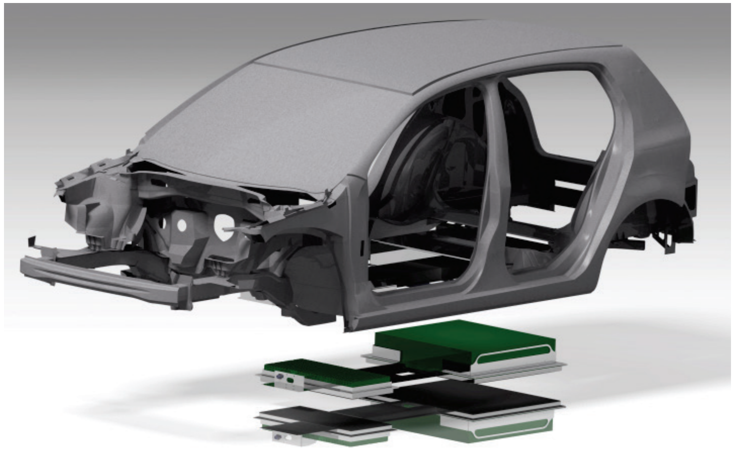

Technical Presentation 1: Cell selection process and impact of future technology

Johnson Matthey Battery Systems

Dr. Jianli Bao
Johnson Matthey Battery Systems
(formerly Axeon)

Organized by

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In collaboration with

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Johnson Matthey Battery Systems

Johnson Matthey

Emission Control Technologies

- Light Duty Catalysts
- Heavy Duty Catalysts
- Stationary Emissions Control

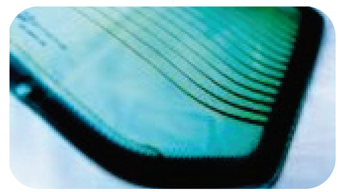
Process Technologies

Chemicals

- Chemical Technologies (DPT)
- Syngas
- Chemical Catalysts (inc. Formox)

Oil and Gas

- Refineries
- Purification
- Tracerco



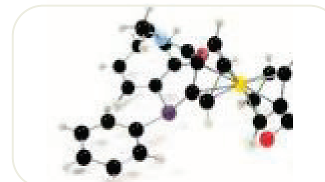
Precious Metal Products

Services

- Platinum Marketing and Distribution
- Refining

Manufacturing

- Noble Metals
- Colour Technologies
- Chemical Products



Fine Chemicals

- Active Pharmaceutical Ingredient (API) Manufacturing
- Catalysis and Chiral Technologies
- Research Chemicals

New Businesses

- New Business Development
- Water
- Battery Technologies
- Fuel Cells

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Johnson Matthey Battery Systems

- Johnson Matthey Battery Systems' core competence is in battery design, development and supply for demanding applications
- Our high volume manufacturing and consumer applications experience gives us cell purchasing power and the ability to trial new chemistries in consumer battery applications
- JMBS processes over 70M cells/year and manufactures around 3M packs/year.

Automotive	Power tools and Mobile Power	E-Bikes
		

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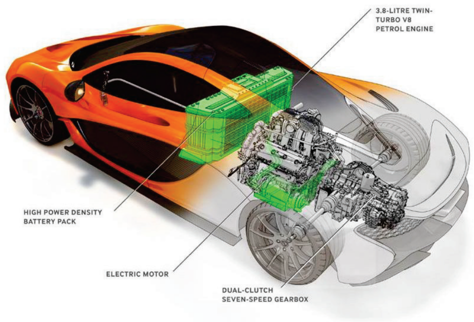
JM Johnson Matthey Battery Systems

- **HEV sports car:** The highest performance battery in the world, developed for the McLaren P1™



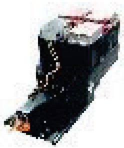
McLaren AUTOMOTIVE

- Prototype fully electric Land Rover Defender

LAND ROVER

- At the time the world's most powerful passenger car battery for the 102EX Rolls-Royce Phantom Experimental Electric

ROLLS ROYCE



- REEVolution project - Parallel Hybrid plug-in electric vehicle, based on a X351 extended wheelbase

JAGUAR

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In collaboration with: EVAAP, EDTA

Supported by: European Commission

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Johnson Matthey Battery Systems

Energy Materials → Cell Tech → BMS / Control Strategy → Battery Assembly and test → Vehicle Integration → Vehicle Usage → End of Life / Recycling

- LCV Demonstrator
- EVAB²MS : Ultra-Efficient Systems
- High energy density TMO/Si-alloy battery for EVs
- REEVolution: Evo. of REEV Techs Building a UK Supply Base
- **SmartBatt : Smart and safe integration of batteries in electric vehicles**
- Innovative nano-porous Carbons for energy storage apps
- LCV Battery Recycling and Re-Use (x2)
- Provoque : 48V MHEV Battery Systems
- SIRBATT : Energy materials / sensors / control stratregy
- MARS : High Energy Age Resistant Materials for EVs
- PICASSOS : Safety Case Simulation Tool Chain
- Practical Li-Air batteries

SmartBatt - Design Concept and Feasibility

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01 Definition of Interfaces

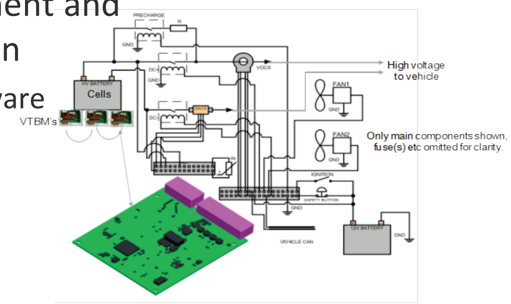
02 Battery Management System

03 Cell Selection

04 Packaging Study

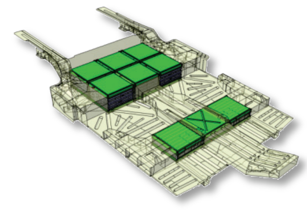
- Mechanical
  - Mounting
- Electrical
  - Connections
- Comms/diagnostics

- Battery Management System development and integration
  - Software



- Electrochemical
- Thermal
- Safety Testing

- Based on previous and concept options



- Identification of standards / regulations, e.g. IEC/ISO, FMVSS, SAE, ECE R100

SmartBatt - Design and Assessment

05
Space Volume Analysis

06
Driving Safety

07
Thermal Analysis

08
Performance, Cost & Weight

- CAD packaging analysis / baseline concept creation

- Numerical vehicle simulation to ensure drive safety
  - Brake test
  - Skid Pan test
  - Slalom test
  - Lane change test
- FMEA

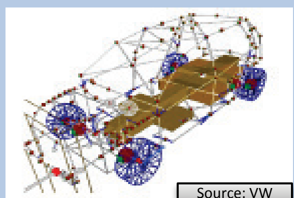
- Thermal Analysis
  - Drive cycle Analysis
  - NEDC
  - UDDS etc
  - Operating Temp -30 to 50°C?

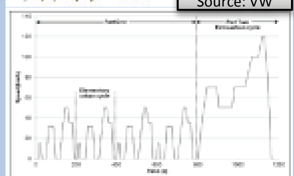
- Whole system prelim Performance Expectations, weight and cost estimation
  - Cells, BMS
  - Module housing
  - Battery housing
  - Different materials

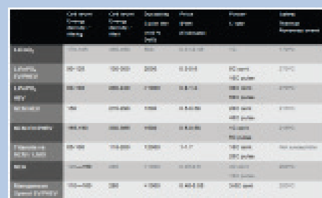
SmartBatt - Cell Selection Process

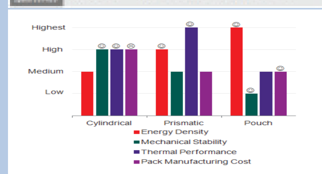
Requirements	Initial Screening Cell chemistry + form	Cost Comparison	Thermal Analysis and pack design	Safety Test

Process

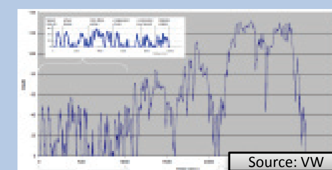


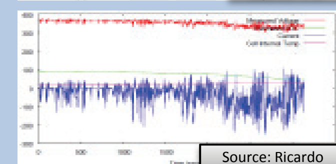


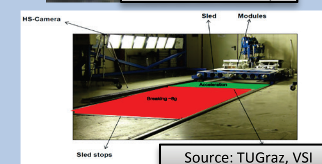




Qty.		1k	10k	100k	1M	10M
A	Cost ($/Ah)		1.43	1.43		1.3
D	Cost ($/Ah)	2.1	1.9			1.4
E	Cost ($/Ah)		2.25	1.99	1.84	1.75
F	Cost ($/Ah)	2.28		1.78	1.46	1.35







Requirements

Requirements
- Top level Vehicle requirements
- Duty cycle
- Usage pattern
- Transient events
- Power/Energy throughput

Initial Screening
- Cell info from supplier
- Energy density/ Power density
- Life

Cost Comparison
- Estimated volume
- Info from cell vendors

Thermal Analysis and pack design
- Drive cycle simulation
- Heat rejection
- Steady state + Transients
- Environmental Req.
- Cell/module thermal management

Safety Test
- Customer requirements
- Automotive safety standards

Outputs

Requirements
- Boundary Conditions
- Inputs for Characterisation

Initial Screening
- Initial cell candidates
- Initial pack design
- Energy / Power
- Estimated weight / volume

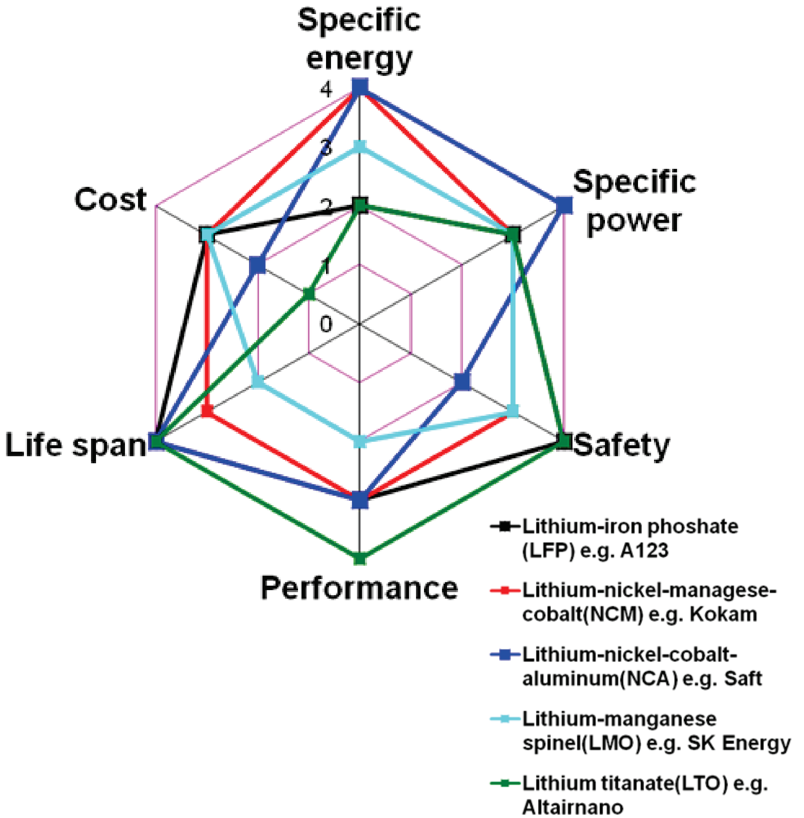
Cost Comparison
- Cell elimination

Thermal Analysis and pack design
- Input to Mech Eng.
- Input to Elec Eng / BMS requirements

Safety Test
- FMEA
- Safety & BMS control strategy

Cell Selection - Main Contender Cell Chemistries

	Specific Energy / Wh/kg	Cell Energy density / Wh/l	Durability Cycle life (100 % DoD)	Price $/Wh (Estimate)	Power C-rate	Safety Thermal Runaway onset
$LiCoO_2$	170-185	450-490	500	0.31-0.46	1C	170ºC
$LiFePO_4$ EV/PHEV	90-125	130-300	2000	0.3-0.6	5C cont. 10C pulse	270ºC
$LiFePO_4$ HEV	80-108	200-240	>1000	0.8-1.2	30C cont. 50C pulse	270ºC
NCM HEV	150	270-290	1500	0.5-0.58	20C cont 40C pulse	215ºC
NCM EV/PHEV	155-190	330-365	1500	0.5-0.58	1C cont 5C pulse	215ºC
Titanate vs NCM / LMO	65-100	118-200	12000	1-1.7	10C cont. 20C pulse	Not susceptible
NCA	120→190	280	>1000	0.45-0.6	4C cont 10C pulse	200ºC
Manganese Spinel EV/PHEV	110→160	280	>1000	0.45-0.55	3-5C cont	255ºC



"No ideal Li-ion chemistry" at the moment!

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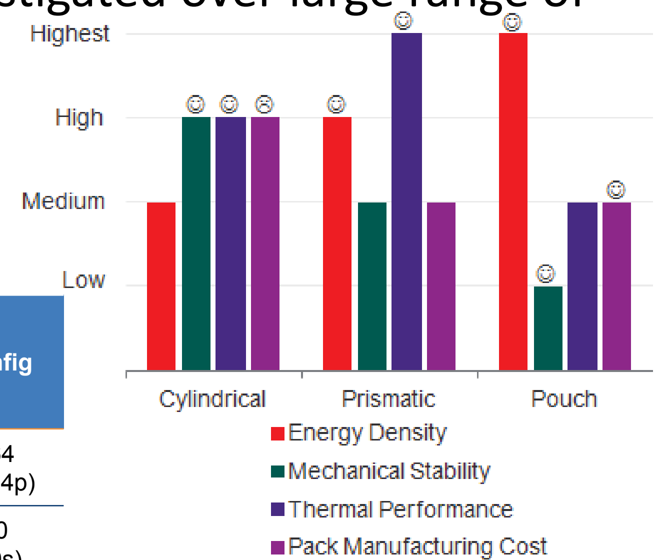
Initial Cell Candidates

- Multiple cell formats and cell chemistries investigated over large range of criteria
  - Chemistry : LFP, NCM, LMO, LCMO
  - Form Factor : Prismatic, Pouch, Cylindrical



	Chem	Pack weight (kg)	Pack volume (L)	Pack energy (kWh)	Pack power (kW)	Pack regen power (kW)	Pack nominal voltage (V)	Config
Pouch 20Ah	LFP	180	96	24.0	96	96	300	364 (91s4p)
Pouch 100Ah	NCM	180	85	29.6	89	59	296	80 (80s)
Pouch 53Ah	NCM	190	94	31.4	157	63	296	160 (80s2p)
Pouch 87Ah	NCM	150	71	26	77	52	296	80 (80s)
Prismatic 6.5Ah	LFP	220	109	25.3	101	51	307	480 (96s5p)
Prismatic 4.4Ah	LCMO	160	68	24.7	67	49	296	1520 (80s19p)

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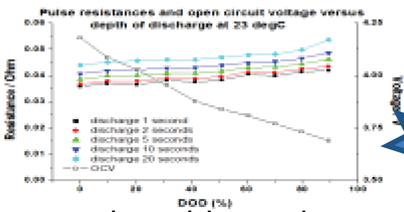
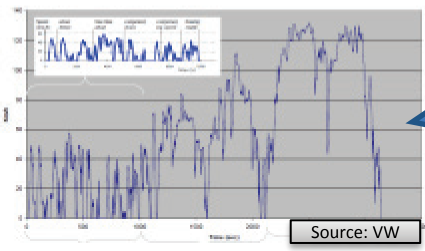
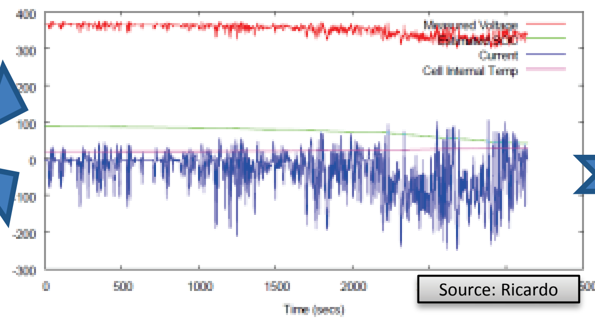
Thermal Analysis and Pack Design



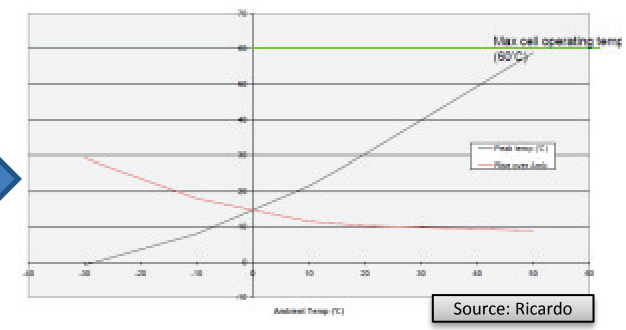
Real world test data



"European real world driving"



Cell level simulation



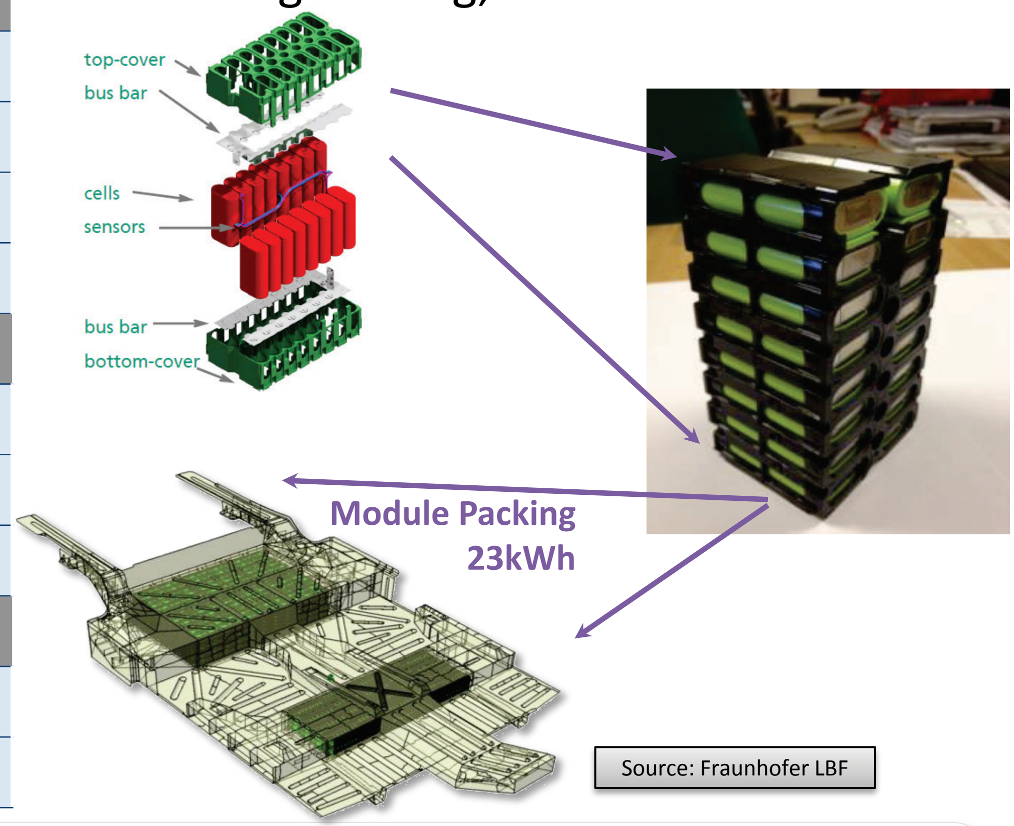
Impact of Ambient temperature

Pouch 87Ah	Cells require heating for cold temperature (<-10°C)
	Cells likely require active cooling at hot temperatures (>38°C)
Pouch 20Ah	Cold end OK
	Hot end will require active cooling (>37°C)
Prismatic 4.4Ah	Would need a little derating below -10°C
	Does not appear to need active cooling

Final Concept -> Module Build

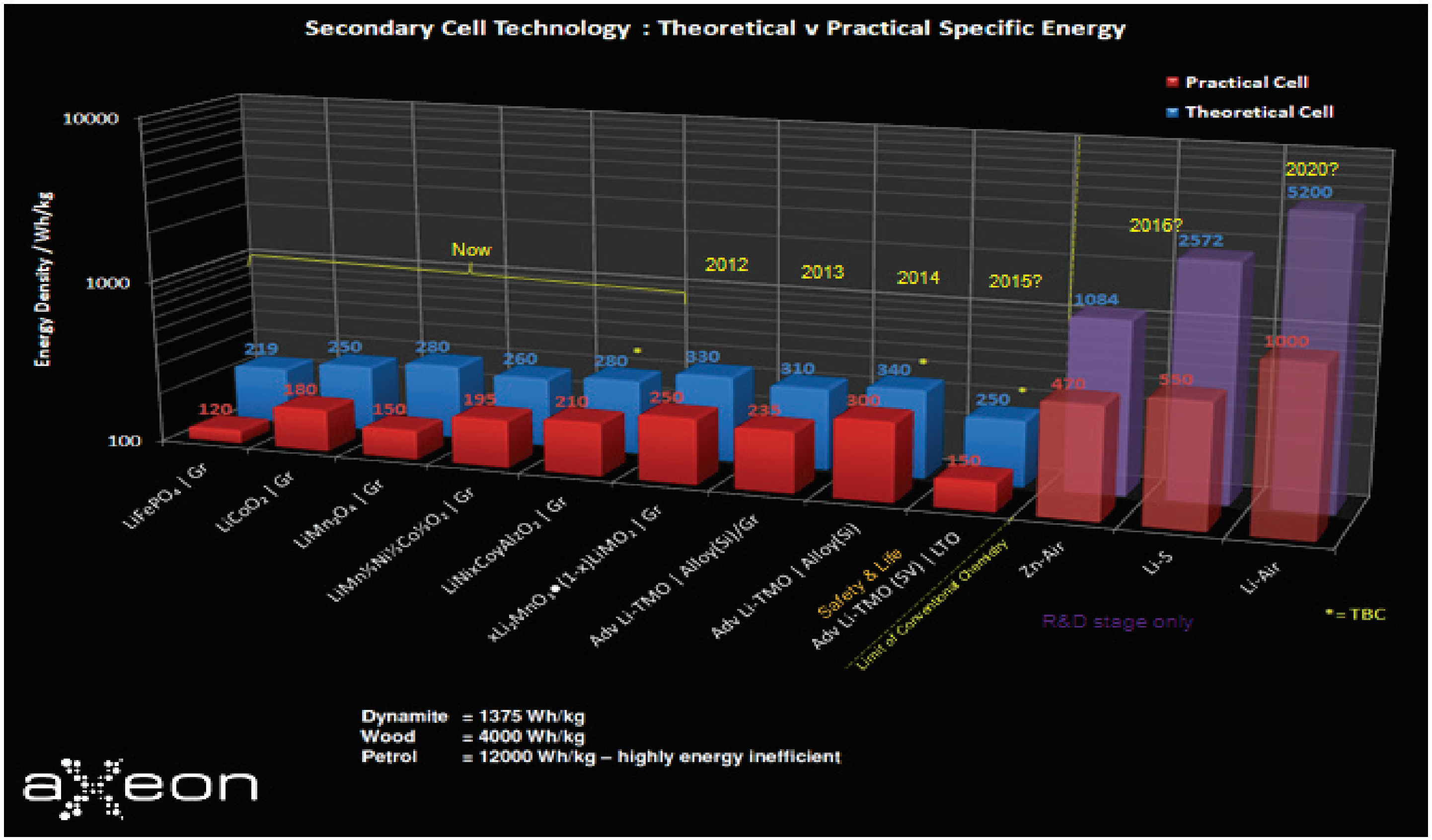
	Final Concept
Cell Level	
Cell Type	**Prismatic**
Chemistry	**LCMO**
Energy Density	**181Wh/kg**
Safety test	**Pass**
Module Level	
Energy Density	**160Wh/kg**
Number of modules	**88**
Thermal management	**No**
Pack Level	
Energy	**23kWh**
Energy Density	**148Wh/kg**

- 16 cells per module
- Weight 1.6kg, of which 88% is “cells”



Impact of Future Cell Chemistry on ‘SmartBatt’ Pack

Theoretical vs. Practical Energy Density



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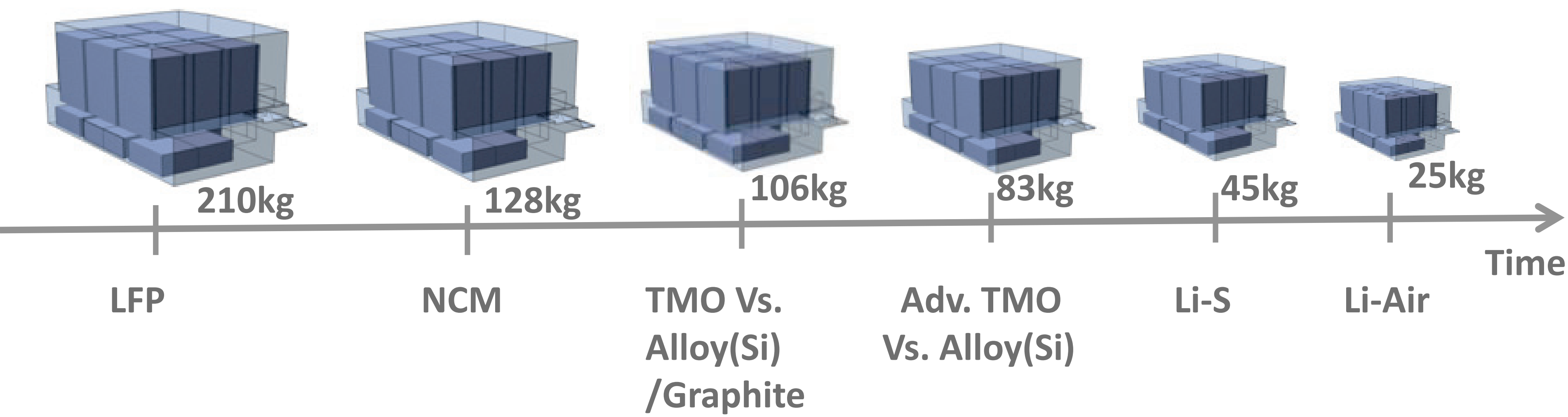
Impact of Future Cell Chemistry on ‘SmartBatt’ Pack

For a 25kWh battery (ie “SmartBatt”)

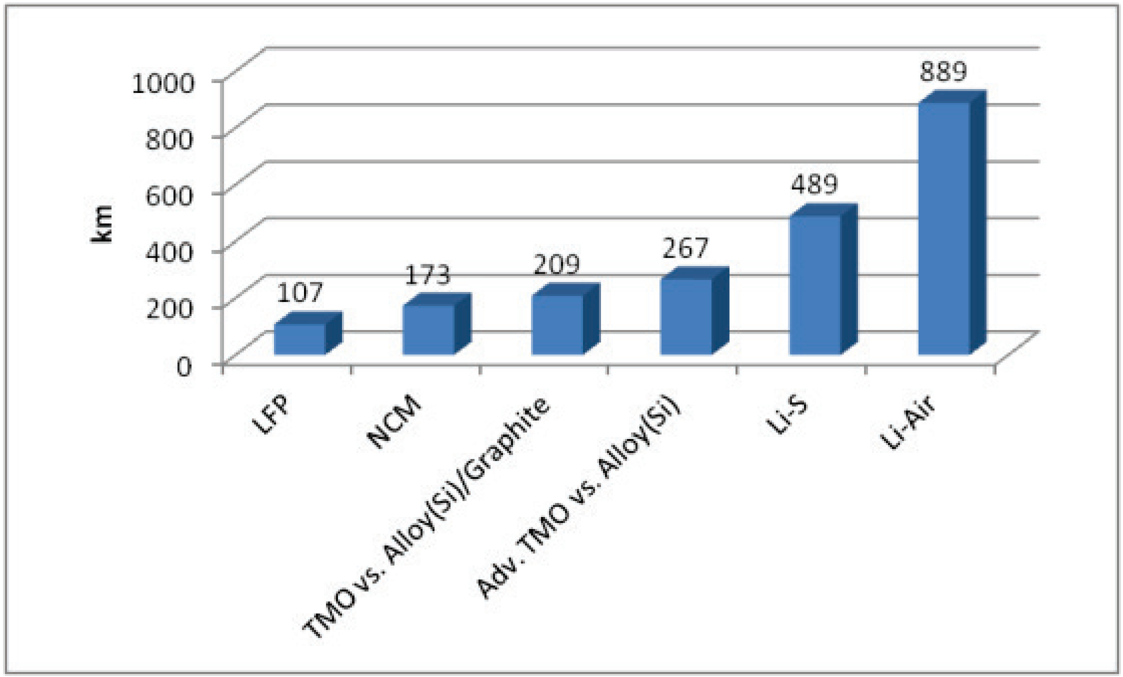
- To provide the same energy, packs in the future will be lighter and smaller (weights here are cells only)



Impact of Future Cell Chemistry on 'SmartBatt' Pack

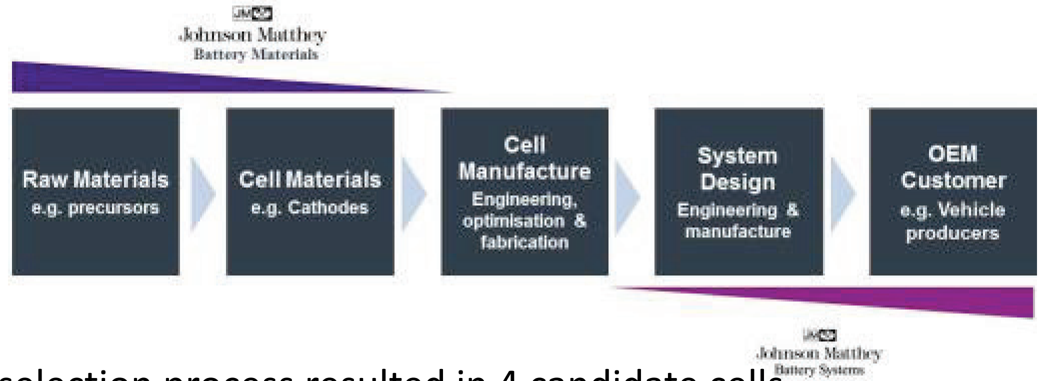
For a 200kg battery (e.g. "SmartBatt")

- To make them the same weight, packs in the future can drive the vehicle for longer distance
- Calculation based on the assumptions of
  - Energy requirement per km per kg is 0.125 Wh/km/kg
  - The weight of the target vehicle is 1,350kg
  - Cell to pack energy density ratio is 0.75



Summary / Conclusions

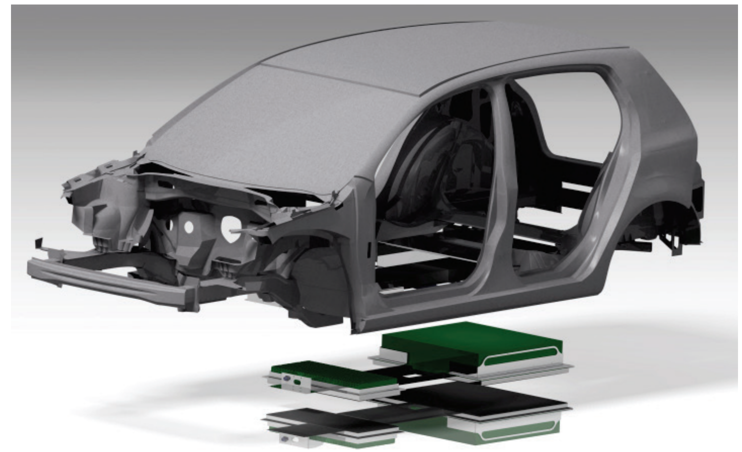
- **Johnson Matthey Battery Systems** has extensive real world experience of engineering high performance energy storage systems, including the integration of a range of cell chemistries and Battery Management Systems.



- The initial cell selection process resulted in 4 candidate cells
- Selection based on cost reduced this to 3
- Thermal simulations and weight & volume considerations reduced this to 2 cells
- Safety tests, as well as the thermal simulations, resulted in the final selection
- Looking forward to the future it is felt that the SmartBatt concepts will be applicable for at least the next 2 generations of cells

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION.

Barcelona, Spain
17th-20th November 2013



Technical Presentation 2: Crashworthy battery integration

DI Peter Luttenberger
Vehicle Safety Institute
Graz University of Technology
[Member of Frank Stronach Institute]

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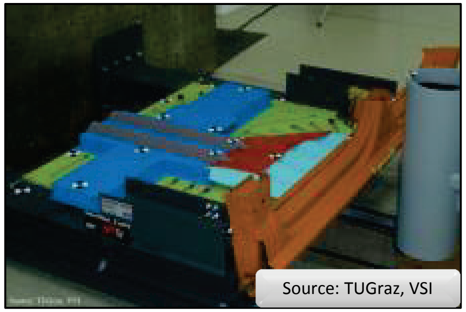
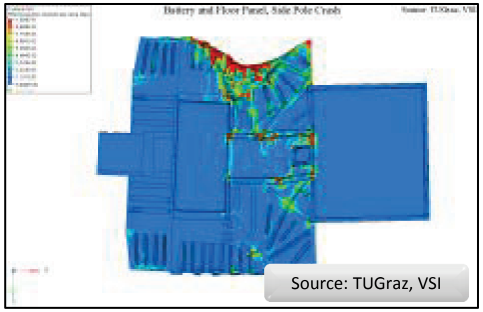
SmartBatt – Smart and Safe integration of batteries into electric vehicles

Content

- Introduction of the Vehicle Safety Institute
- SmartBatt, Project Presentation:
  - Aims and Methodology
  - Excerpts of a crashworthy integration w.r.t. the Methodology
  - Conclusions



Source: TUGraz, VSI



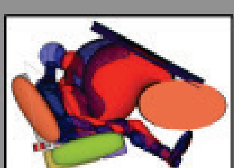
Source: TUGraz, VSI

Vehicle Safety Institute

- **General Information**
  - Institute of the Graz University of Technology
  - Head of the Institute:
    - Univ.-Prof. Dipl.-Ing. Dr. techn. Hermann Steffan
  - Location: Graz, Austria

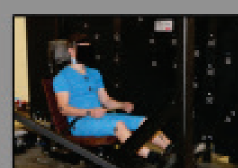
Research Topics of the Vehicle Safety Institute:

Child Safety



Accident Research

Biomechanics



Integrated Safety

E-Mobility

Test and Verification

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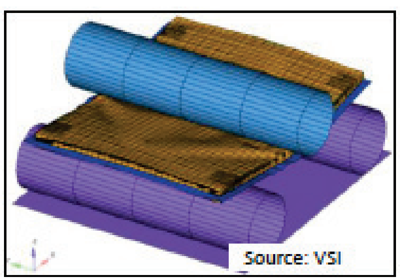
Vehicle Safety Institute,
Graz University of Technology
[Member of Frank Stronach Institute]

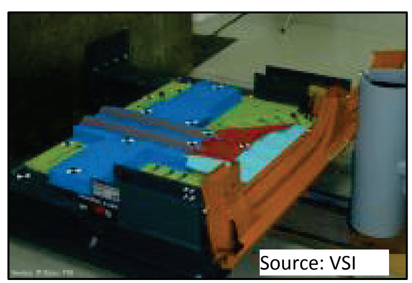
E-mobility

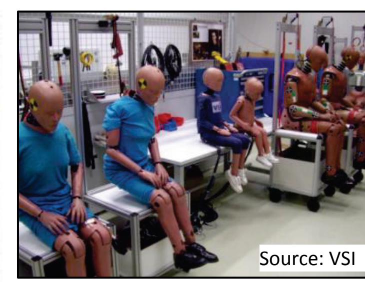
- Integration of batteries
- Identification of possible loads of REESS
- Identification of alternative tests
- Finite element simulation models

Testing and verification

- Determination of validation data for the numerical simulation (material data)
- Performing overall crash tests
- Development of innovative approaches for reliable and cost effective testing







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SMARTBATT,
PROJECT PRESENTATION:

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SmartBatt – Smart and Safe integration of batteries into electric vehicles

Aims:

- Crashworthy integration of a REESS
  - Different impact scenarios (Pole Crash, …)
- Lightweight design
  - Developing the pack as an integrated structure
- Multifunctionality of new REESS parts

Restrictions / Boundary conditions:

- No sandwich floor
- No deformation of the cells / REESS

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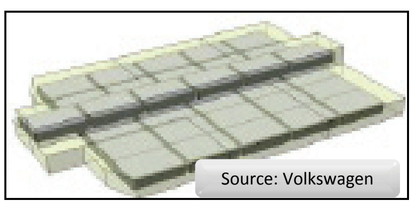
SmartBatt – Smart and Safe integration of batteries into electric vehicles

Requirements and Specifications for the REESS integration

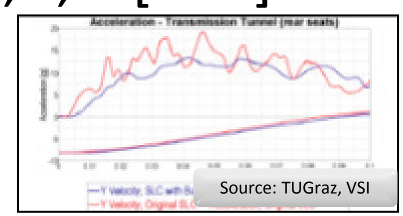
Parameters defining the ***system volume****:*

- Energy of REESS [kWh]
- Voltage of REESS [V]
- Cell measures [mm]
- Cell data [V], [Ah]
- …


Source: Volkswagen

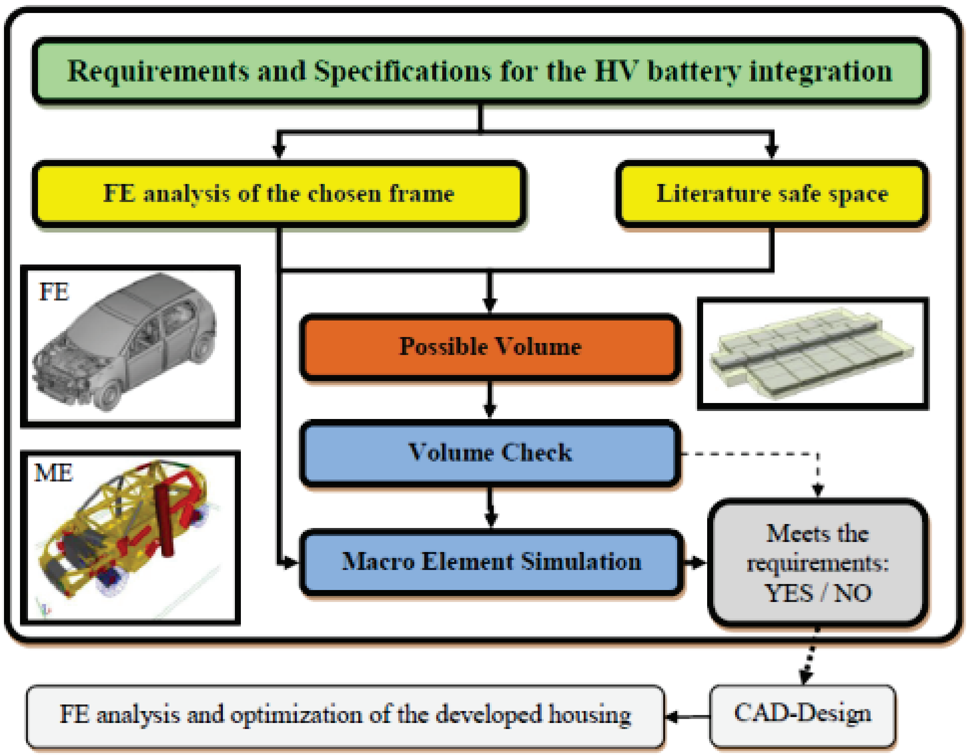
Parameters defining ***system location*** *in the BiW:*

- Acceleration [g]
- Intrusion depth [mm]
- Usable Volume [m³]
- CoG: X, Y, Z [mm]
- …


Source: TUGraz, VSI

SmartBatt – Smart and Safe integration of batteries into electric vehicles

- Methodology for Battery Integration[1]



Selected topics are shown within the next slides

FEM optimization only:

- Many variants
- Vehicle boundaries
- Calculation time

The methodology was applied to a frame (SuperLightCar[2])

(1) Luttenberger et. al; Structural analysis of a body in white for battery integration using finite element and macro element; ECCOMAS, Vienna. 2012.
(2) Goede: SuperLiGHT-car project - An integrated research approach for lightweight car body innovations. *Innovative developements for lightweight vehicle structures*, 2009.

SMARTBATT

Excerpts of a crashworthy integration w.r.t. the Methodology

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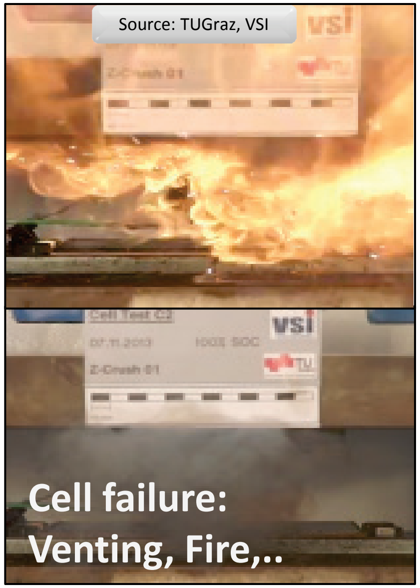
Literature Review

Literature safe space:

- Identify possible REESS positions
- The major problem for battery housings regarding crash safety
  - **Deformations due to high mechanical loadings (Can cause CELL FAILURE)**

Brand & Vehicle Model	Battery Pack / location
BMW Mini E (EV)	Below rear seats
Daimler Smart ED (EV)	Below front seats
Mitsubishi i-MiEV (EV)	Floor panel
Tesla Model S (EV)	Floor panel
Tesla Roadster (EV)	Below rear seats
Chevrolet Volt (EV with range extension)	Below rear seats and tunnel
Nissan Leaf (EV)	Floor panel

Source: (1)



Actual batteries within the passenger compartment:
Initial target → Designed as a „safe“ place (passenger)

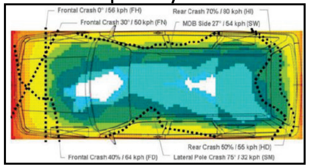
Crash / Crash Test Results:

- Pole and Side MDB test
  - **Pole: 300mm - 440mm**
  - Side MDB: 65mm and 145mm

Crash data of the NHTSA database [4]:

Vehicle Model	Crush distance [mm]	Test Configuration
2011 KIA Optima	370	US NCAP Pole
2011 Honda CR-Z	300	US NCAP Pole
2011 VW - Jetta	370	US NCAP Pole
2011 Toyota Prius	320	US NCAP Pole
2011 Mazda 3	440	US NCAP Pole

Deformation frequency overlaid with crash tests [3]:



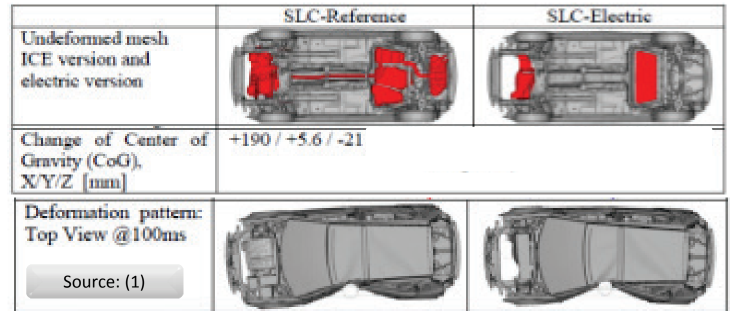
Pole crash is crucial regarding deformation patterns

(3) Source: Justen R. and Schöneburg R.: Crash Safety of Hybrid- and Battery Electric Vehicles. *22th ESV-Conferen.*
(4) NHTSA; NHTSA Test Database; www-nrd.nhtsa.dot.gov (7)

FEM simulations (1/2)

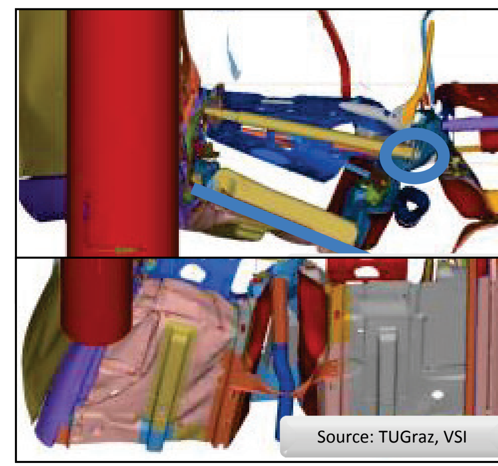
- Mass and CoG modifications influencing the behaviour in crash tests
  - Effects of new CoG
    - i.e. Higher intrusion depth possible
- Weak points in side pole collision:
  - Open tunnel → loss of stiffness
  - Seat cross member penetrating the tunnel
  - Cross member below front seats
    - Causing REESS damage and possible hazards

→ Improve side crash absorbers



	SLC-Reference	SLC-Electric
Undeformed mesh ICE version and electric version		
Change of Center of Gravity (CoG), X/Y/Z [mm]	+190 / +5.6 / -21	
Deformation pattern: Top View @100ms		

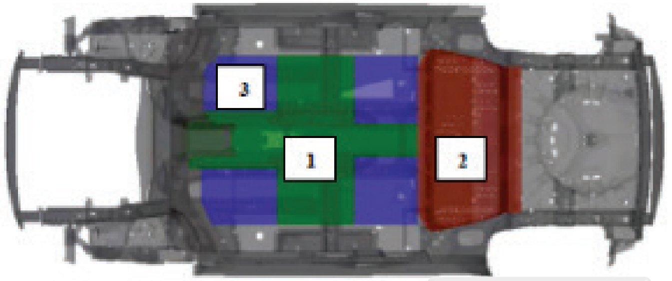
Source: (1)



Source: TUGraz, VSI

FEM simulations (2/2)

- Results of this analysis define a „safe“ battery area
  - Concept developments in this area
- Lateral position: ~350mm inside the rocker (without improvement)
- Rear and Front end not a safe pack location
  - High intrusions, CoG movement



Source: TUGraz, VSI

The possible concepts can be anywhere in this area (Area 1, 2, 3)

Input for:
- CAD design &
- **ME model**

ME simulations

- ME model used in concept phase

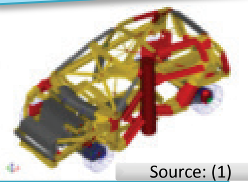
Performance of versions A and B:

- Advantages of lateral impact absorbers:
  - Distributed absorbers in Version B are superior in terms of energy absorption (area below force-displacement function)
  - Equal support of the rocker during crash
- Final Concept: Version A due to project restrictions

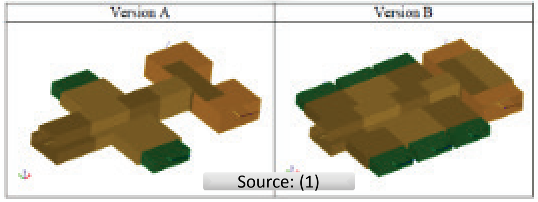
Intrusions	Reference [mm]	Version A [mm]	Version B [mm]
Pole Crash	~320	~200	~230

ME model

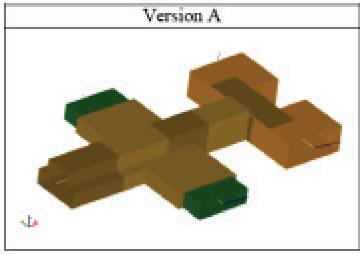
Different Concepts



Selected Versions



Final Concept



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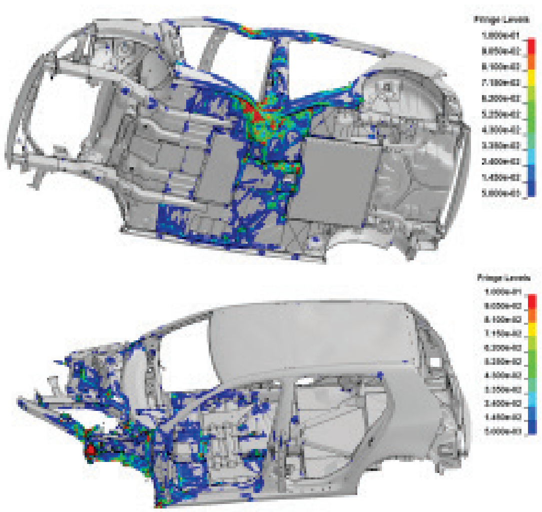
FEM simulations of the final concept compared to the baseline model

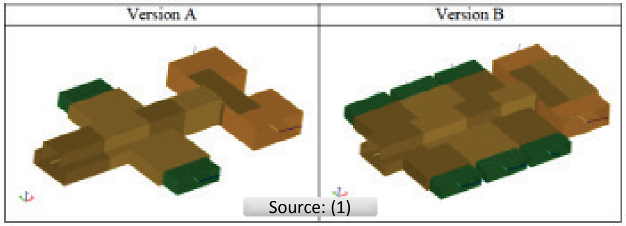
- Front: Peak acc. lower (<~4%)
- Front: Footwell intrusions less than baseline
- Side deformation lower
- More survival space (pole crash)
- Plastic hinge in the tunnel part reduces loading on the REESS parts equipped with modules.

Effective plastic strain @100ms



Source: Impact Design

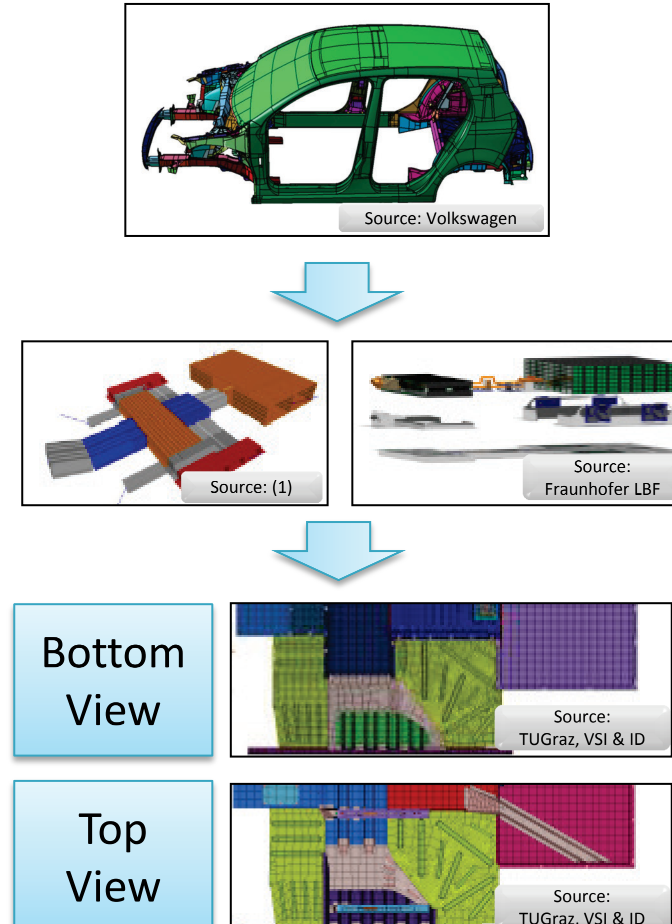
Conclusions (1/2)



- Performance of versions A and B:
  - Less Intrusion for Version A
  - Version A: Enough volume to fit the requirements
  - Plastic hinge in tunnel reduces pack loading
- Side pockets (at least central, below front seats) are highly recommended
  - Significant improvement of side collision response
  - Equal support of the rocker during crash
  - Version B: Force-Displacement curve near idealized square

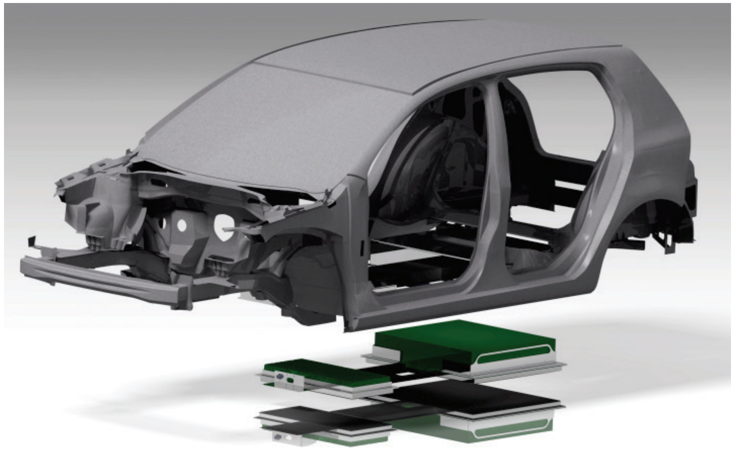
Conclusions (2/2)

- Battery integration influencing vehicle dynamics (CoG)
- Advantages in concept phase:
  - Time reduction, optimization applicable to structural components too
  - Significantly improved pole crash behaviour
- FEM optimization → final design needed only a few modifications



The 27th **INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION.**

Barcelona, Spain
17th-20th November 2013



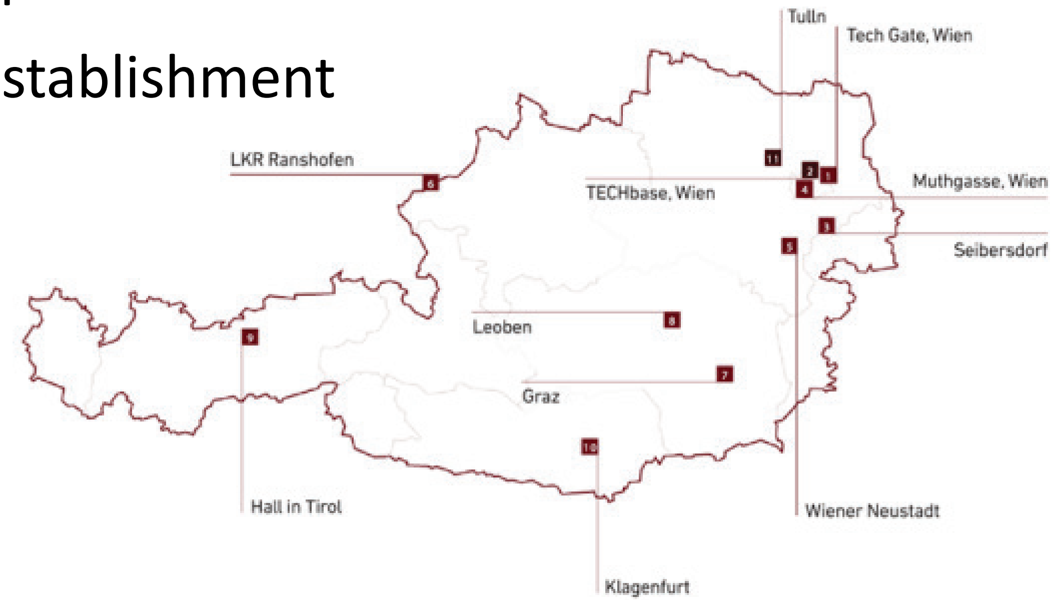
Technical Presentation 3: Build-Up of the SmartBatt housing based on the proposed design

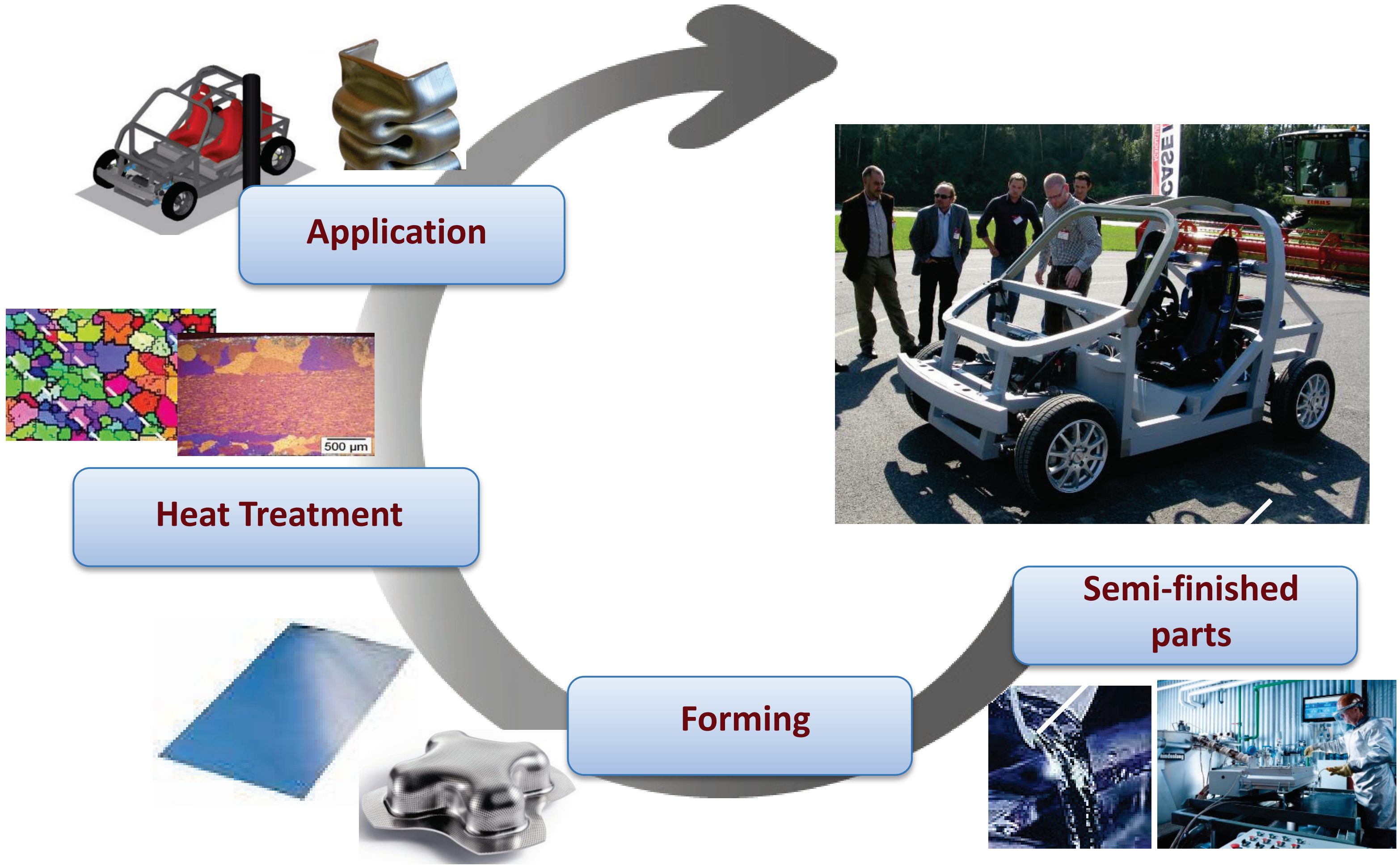
DI Matthias Hartmann
Light Metals Technologies Ranshofen,
AIT Austrian Institute of Technology

Organized by Fira Barcelona, avele
Hosted by AVERE, neA, Ajuntament de Barcelona
In collaboration with EVAAP, EDTA
Supported by European Commission

- Number of employees: about 42
- Location: Ranshofen, Austia
- Operating performace: about 5.8 million €
- 100% subsidiary of the AIT
- Non-university research establishment

- Certificates
  - ISO 9001:2008
  - ÖNORM, EN ISO/IEC 17025





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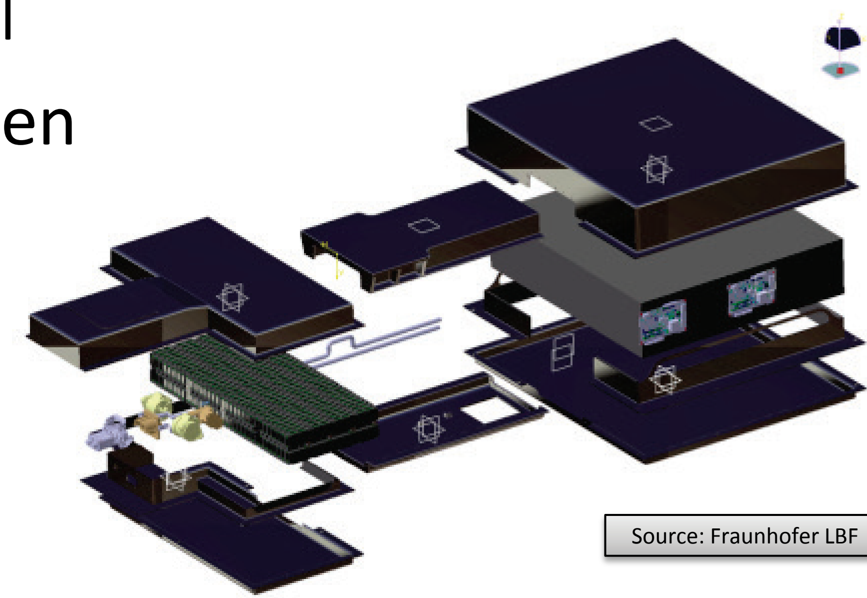
Battery Layout

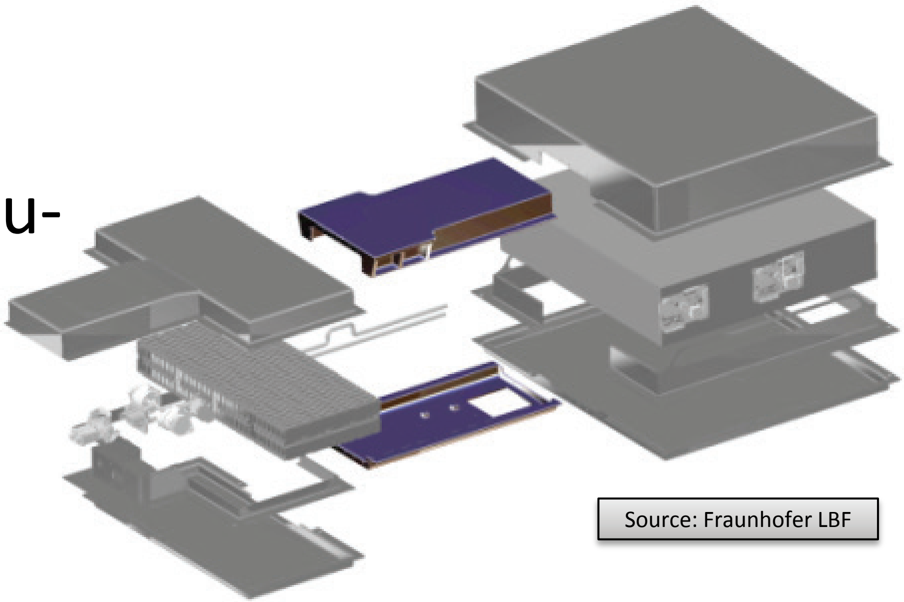
- Battery has three major mechanical parts
  - Al hybrid foam sandwich structure
  - Integrated „Plug balcony“
  - Aluminium die-cast tunnel
- Prismatic cells were chosen
- Cells are combined in modules
- Middle tunnel is used as additional storage



Source: Fraunhofer LBF

Tunnel

- Tunnel connects front and rear package
- Reasons for a casting solution
  - Battery package challenging
  - Functional integration
- Low pressure die casting process was used to manu-facture the prototype

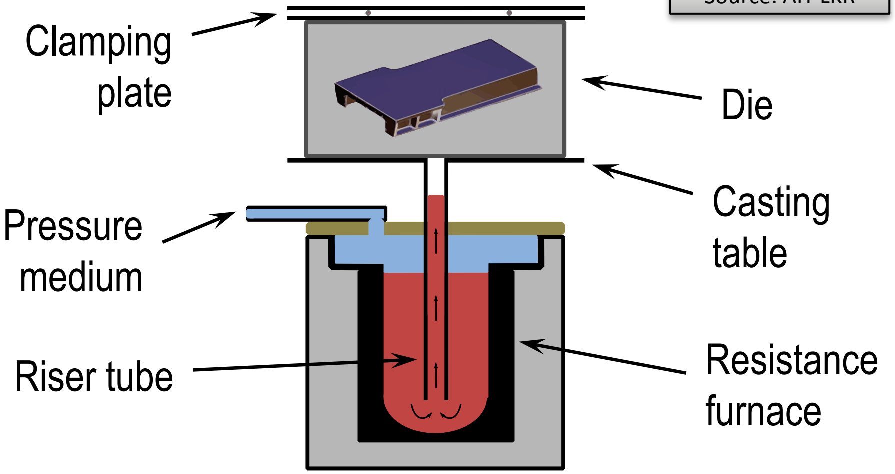


Source: Fraunhofer LBF

Casting Process

- Low pressure die casting for prototyping
  - Cheaper for low quantity
  - Higher wall thickness necessary
- Casting of the prototype parts on the inhouse facilities
- Lost form process
- For serial production: High pressure die casting process recommended

Source: AIT LKR



George E. Totten and D. Scott MacKenzie. *Handbook of Aluminium, Volume I: Physical Metallurgy and Processes*. Taylor & Francis, 2003.

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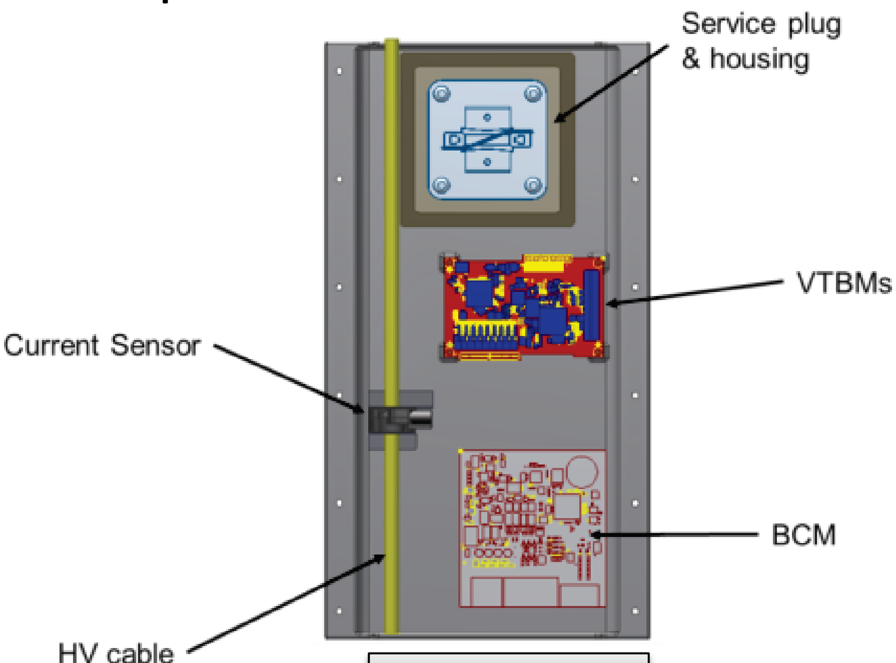
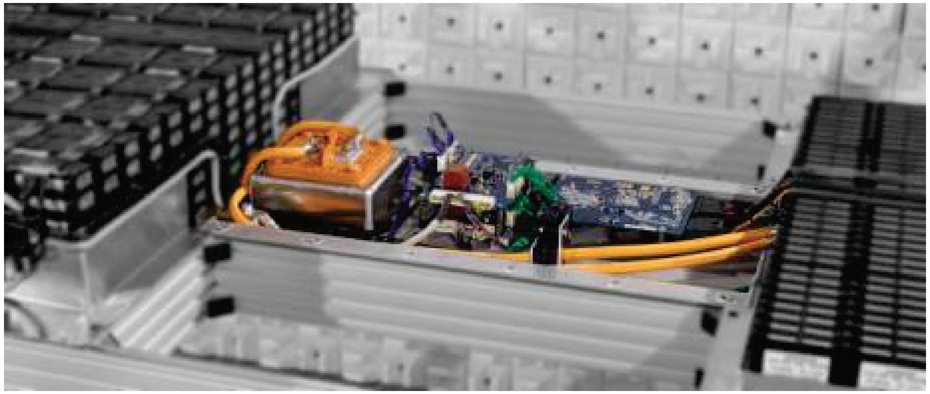
Tunnel layout

- Usage of the tunnel as extra space
- Several electrical components placed in the tunnel



Source: Fraunhofer LBF

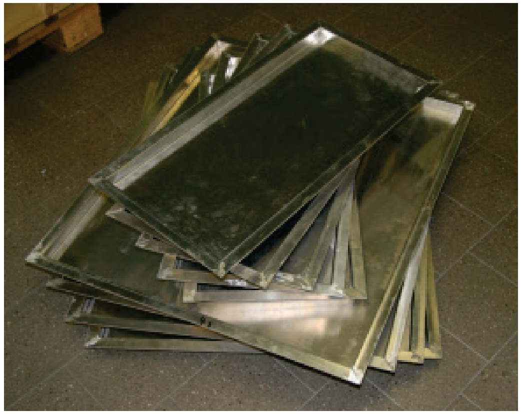
Source: AIT LKR

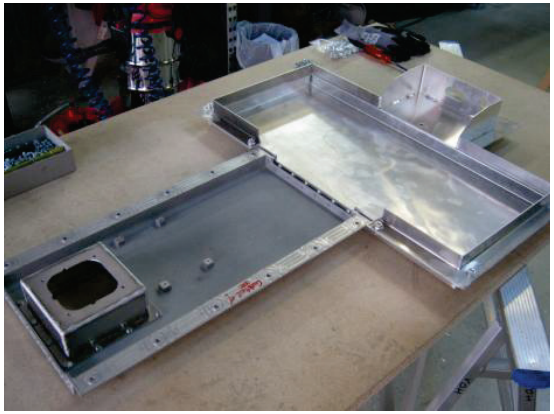


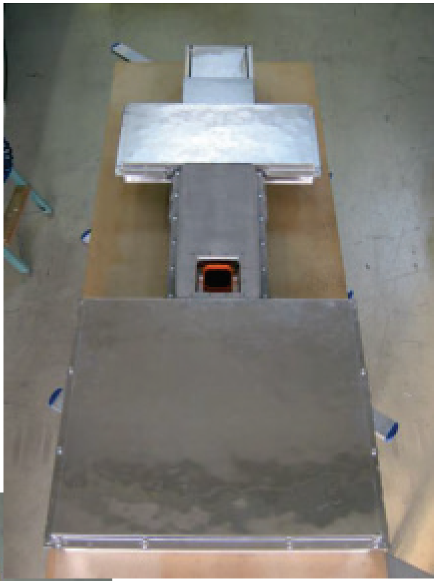
Source: SP Technical Research Institute of Sweden

WP 6 - Hardware Build-Up: Mechanical components

- Different mechanical parts from different companies had to be assembled:
  - Sandwich plates for front and rear housing
  - Inner frame with plug balcony in the front
  - Tunnel in the middle
- Application of an adhesive, which also conducted as a sealing







Source leftmost picture: Fraunhofer IFAM

Source other pictures: AIT Mobility

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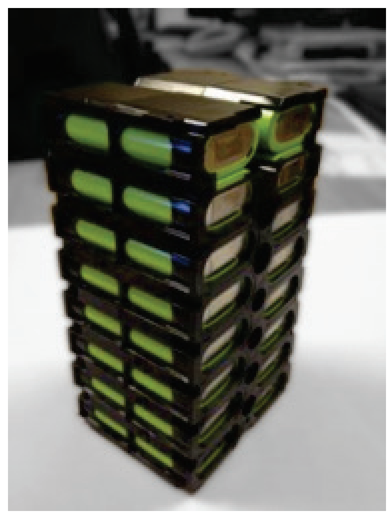
WP 6 - Hardware Build-Up: Electrical components

- Modules were built up of plastic housing, cells and busbars
- Smart inter-module connection scheme makes HV-cables obsolet
- Balance of plant is integrated into the middle tunnel
- Active balancing



Source all: AIT Mobility

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Conclusion

- Housing and electrical components were built-up from the proposed design
- Front and rear made from Al hybrid foam
- The tunnel in the middle has been casted, due to higher functional integration
- Prismatic cells were combined in modules
- The modules and the wiring were integrated into the housing

Thank you for your attention

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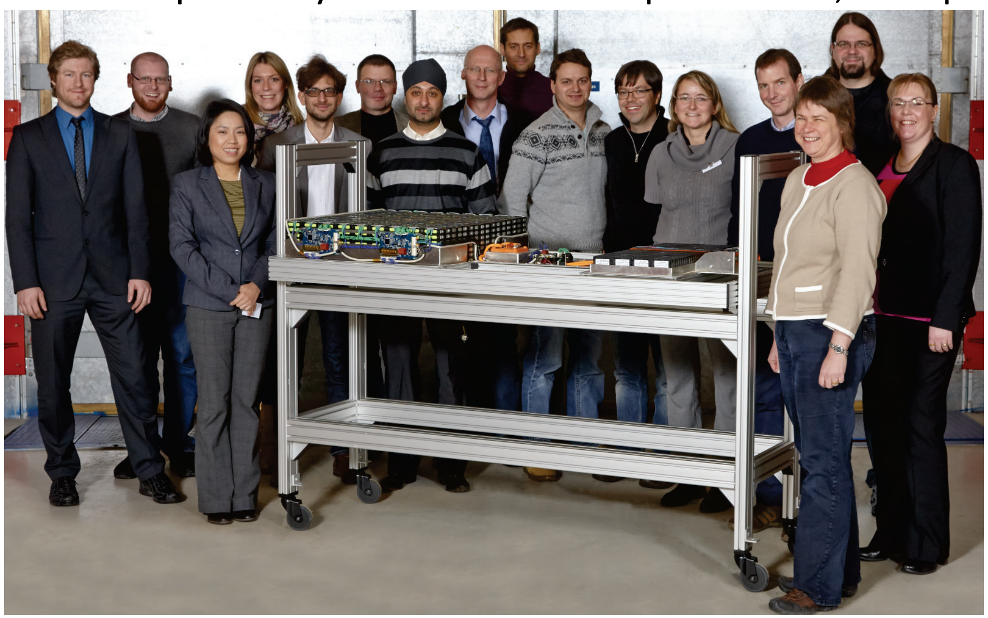
Summary and Highlights

- Complete assembled and fully functional battery SmartBatt prototype available.
- Total weight of 155 kg achieved (goal was 169 kg).
- 23 kWh with a total mass of 155 kg (reduction in housing mass to just 8.5 kg).
- Improved energy density of 148 Wh/kg (system level)
- The smart integration in the chassis improves the crash safety of the whole vehicle frame
- The concept is very suitable for mass production, with potential cost savings.



www.smartbatt.eu

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