Electric Energy Storage in Smart Buildings

Dr. Bettina Lenz, Meinert Lewerenz| November 2010
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EWE-Research Center NEXT ENERGY at a glance

EWE

CARL VON OSSIETZKY universität OLDENBURG

Niedersachsen

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie Oldenburg

- Independent & free to work with any other company
- Associated Institute of Oldenburg University
- Staff of ~76; financed by EWE, complemented by third-party funds
- Nonprofit association, results belong to institute and can be published

Target size: ~100 People
New building operational since Q3 2009
>4500m², Laboratories > 1600 m²

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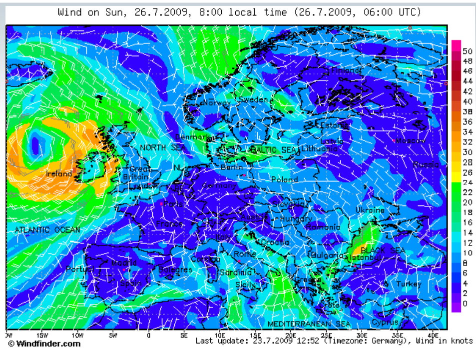
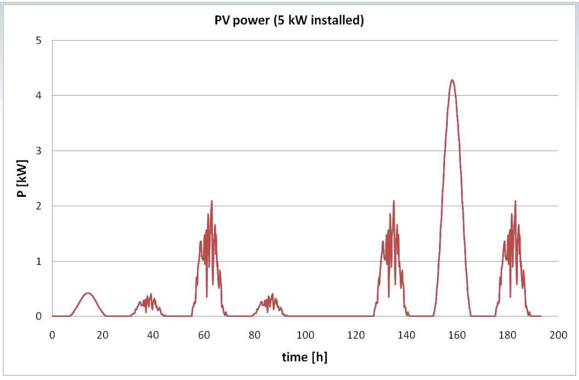
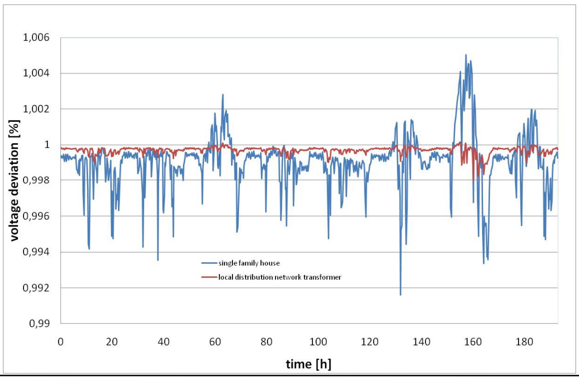
Motivation: Before storing Energy



- Forecasting Energy Demand and Production
  - Weather Forecast (Solar and Wind Power)
  - Optimizing PV/Wind/Biogas Balance
- Consume Energy
  - Demand Side Management (Cold Storage House…)
  - Energy Distribution (Grid extension)

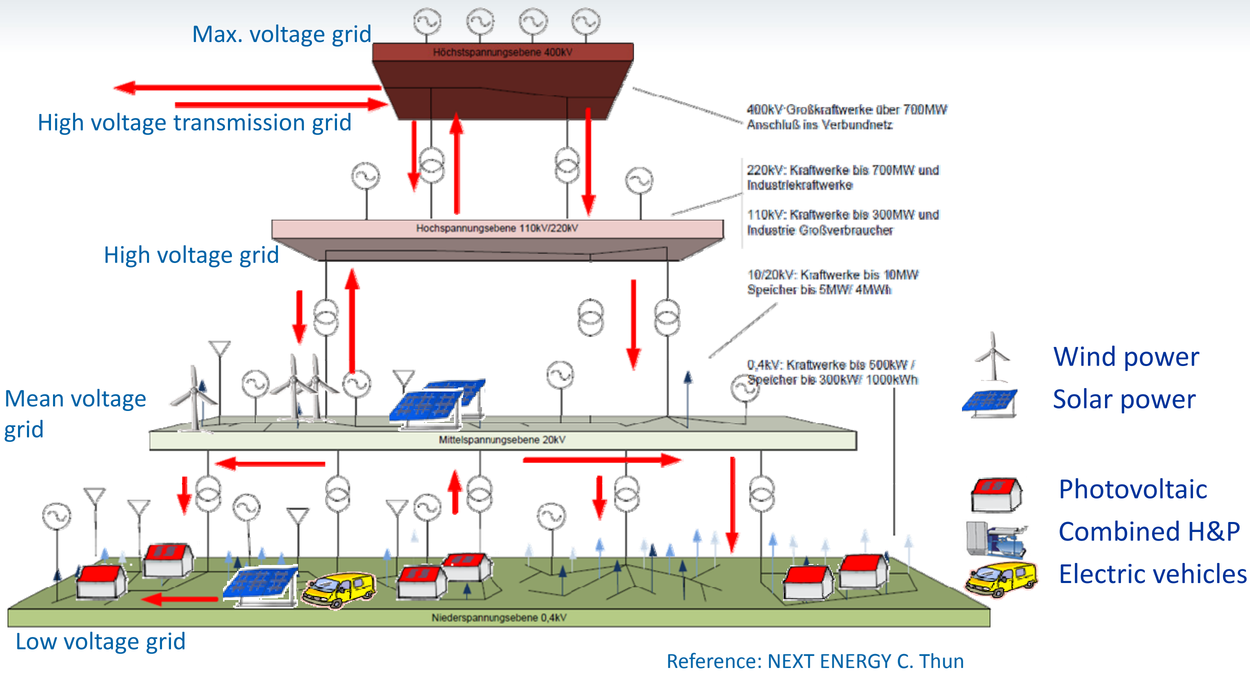
Problems caused by feed-in of PV-power in typical low voltage power grid





- Voltage increase/decrease
- Capacity overload of transformers in the power grid

Hierarchical Power Flow



Reference: NEXT ENERGY C. Thun

Storage Technologies

Electricity storage

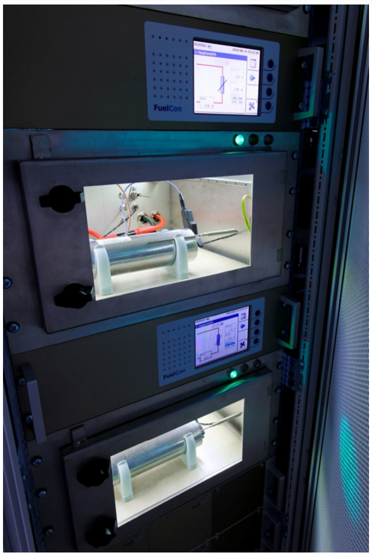
Mechanical energy	Chemical energy	Electrical energy
Potential energy	❑ **Batteries**	❑ Capacitors
❑ Pumped hydro	❑ Hydrogen	❑ SMES (Superconducting magnetic energy storage)
❑ Compressed air	❑ (Fossil energy carriers)	
Kinetic energy	❑ (Biomass)	
❑ Fly wheels		

Battery Storage in General

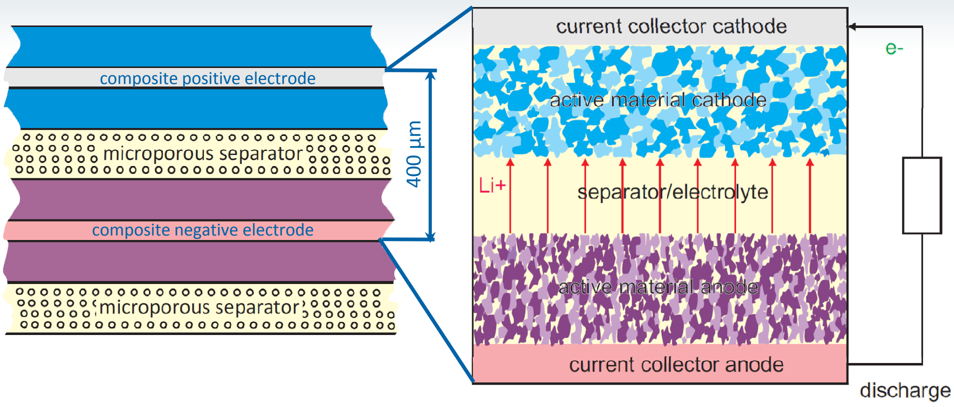
- Fast Responding (in ms)
- Nearly Maintenance free
- Mid Range of Energy-to-Power Ratio
- Modular Setup
- Mid Range Price
  - Price Reduction partially possible
- Best Temperature around Room Temperature (except HT-Batteries)

Battery Storage: Li-Ion

- High Cell Voltage up to 3,6V
- High Power Battery (Low Internal Resistance)
- High Energy Density
- Safety Issues (Overcharging, Overheating)
- Mobile Application (EV, 4C-Market)
- High Efficiency (DC-DC-Efficiency of over 95%)
- Lifetime around 10 Years (2000-4000 full cycles)

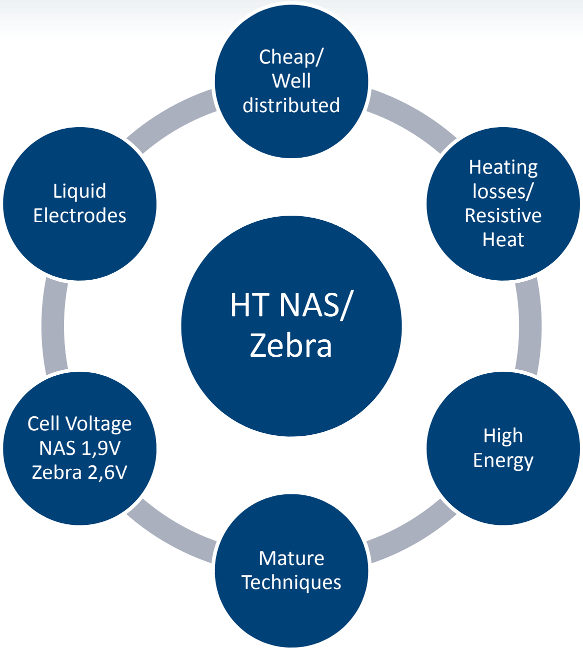


Lithium-ion batteries – Basic principle



Active anode material:	graphite
Active cathode material:	$LiFePO_4$, $LiCoO_2$, $LiNiO_2$, $LiMn_2O_4$, $Li(Ni_xCo_yMnz)O_2$, etc.
Separator:	PE, PP, ceramic foil (separion)
Electrolyte:	solvent is propylene carbonate, ethylene carbonate, dimethylcarbonate, ethylmethyl carbonate, $LiPF_6$

Battery Storage: High Temperature (Sodium Sulfur and Zebra)



- Application:
  - Sodium Sulfur (stationary)
  - Zebra (mobile)
- Minimal Size Sodium Sulfur 1MW/ 7MWh
- Heating: Minimum Energy Turnover recommended
- Aging in Electrolyte/Separator
- Only two Cell Producers

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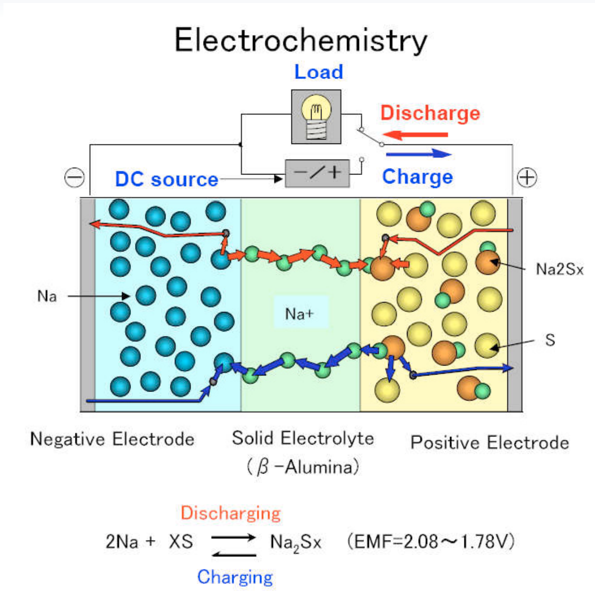
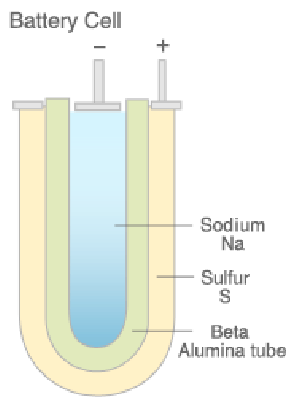
HT-Battery: Sodium Sulfur (NaS)





Source: NGK insulators

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Advantages of the Redox Flow Batteries (RFB) :

Redox-Flow-Battery (RFB)

- The energy is stored in liquid electrolyte =>Modular assembly
- The electrolyte is aging slowly and is restorable
- Reliable determination of the state of charge (SOC)
- Deep discharge leads to reversible damages
- Vanadium-Vanadium-H_2SO_4
  - 1,6 – 1,8 V
  - 5 – 40 °C
  - 72 %
  - most promising

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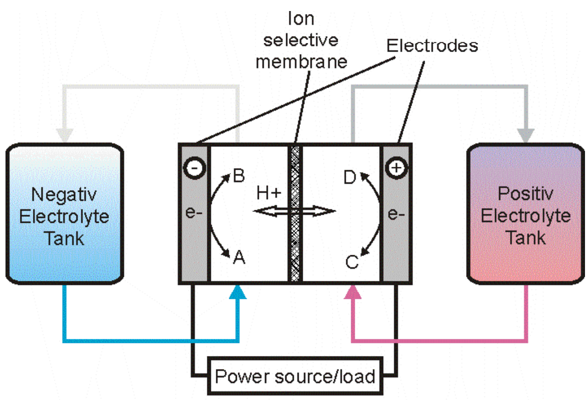
Principle of Redox Flow Cell:

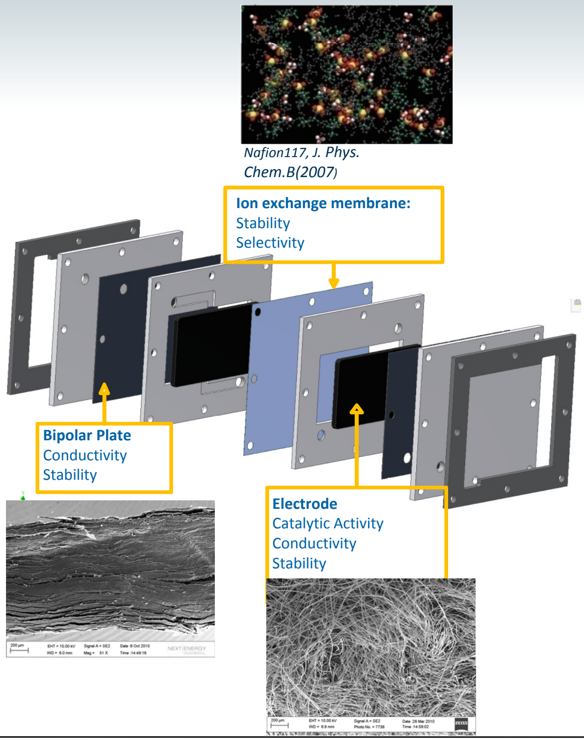
- The redox reactions take place in solution on inert graphite electrodes.
- The reactants flowing across the electrodes are supplied from containers outside the electrochemical cell.
- A special ion- selective membrane prevents the mixing of the two electrolytes.
- The changes in the valence number (oxidation state) of the ions enable the battery to store and discharge electric power.



Positive Electrode: C + e- ⟷ D
Negative Electrode: A ⟷ D + e-

Construction of the Cell Stack:

- The single cell contains 2 carbon felt electrodes separated by an ion exchange membrane
- Multiple cells combined in cell stacks
- Multiple cell stacks can be connected either in series or in parallel, according to the required output of the system
- Modular assembly with variable energy by constant performance



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Battery Storage: Other Mature Storage Technologies

Lead Acid

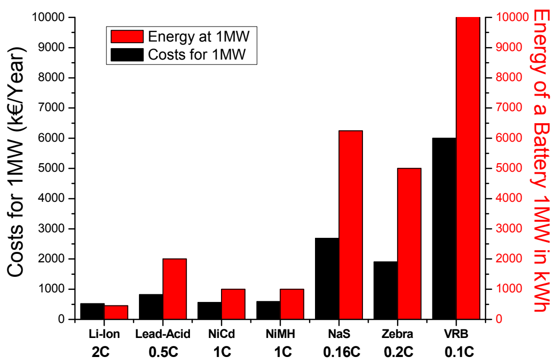
- Only Few Full Cycles
- Low Energy Density
- Efficiency of 70%
- Calendar Lifetime 7 years

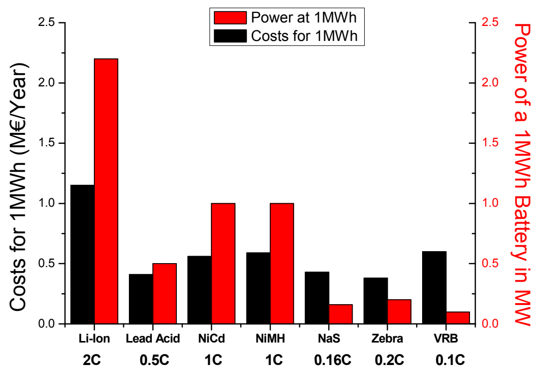
Alkaline: NiCd & NiMH

- Many Thousands of Cycles
- Mid Energy Density
- Efficiency of 70-75%
- Calendar Lifetime 10-20 years

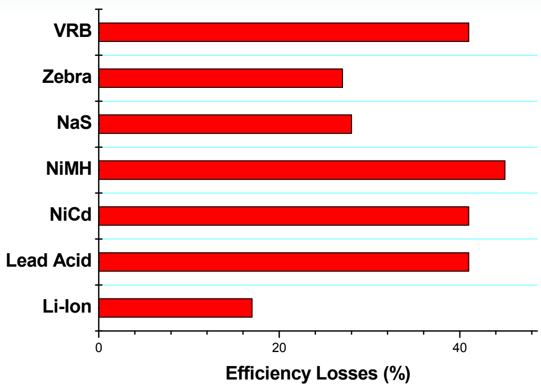
- Recycling system available
- Many Manufacturers
- High Safety
- Toxic Contents

Costs for Energy and Power





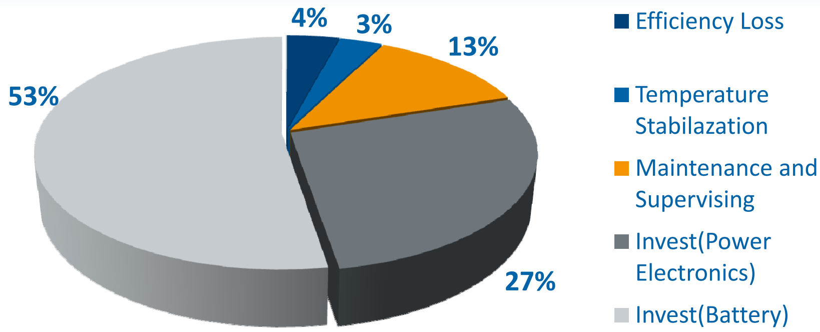
Efficiency Comparison



- Power Electronics
- Battery
- Self Discharge
- Battery Interconnections
- Auxiliary Energy (BMS)

- Complex Values: Temperature, C-Rate, DOD, SOC and Load per Day
- Not included Heating/Cooling
  - 10-50kW for 1MW NaS
  - 3kW for RT

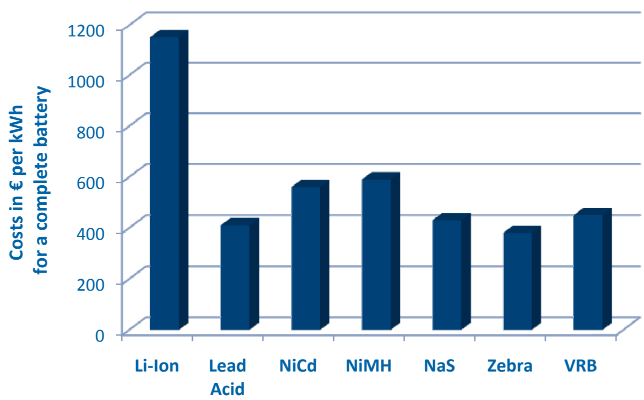
Cost Distribution Normalized for one Year



Example: 1 MW / 700 kWh Lithium Ion Battery

Application: Reserve Power

Costs per kWh



- Additional Costs for VRB of around 1,500€/kW

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Applications in Low Voltage Grid

- Local Storage in House
  - Small Sized (Low Power and Energy)
  - Low Maintenance
  - Using the Self-Produced Energy
  - More Expensive than Larger Storages
  - Owner is Landlord
- Vehicle-To- Grid (V2G)
  - Dual Use of Electric Vehicle
  - Grid Connected Battery (Energy Distributer)
  - Economy of Scale
  - Benefits for Owner

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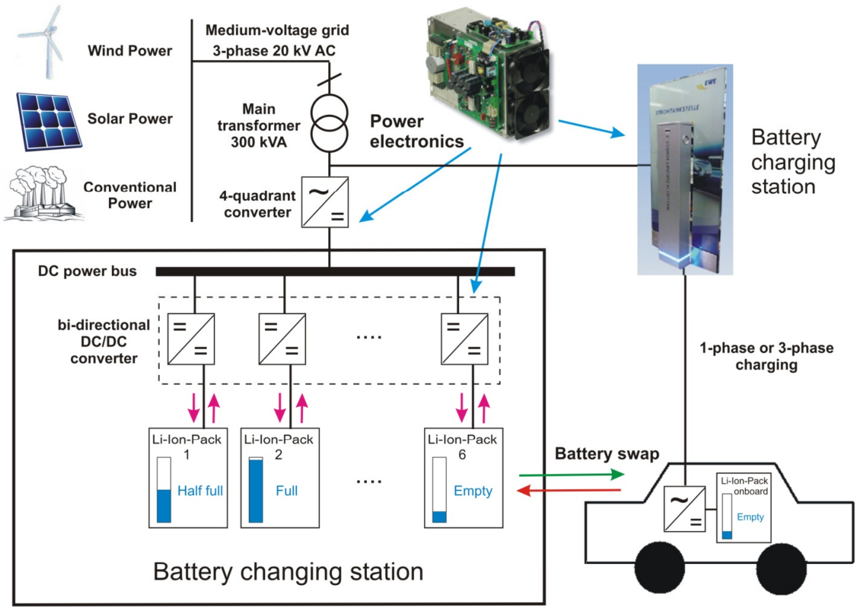
Applications in Low Voltage Grid

- Storage for Residential District
  - Big Sized (High Energy Storage)
  - Cheap costs
  - Better Utilization Capacity
  - Cooperative Ownership
- Storage for Grid Stability
  - Energy Provider as Owner
  - Preventing Grid Expansion
  - Power Quality (Shape, Voltage, Frequency)
  - Location at
    - Long Branch Lines
    - Substations

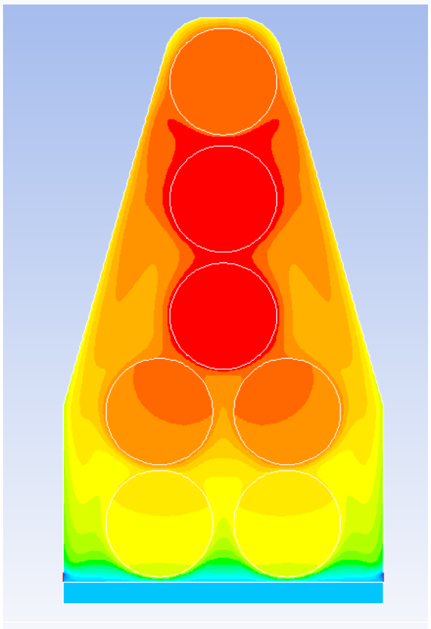
Grid integration and power electronics



- Energy storage and energy dispatch
- Storage capacity: 180 kWh
- Grid integration with FACTS Features (Flexible AC Control System)
- Grid regulation via reactive power dispatch

Packaging and battery management

- Next generation battery control for reduced aging and save operation
- Thermal management at cell level
- Characterization of single cells
- Analysis and optimization of battery packs
- Development of multiphysical simulation models
- Efficient thermal management by elaborate design and material choice (passive thermal management)



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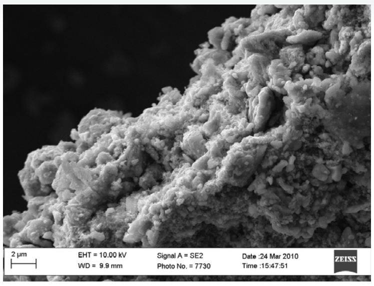
Development and electrochemical performance of electrodes for Li- Ion Batteries

- Material characterization
- Electrode preparation
- Electrochemical diagnostics in three-electrode arrangements
  - Electrochemical Impedance Spectroscopy
  - Cyclic Voltammetry
  - Galvanostatic and potentiostatic Transients
- Electrolyte optimization
- Innovative test cell designs
- Detection of aging phenomena under dynamic load profiles



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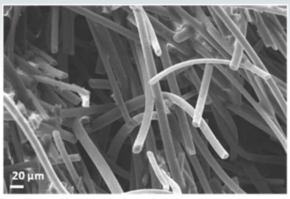
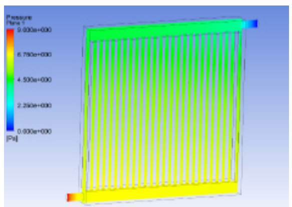
Vanadium Redox Flow Battery (VRB)

- Single cell design - optimization of the electrode geometry and the electrolyte flow field
- Investigation of the properties and the performance of various electrodes materials and membranes
- Electrolyte development and optimization
- Electrochemical diagnostics

  The goals are reduction of aging and self discharge processes, enhancing of the battery performance and cost reduction

- Stack design - optimization of the electrolyte supply and electrical interconnection
- Long term cycling under real climate conditions and load profiles
- Application of VRB as a stationary energy storage for renewables





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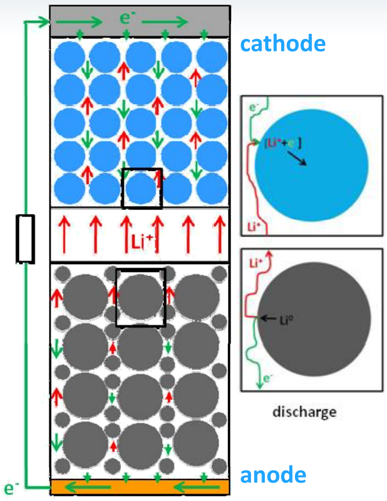
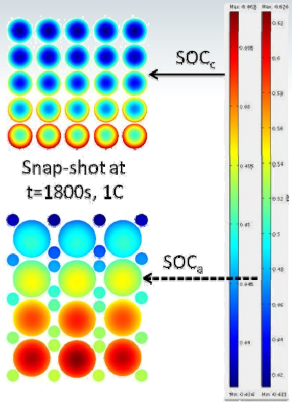
Modelling and Simulation, virtual cell design



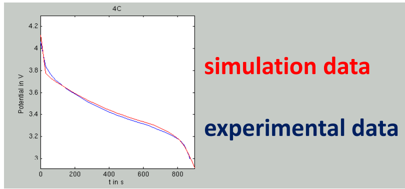
2-dim. model of current collectors, active anode and cathode layers and separator

Transport equations:
- Ohm's Law of conduction
- Fick's Law of diffusion

Charge Transfer:
Butler-Volmer-equation



Particle-dependent State of Charge



Model validation at 1C-5C, here: 4C

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Thank You!