REDOX FLOW BATTERIES

Status of Vanadium-Redox-Flow-Batteries
and current work at Fraunhofer ISE

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Fraunhofer Institute for Solar
Energy Systems ISE

Solar Summit 2013

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AGENDA

- Principal and classification of Vanadium-Redox-Flow-Batteries (VRFB)
- Status of VRFB
- Challenge with other technologies
- Applications for VRFB
- Ongoing work at Fraunhofer ISE
  - Cell and Stack development
  - Battery management system
  - Life cycle cost analyses
- Conclusion and Outlook

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Classification of Flow-Batteries

Battery
Energy carrier is the electrode matierial

Flow Batteries
Energy carrier is the electrolyte

Fuel cell
Energy carrier is the liquid fuel

Flow Batteries

→ **decoupling from power and capacity**

- Vanadium-vanadium
- Vanadium-bromine
- Polysulfid-bromine
- Iron-chrome

Hybrid-Flow batteries

→ **No decoupling from power and capacity**

- Zinc-bromine
- Zinc-cerium
- Lead-acid

Redox Fuel cell

→ **No decoupling from power and capacity**

- Vanadium-air

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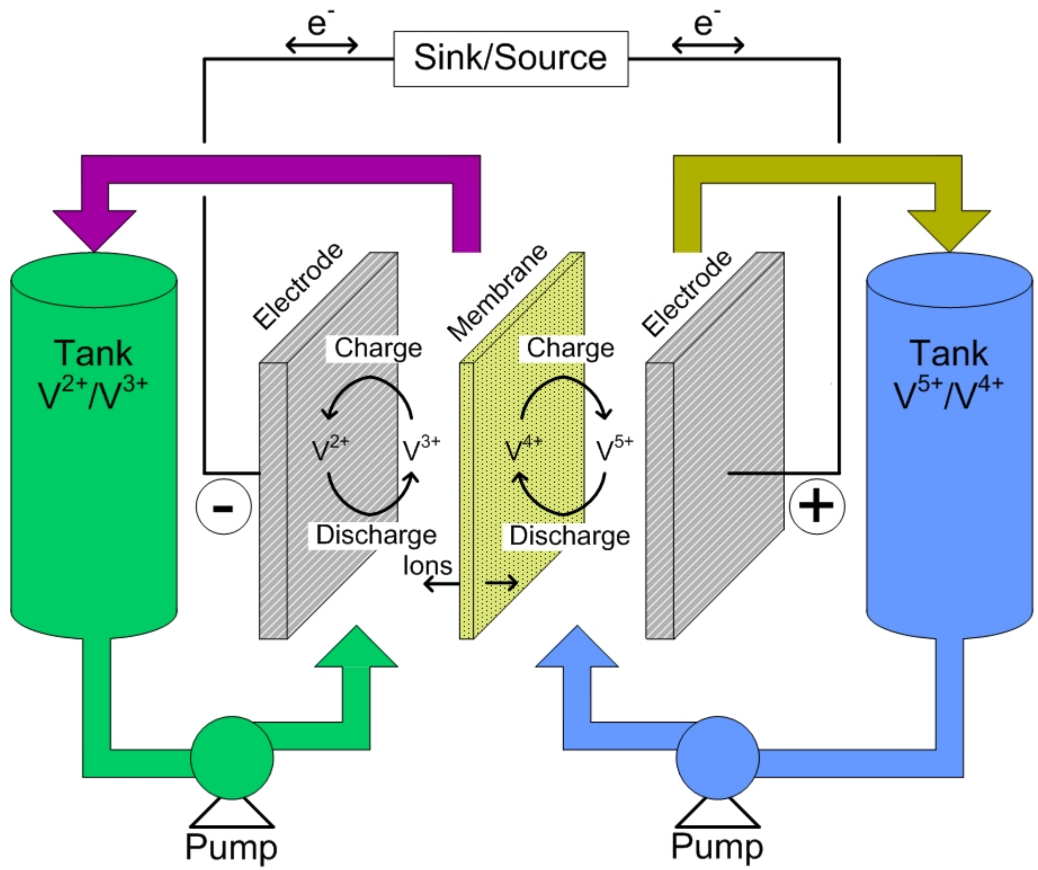
Vanadium-Redox-Flow-Batteries



General layout of a RFB

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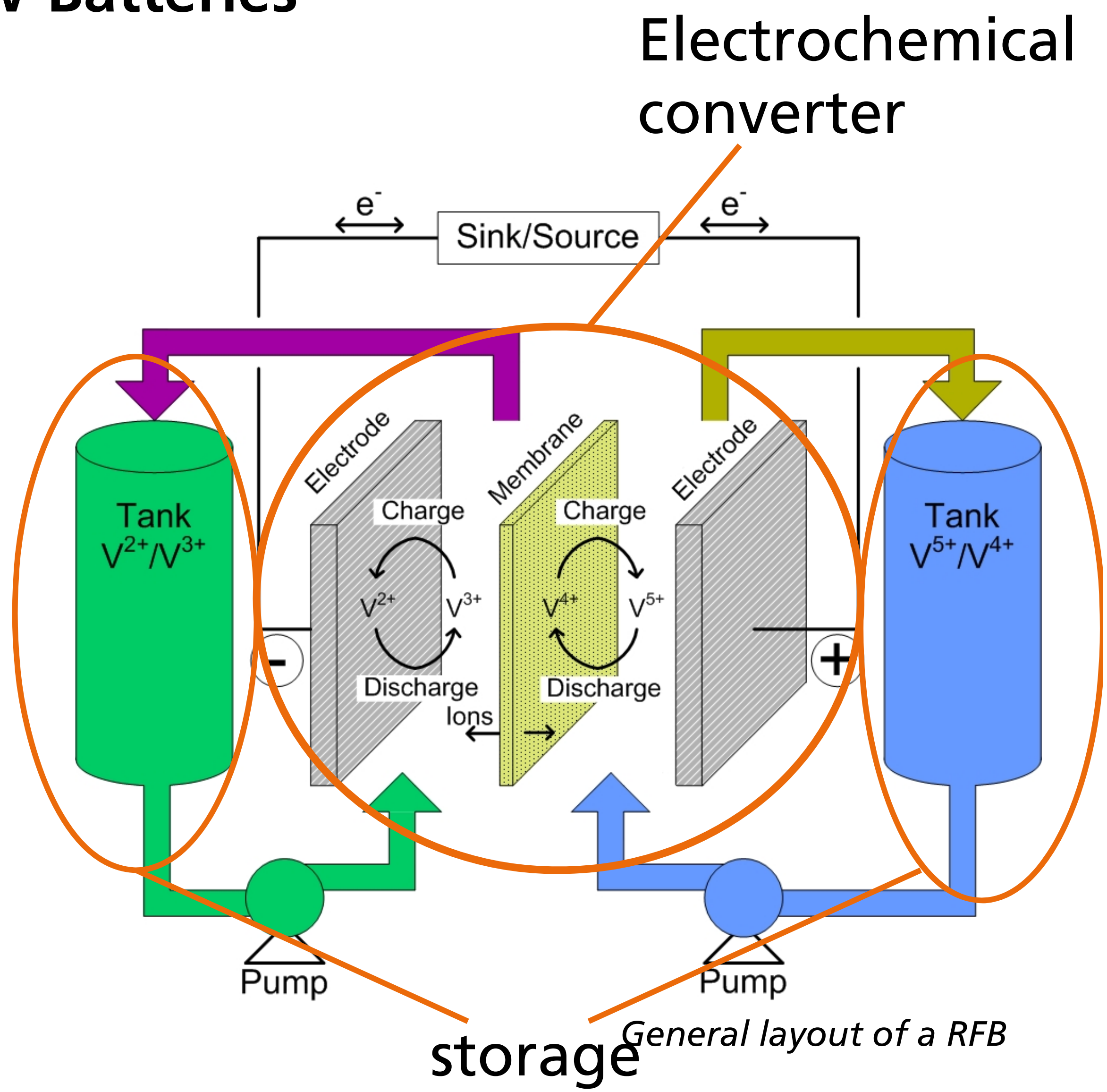
Vanadium-Redox-Flow-Batteries



General layout of a RFB

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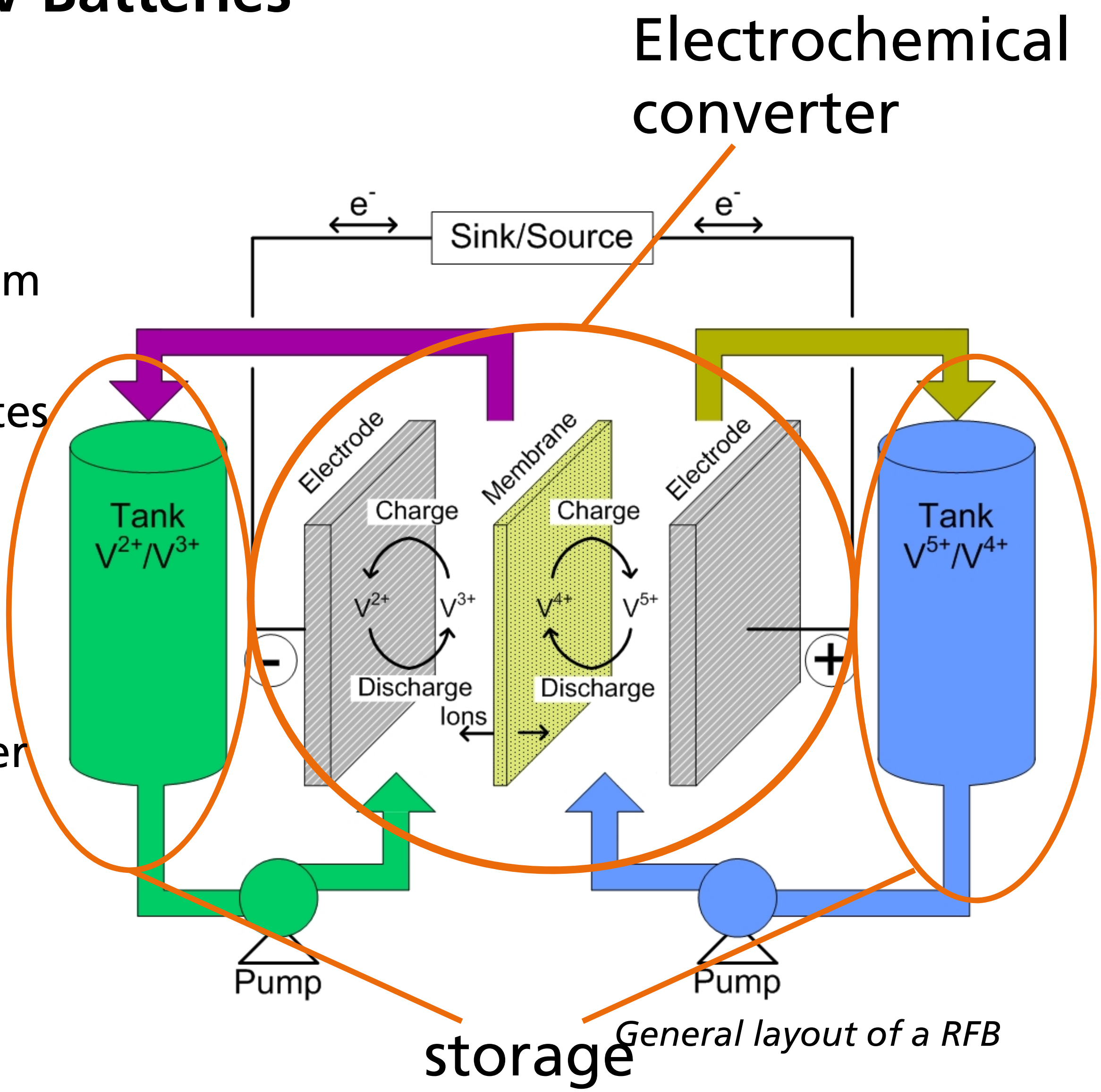
Vanadium-Redox-Flow-Batteries

- VRFB:
  - Decoupling capacity from power
  - Modular design facilitates different applications
  - Fast response time
  - High efficiency (>75 % possible)
  - No irreversible cross-over of active mass over the membrane
  - Long calendar life-time, cycle ability (> 10.000)



General layout of a RFB

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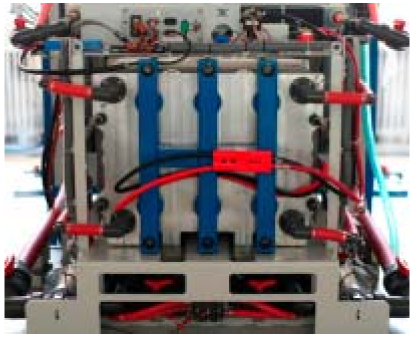
Commercial Batteries: vanadium



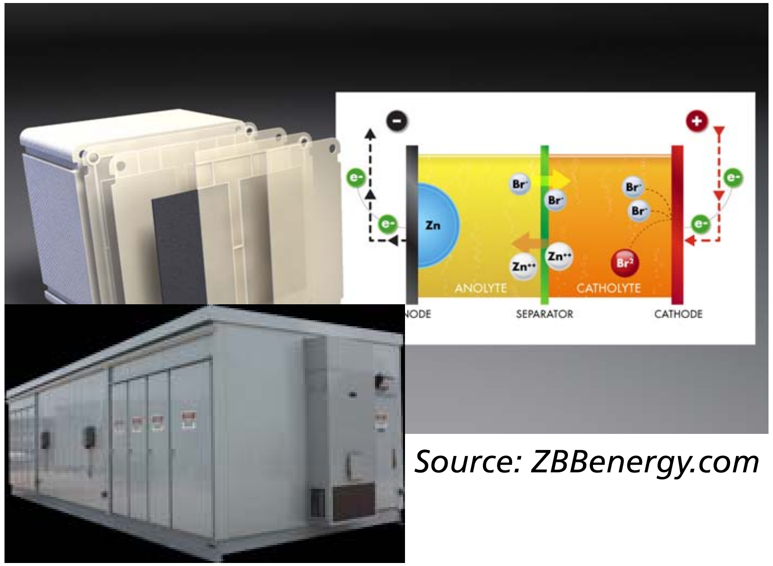
Source: pdenergy.com

- Prudent energy – vrb power
- 7 kW stacks
- Different sizes from kWh to MWh range
  - Realized installations in Europe and North America

Source: Cellcube.com

- Cellstrom
  - FB 10/100: 10 kW / 100 KWh
  - FB 200/400: 200 kW / 400 KWh
- All vanadium
- Output voltage 48 V_{DC}/ 400 V_{AC}
- Max. DC Efficiency: 80 %
  - Realized installations in Europe and India

Commercial Batteries: Zinc-bromine



Source: ZBBenergy.com

ZBB energy:

- Hybrid flow battery
- EnerStore
  - 50 KWh / Discharge Rate 17 kW
- EnerStore 500
  - 500 kWh / 250 kW discharging
- 75 % roundtrip efficiency DC side

Redflow:

- Hybrid flow battery
- High energy density
- Performance:
  - 5 kW / 10 kWh
  - 220 kg
  - 70 % roundtrip efficiency AC side

Source: redflow.com

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Field installations: VRB – powers / Prudent Energy

King Island / Australia

- Pinnacle VRB
- Wind farm with 2.45 MW
- 200 kW for 4 h
- 300 kW for 5 min
- 400 kW for 10 sec

Source: Skyllas-Kazacos, IRES 2006

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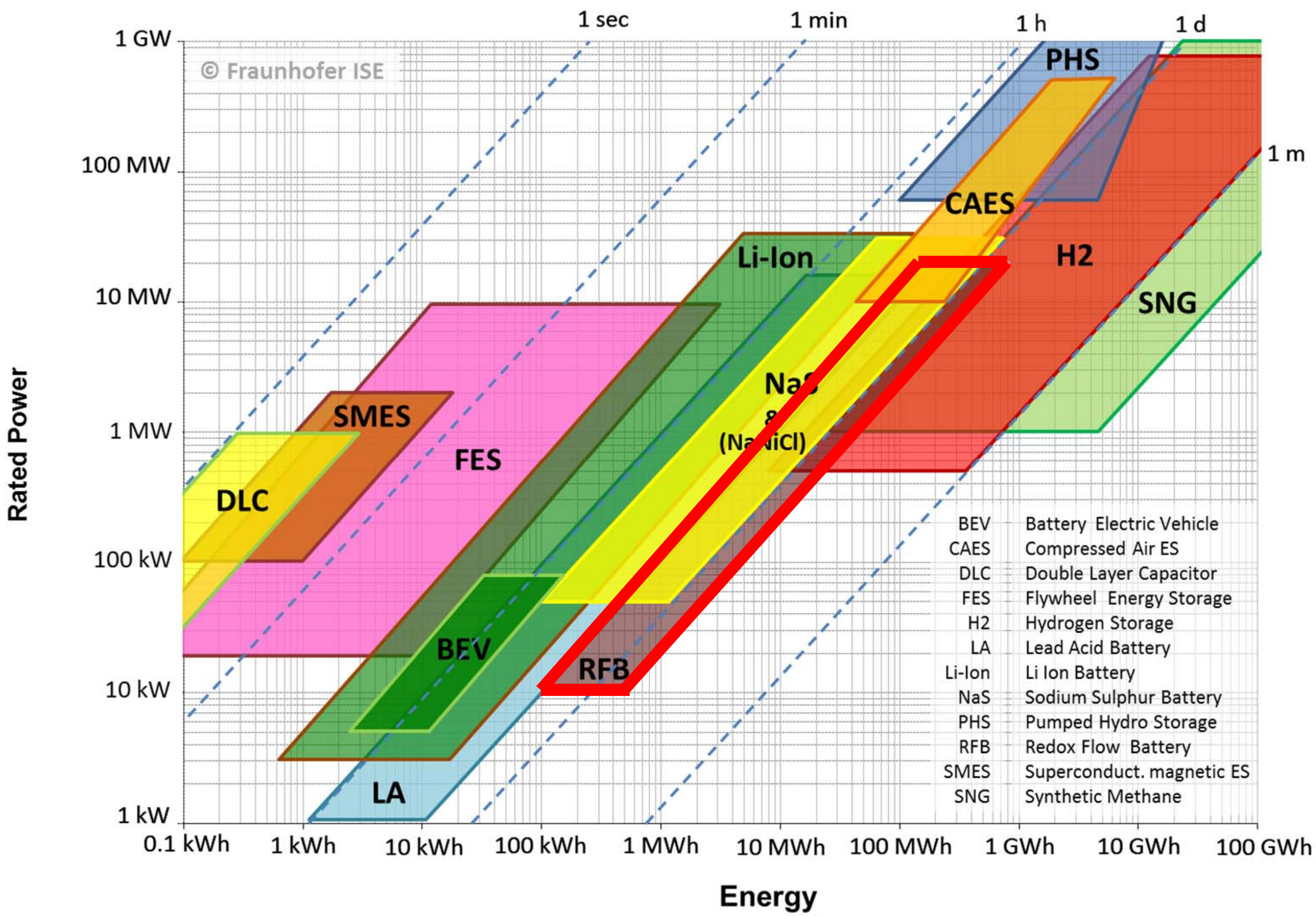
Challenge with other technologies

- From kW to MW
- From kWh to MWh
- Many competitors
  - NaS
  - Lead-Acid
  - Li-Ion
  - H2
  - CAES
  - Pumped Hydro



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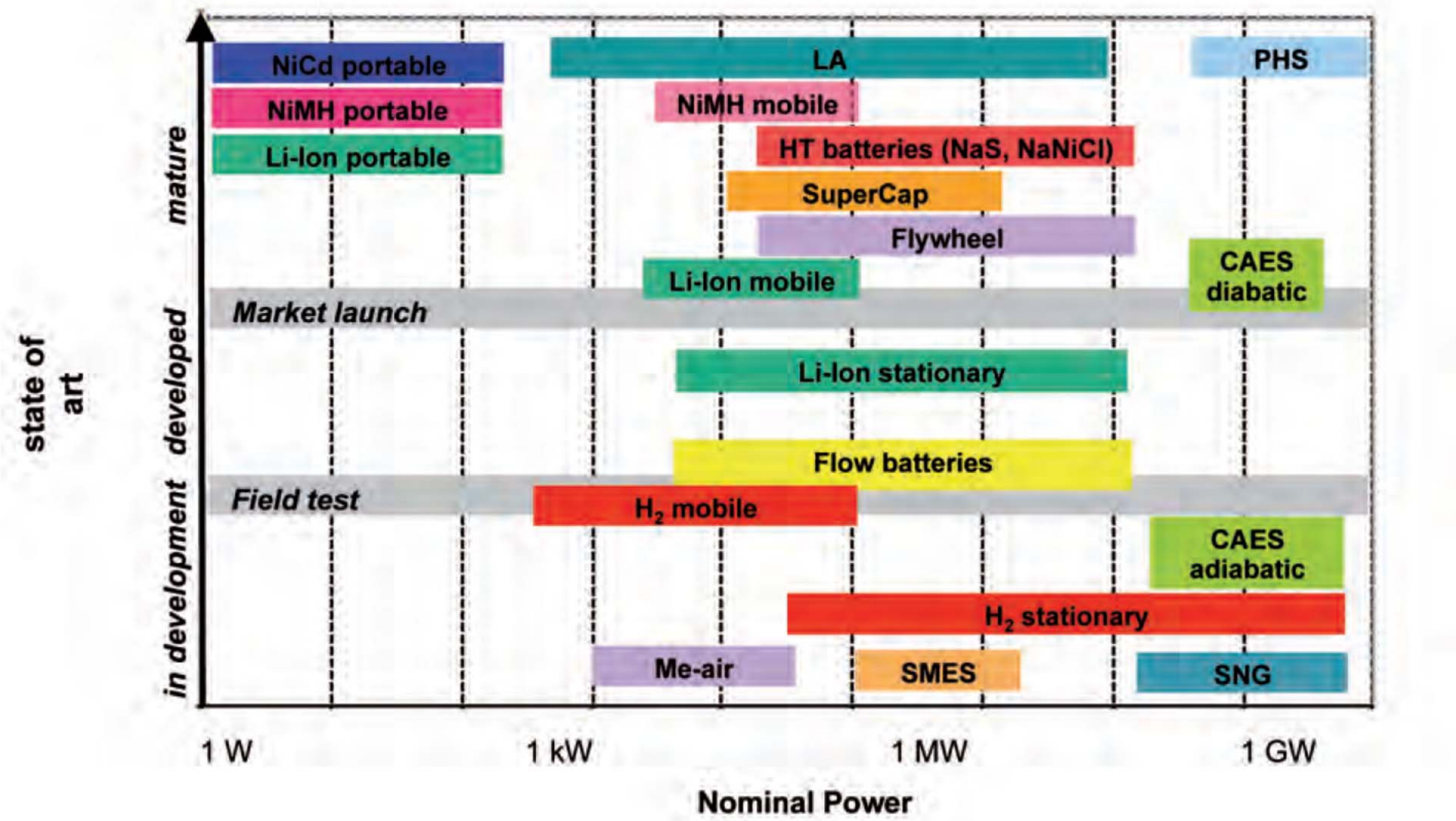
Challenge with other technologies



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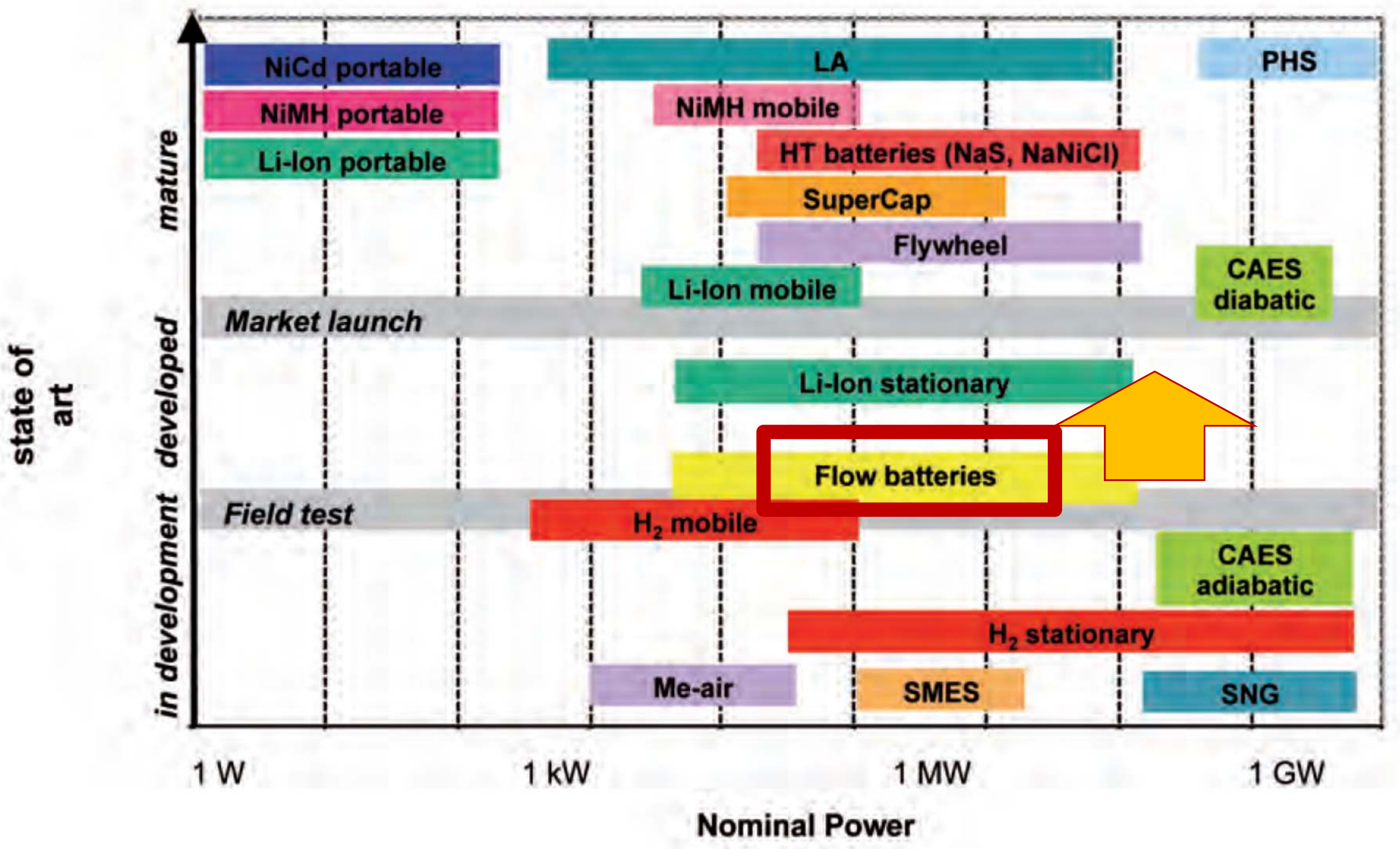
Challenge with other technologies



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Fields of applications:

Off-grid / mini-grid

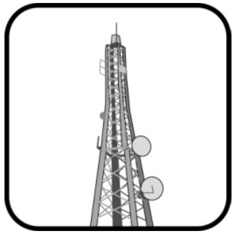
- kW/kWh range
- Seasonal storage

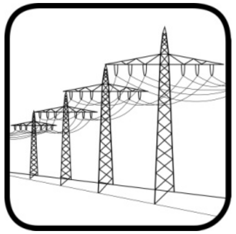
Distribution network

- MW/MWh range
- Energy management

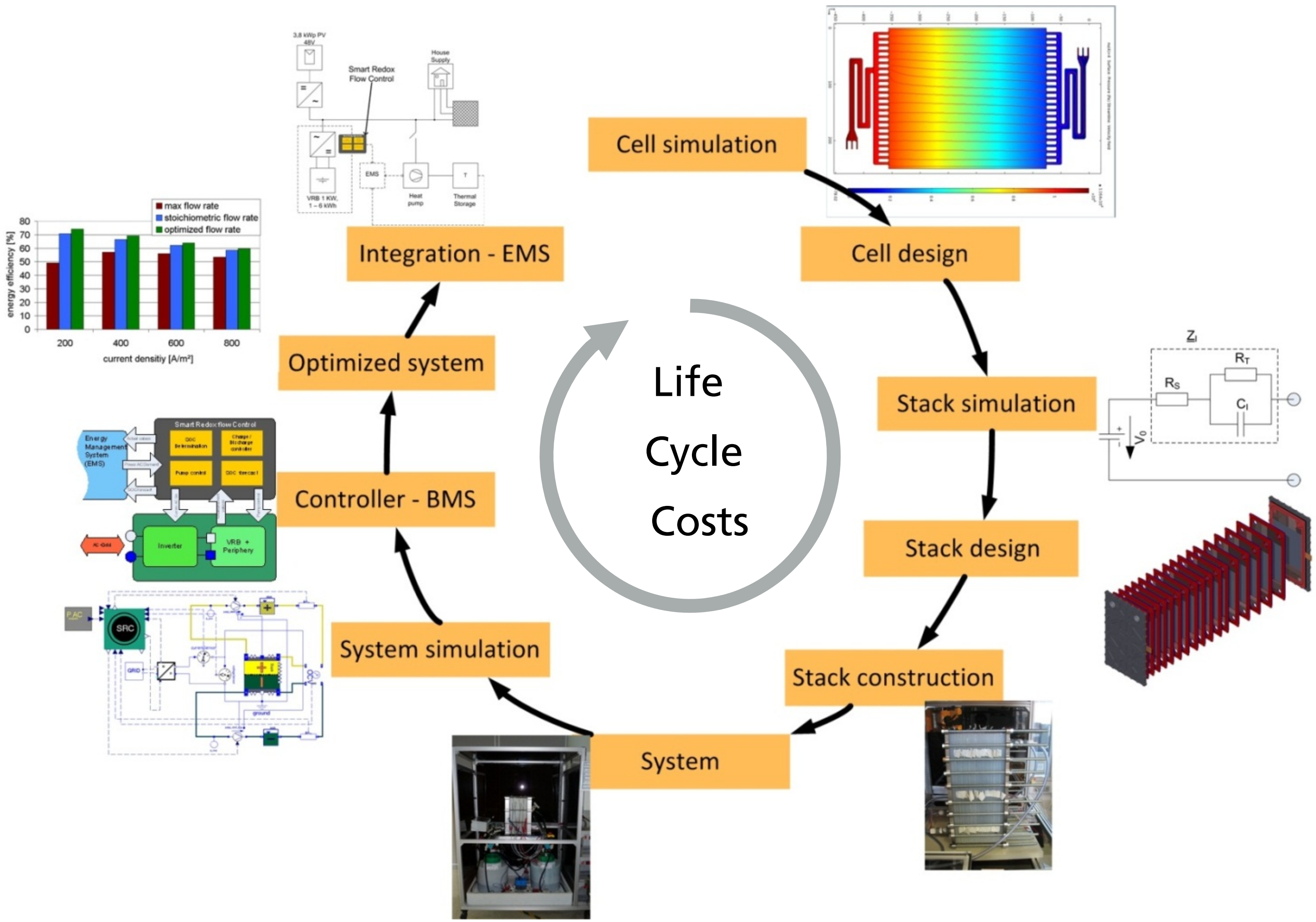
Industrial

- Backup power
- Load management





Redox Flow Batteries: Portfolio at Fraunhofer ISE



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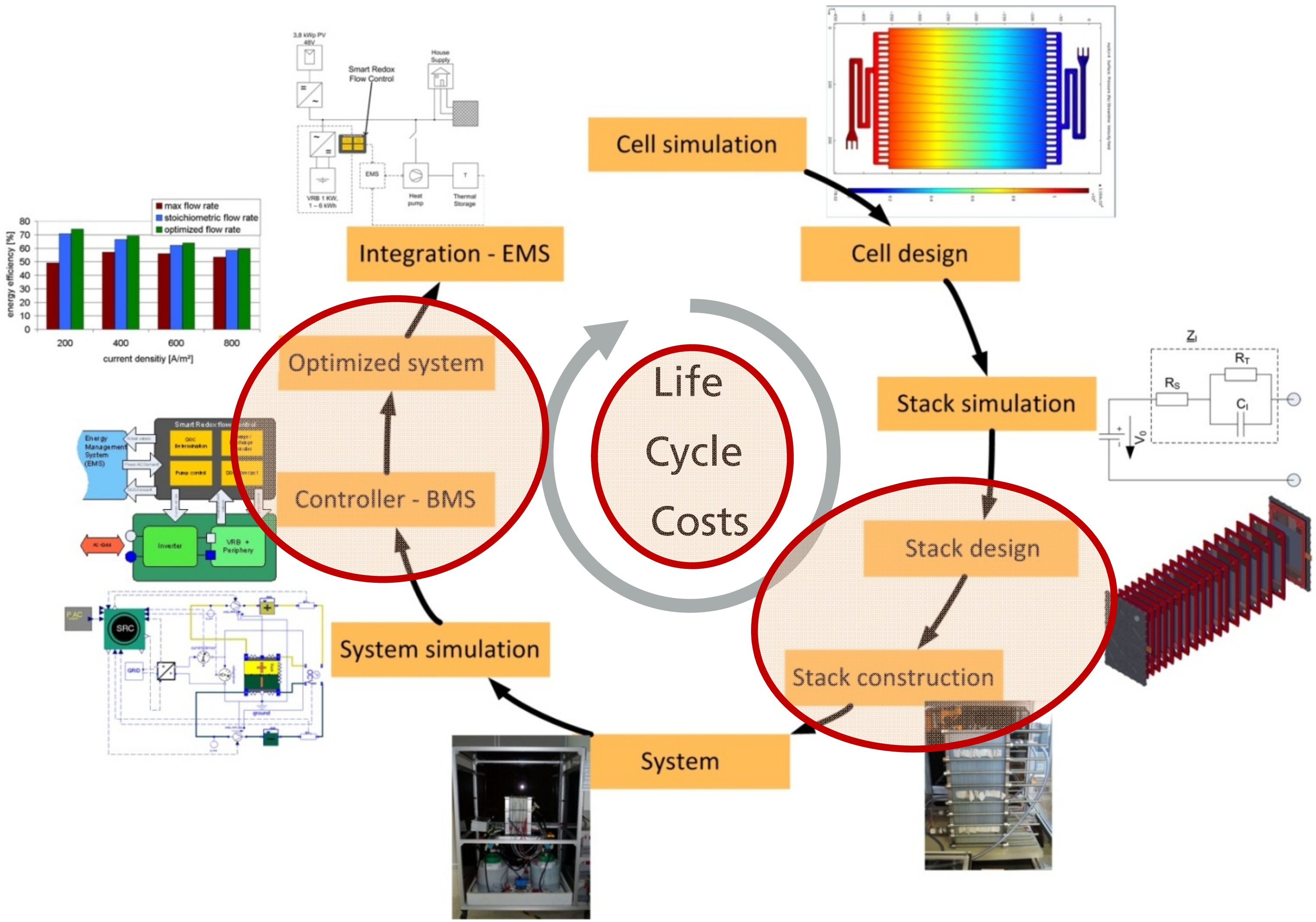

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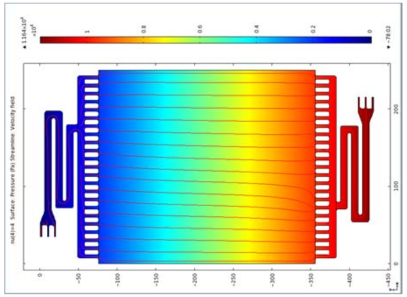
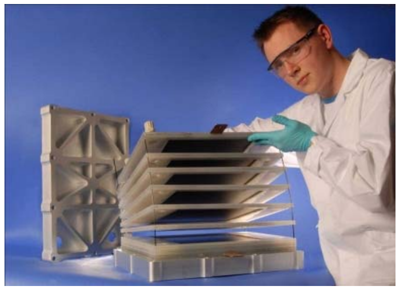
Major Challenges in Cell and Stack Design





- High coulombic efficiency
  - Assembly must be leak-free
  - Low vanadium ions cross-over (membrane)
  - Minimising shunt currents (bypass)
- High energy efficiency
  - Low overpotential…
  - Low elec…
- Unif… stack level
  - … (no H_2, O_2 formation)
  - … to minimise pumping energy
- Si… for frame and sealing
  - Easy and fast assembly/disassembly -> Quick material changes
  - Simple fabrication, suitable for injection molding

- Stack design means always to find a trade-off!
  - application (power, cycle number, standby time)
  - materials (availability, costs)
  - production technology (quantity)

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Design of a 5kW Stack
Electrical Specifications

Data		peak / nom.
cell voltage	[V]	1.2 / 1.1
current density	[mA/cm²]	60 / 40
cell area	[cm²]	2016
no. cells	[-]	40
stack voltage	[V]	48 / 44
stack current	[A]	120 / 80
stack power	[kW]	5.7 / 3.5

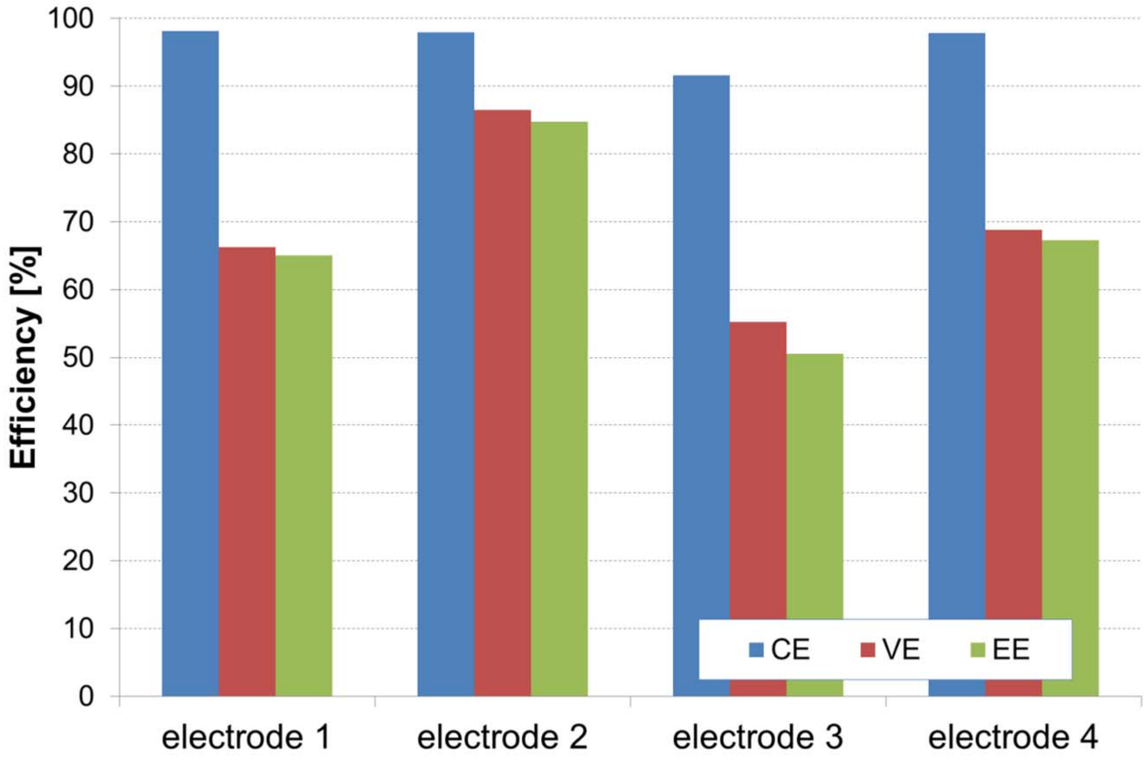
This work was partly funded by the German BMBF.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Material Screnning and Parameter Extraction

Evaluation of different electrodes

- Electrodes provided by different commercial suppliers



- 40 cm² test cell
- Operation parameters:
  - Electrode compression (25%)
  - Temperature (25 °C)
  - Mass flow (100 ml)
  - Current density (60 mA/cm²)
- Membrane M-2

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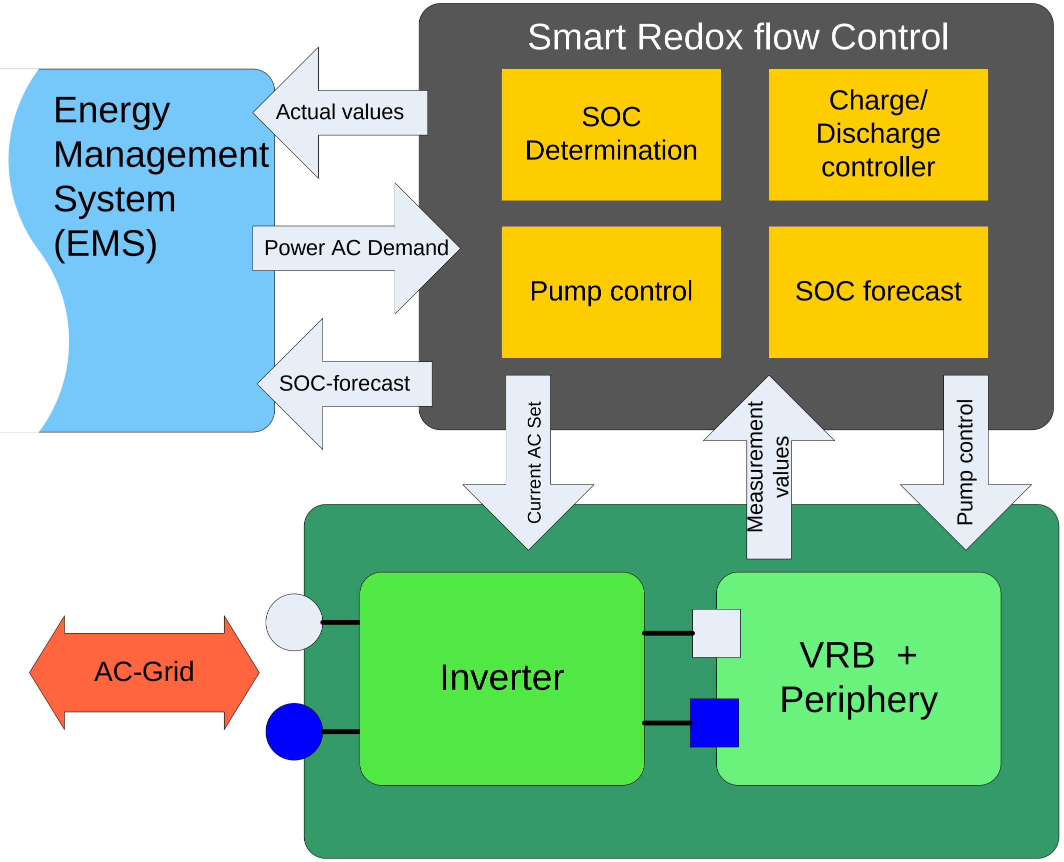
Battery management - “Smart Redox Flow Control“

Smart Redox Flow Control:

- Control loops for devices of redox flow battery
- Determination of set points (e.g. inverter, pumps)
- Optimization of the process cycle

  → energy efficiency
- Interface with energy management system



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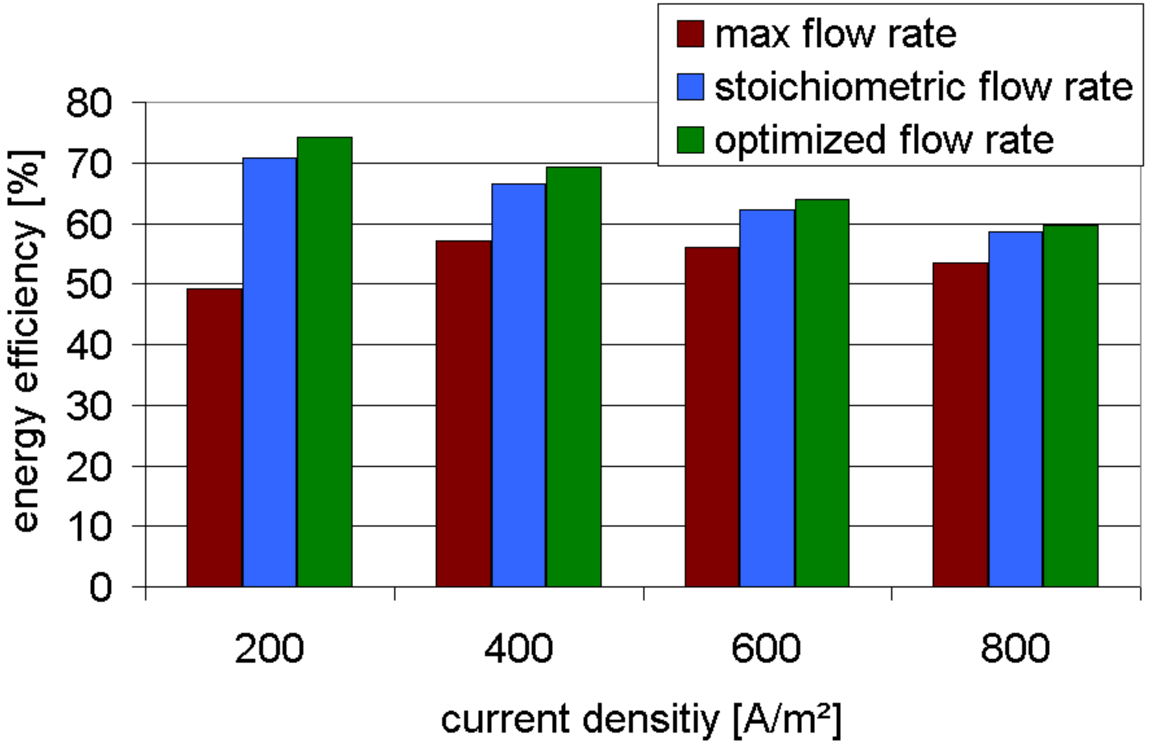
“Smart Redox Flow Control“ – pump control

- Stoichiometric flow rate depends on current and SOC
- SOC difference between stack and tanks should not too large

→ Pump control is important for the energy efficiency of the VRFB



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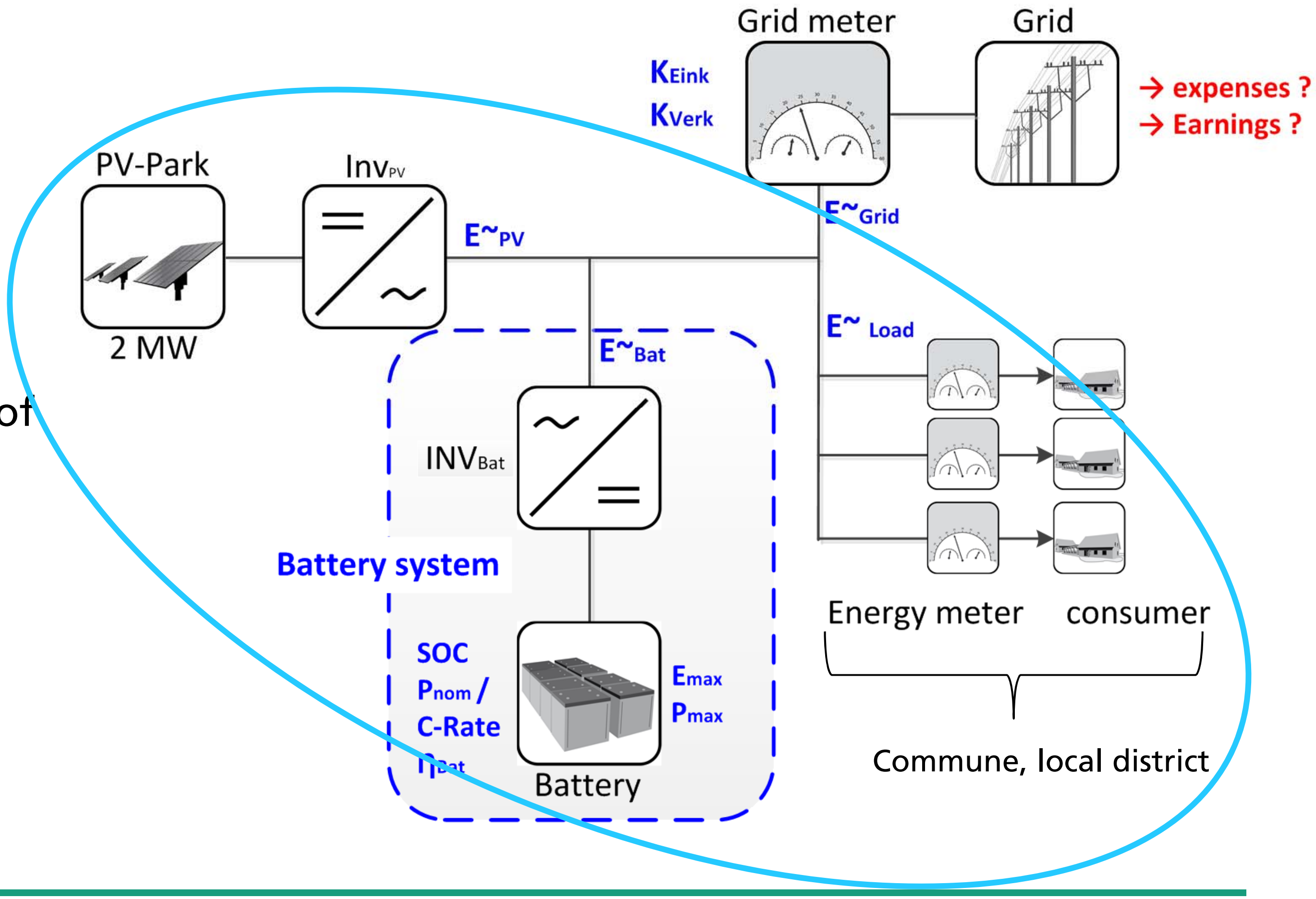
Case study – PV-plant - scenario

- Objective targets:
  - Maximization of solar fraction
  - Minimization of grid electricity use
  - Quick amortization of the battery
  - No taxes for local grid use



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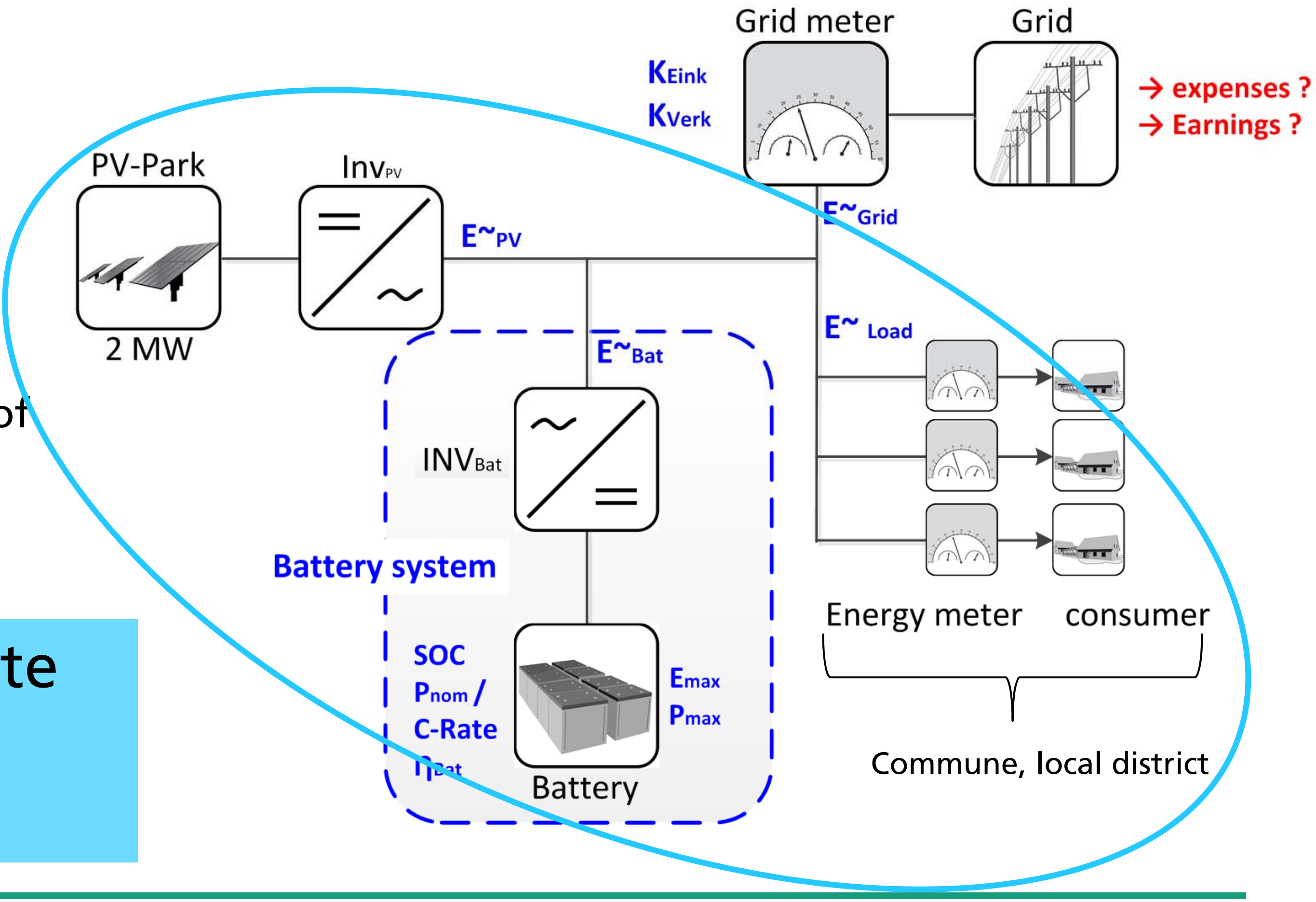

Goal: to calculate the allowed battery costs

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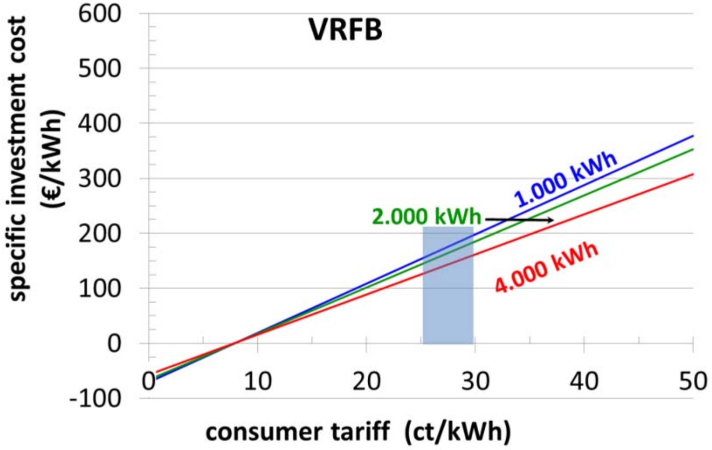
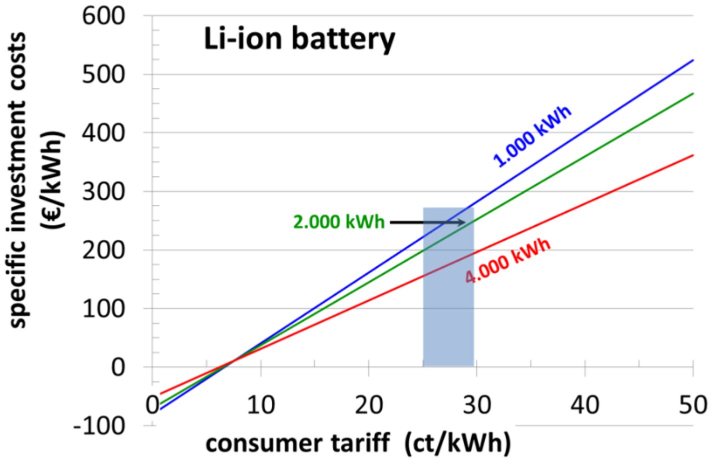
Allowed battery costs for self consumptioin

- Redox flow
  - Around 150 up to 200 €/ kWh
- Lithium-ion
  - Around 150 to 220 € / kWh





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Allowed battery costs for self consumptioin

- Redox flow
  - Around 150 up to 200 €/ kWh
- Lithium-ion
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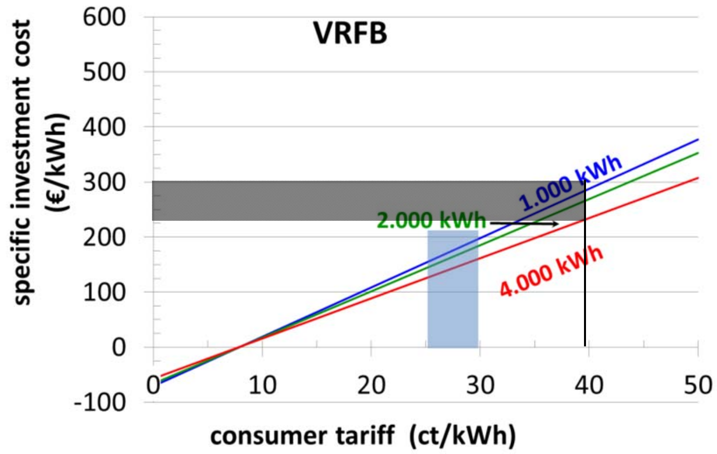
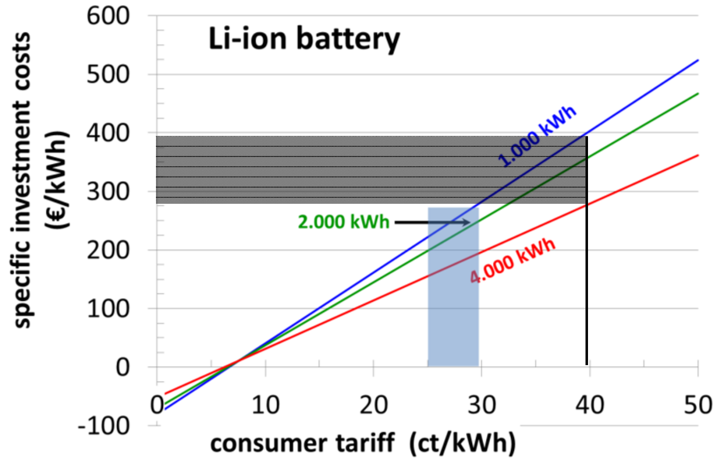
- Scenario: 4% increase of the consumer tariff every year
  - 2020 – 0.397 €/kWh
  - Redox flow
    - 220 to 300 €/kWh
  - Lithium-ion
    - 300 to 400 € / kWh





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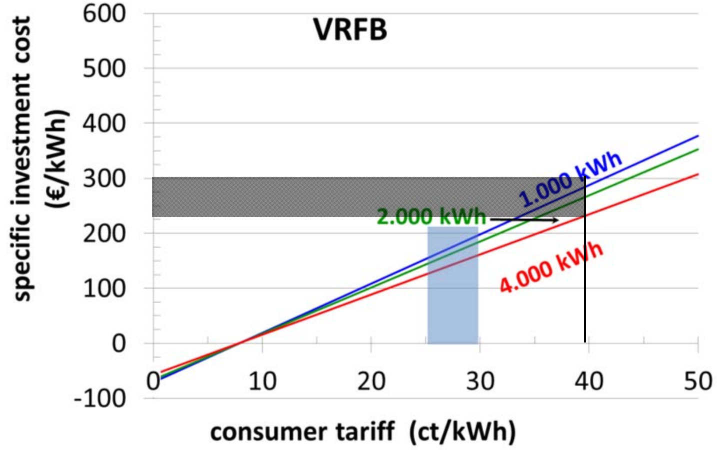
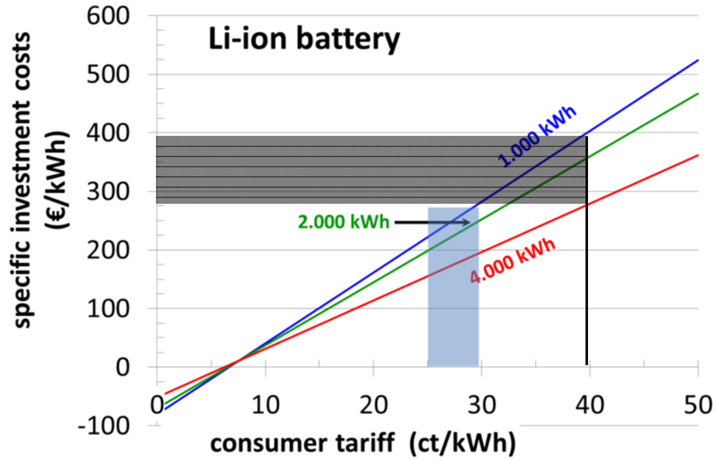
Batteries are still too expensive





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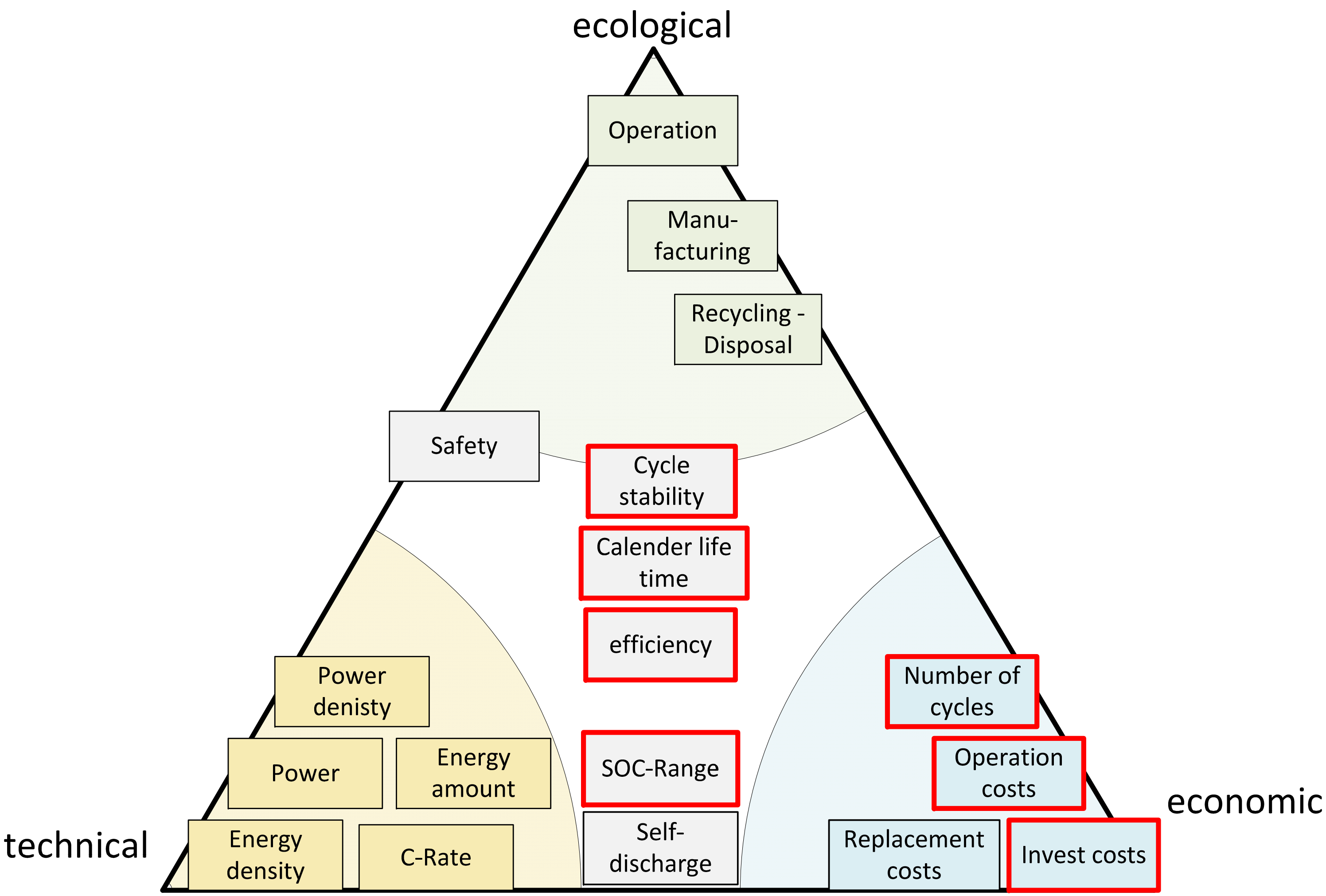
What key parameters have to be changed?



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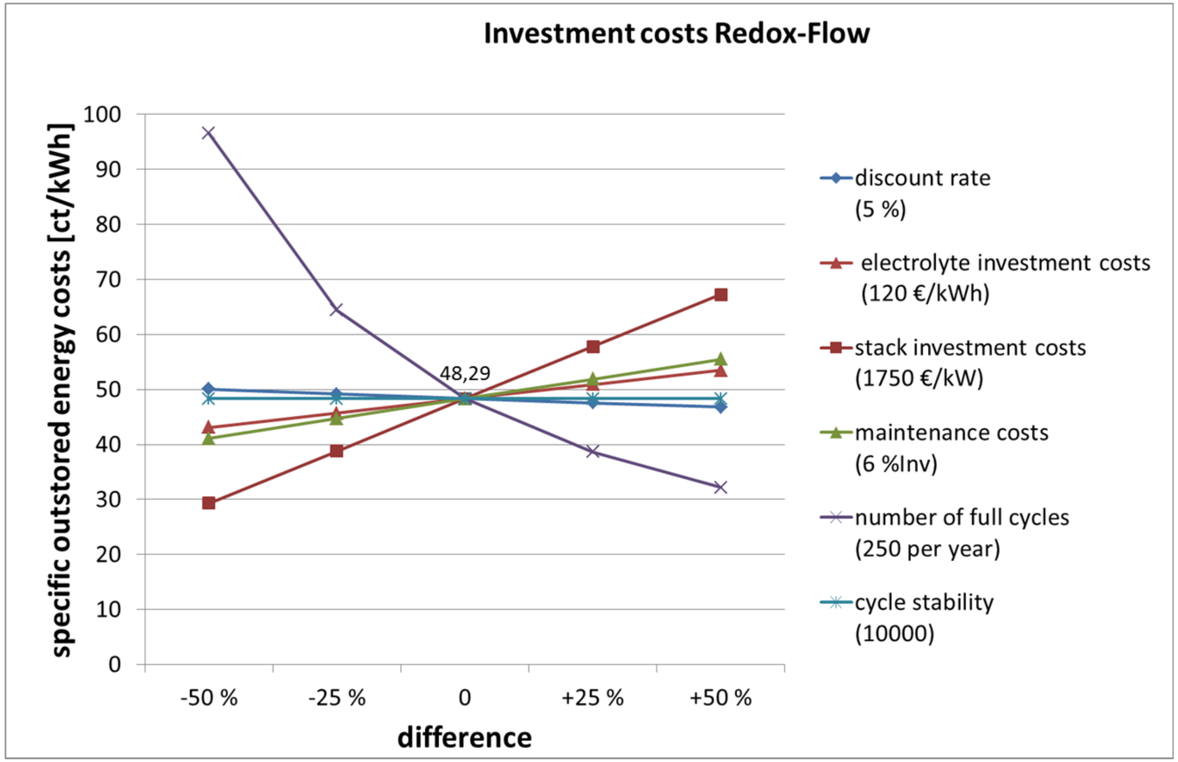
What are the key parameters?

- Redox flow
- Sensitivity analysis
  - 10 years project lifetime
  - Efficiency 77.5 %
  - SOC-range 80 %
  - 250 cycles per year
  - Ratio power to energy 0.25



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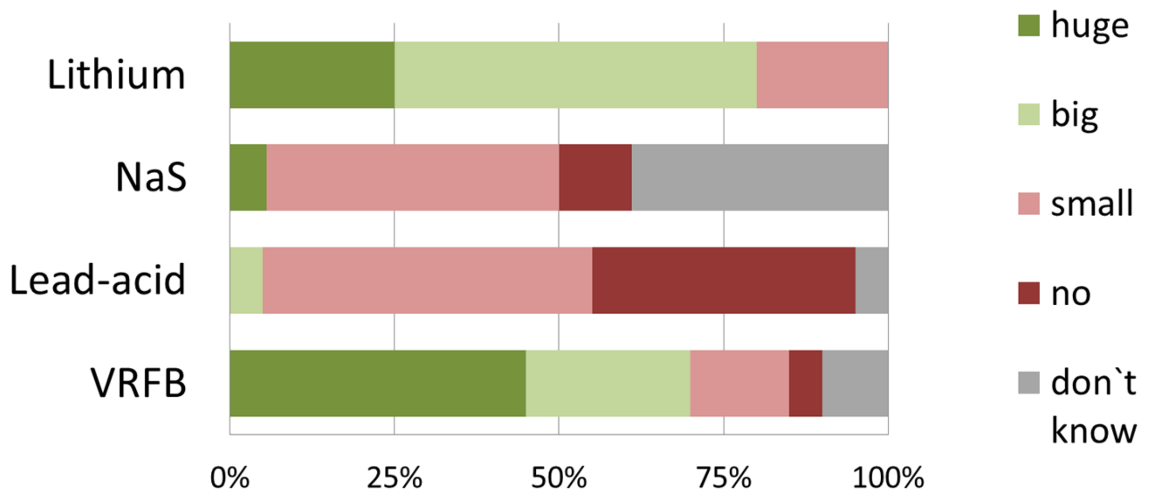
Cost reduction potential

- Lithium and VRFB has the biggest cost potential
- Lead-acid is almost fully developed
- Less knowledge about NaS

Expert Survey:

How big is the cost potential for each technology?



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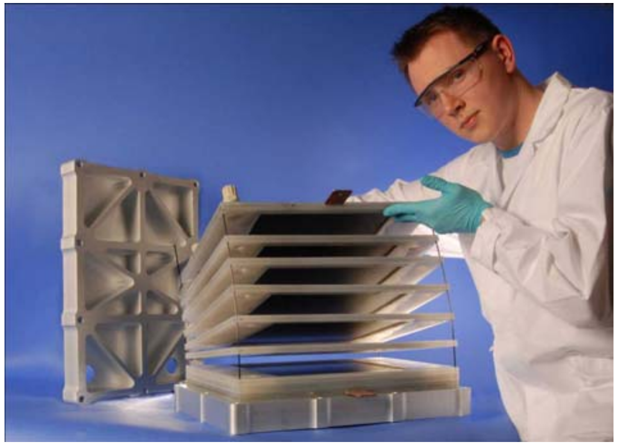
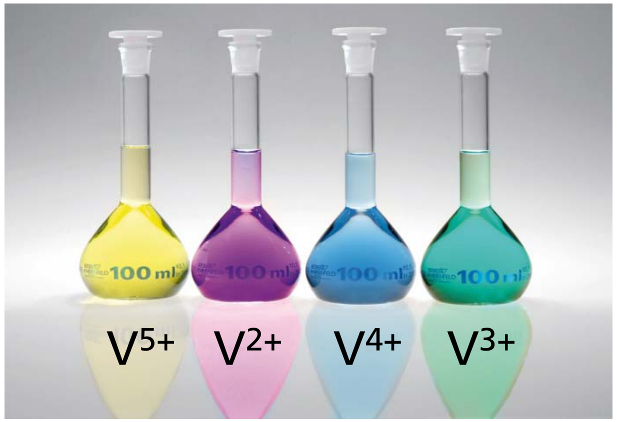
Conclusion

- VRFB has a lot of advantages against other batteries, but also some drawbacks
- There is no ideal battery – the application decides which battery is the best
- VRFB has a big technical potential
- The market is moving
- The costs have to be going down





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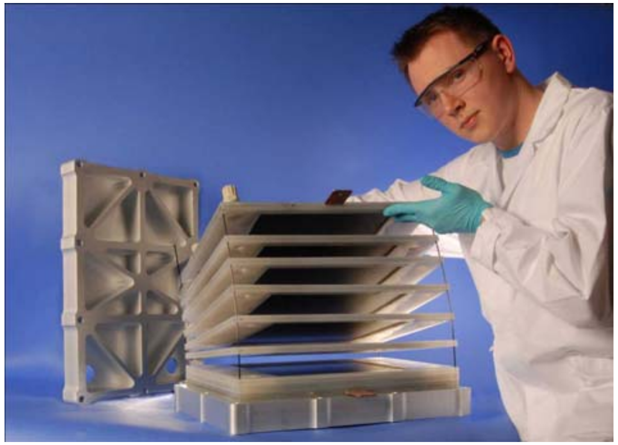
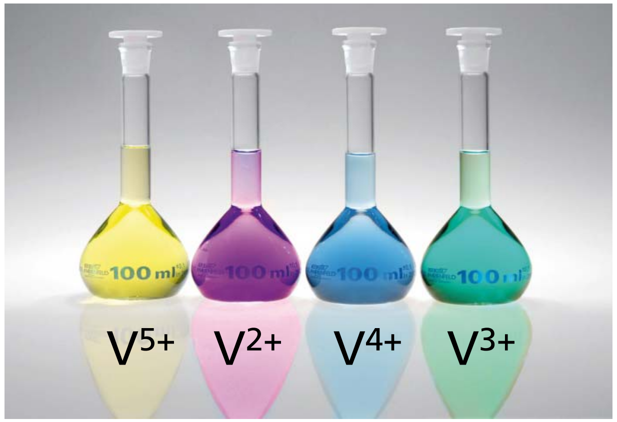
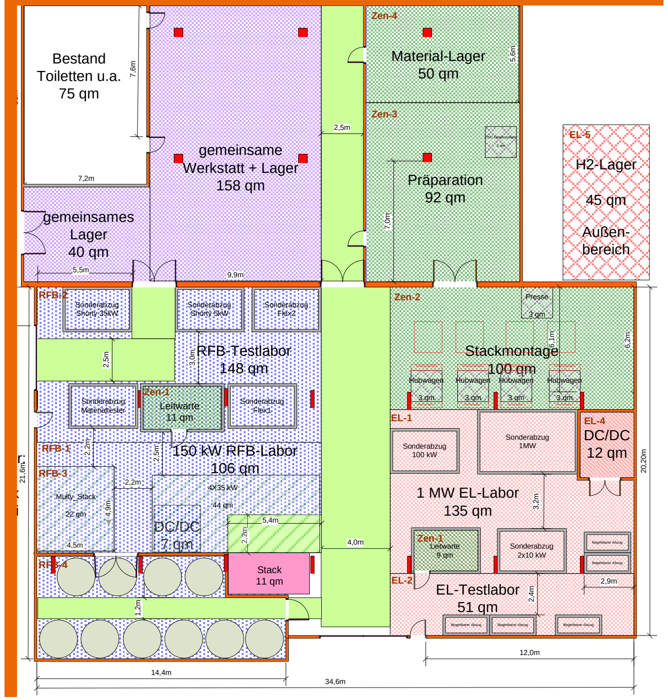


But we work on it!



Outlook

- Redox flow laboratory
  - Complete power 100 kW
  - 400 m²
  - Multi-test bench with 4*5kW
  - 35 kW test bench
  - Material test bench
  - Stack preparation and assembling
- Stack and system designs
  - Larger an optimized stacks
  - Tools for system and stack design
- Advanced controller



May the flow be with you,
and thank you for your kind attention!

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Questions?

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