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A centrifugation-based direct recycling approach for lithium-ion batteries

Green Batteries Conference 2021

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2 CEPA – WE KNOW CENTRIFUGES – INSIDE OUT

3 SYMPATEC GmbH System | Partikel | Technik

AUTOKLASS

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Motivation

- „Established“ approaches for LIB (Li-ion battery) recycling have some disadvantages[1]
- **Direct Recycling**: Recover *still functional* active materials
  - Key step: Clean separation of materials
  - Not established yet, only research / max. pilot scale
- **Digitalization** also in process engineering: Digital Twins, Automation…
- **Approach**: A Direct Recycling process for LIBs, which
  - includes centrifugal separation
  - applies digital tools coupled with on-line measurements
- **But**: For a start, keep it simple!
  - Water-based lab-scale process
  - Only cathode: LFP and Carbon Black

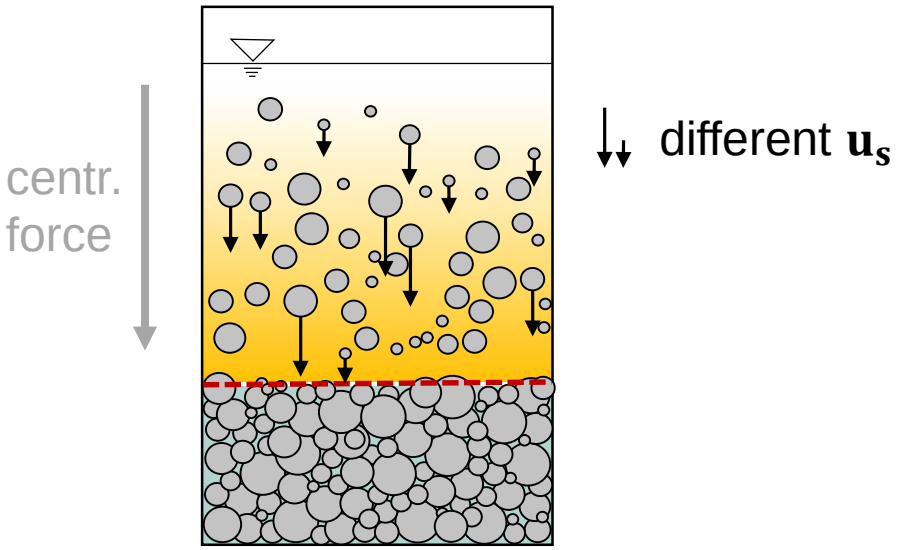
A good overview is given in [1]Harper et al. *Nature* 2019. DOI: 10.1038/s41586-019-1682-5

Centrifugation and Fractionation Basics

- Density difference induces settling

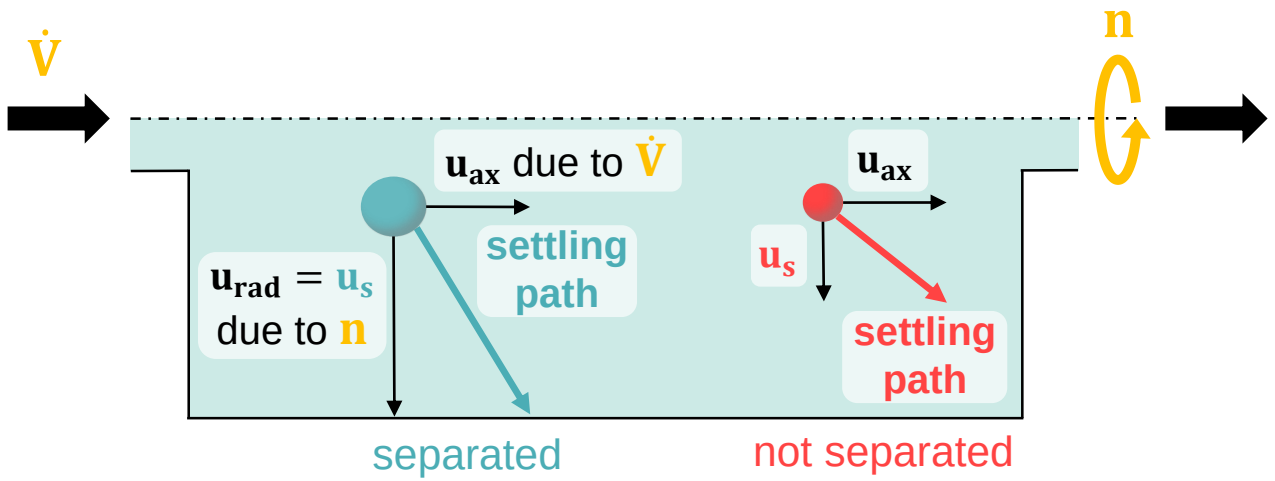
$$\rho_{particle} > \rho_{liquid}$$

- Settling velocity $u_s \uparrow$ with $\rho_{particle} \uparrow$
  and with particle size $x_{particle} \uparrow$



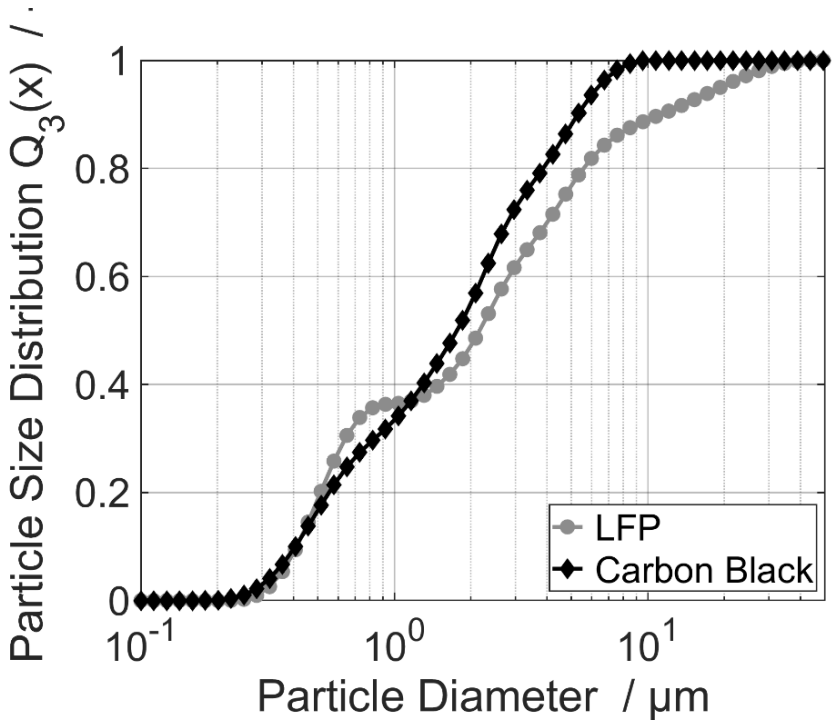
➡ Species with differing ρ and x can be **fractionated**

- In an apparatus, parameters must be set accordingly:
  - rotational speed n
  - volumetric flow rate $\dot{V}$ (feed)

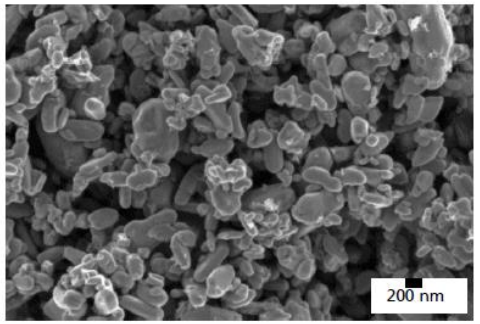


Materials: LFP and Carbon Black

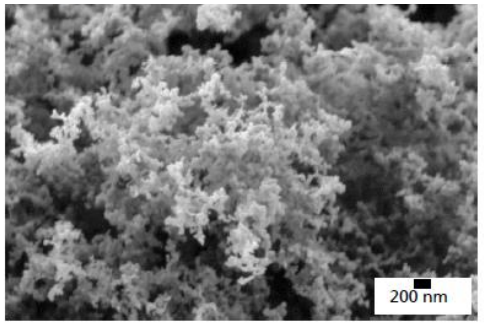
- Safe handling
- Water-based processing possible
- Differ sufficiently in settling behavior



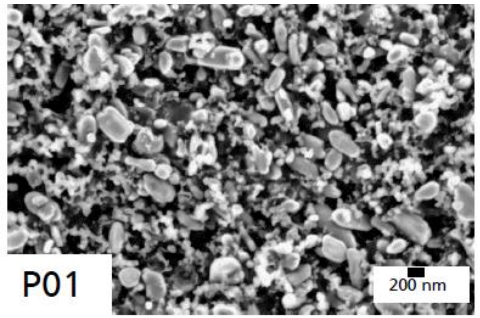
LFP
$3{,}5\ g/cm^3$



Super C65 (Carbon Black)
$1{,}9\ g/cm^3$



→ Feed dispersion:
LFP-based cathode slurry
(incl. binders: CMC, SBR)



Process: Fractionation in a centrifuge

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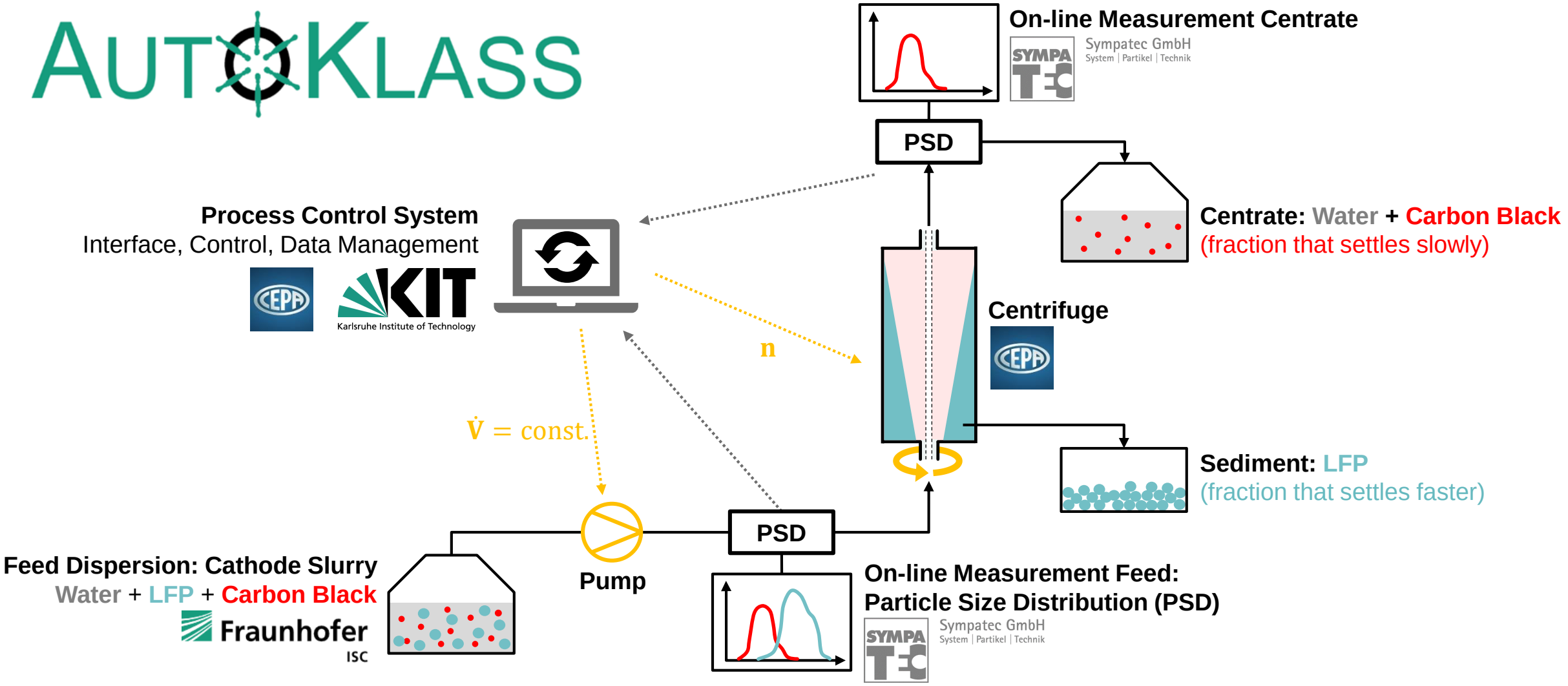
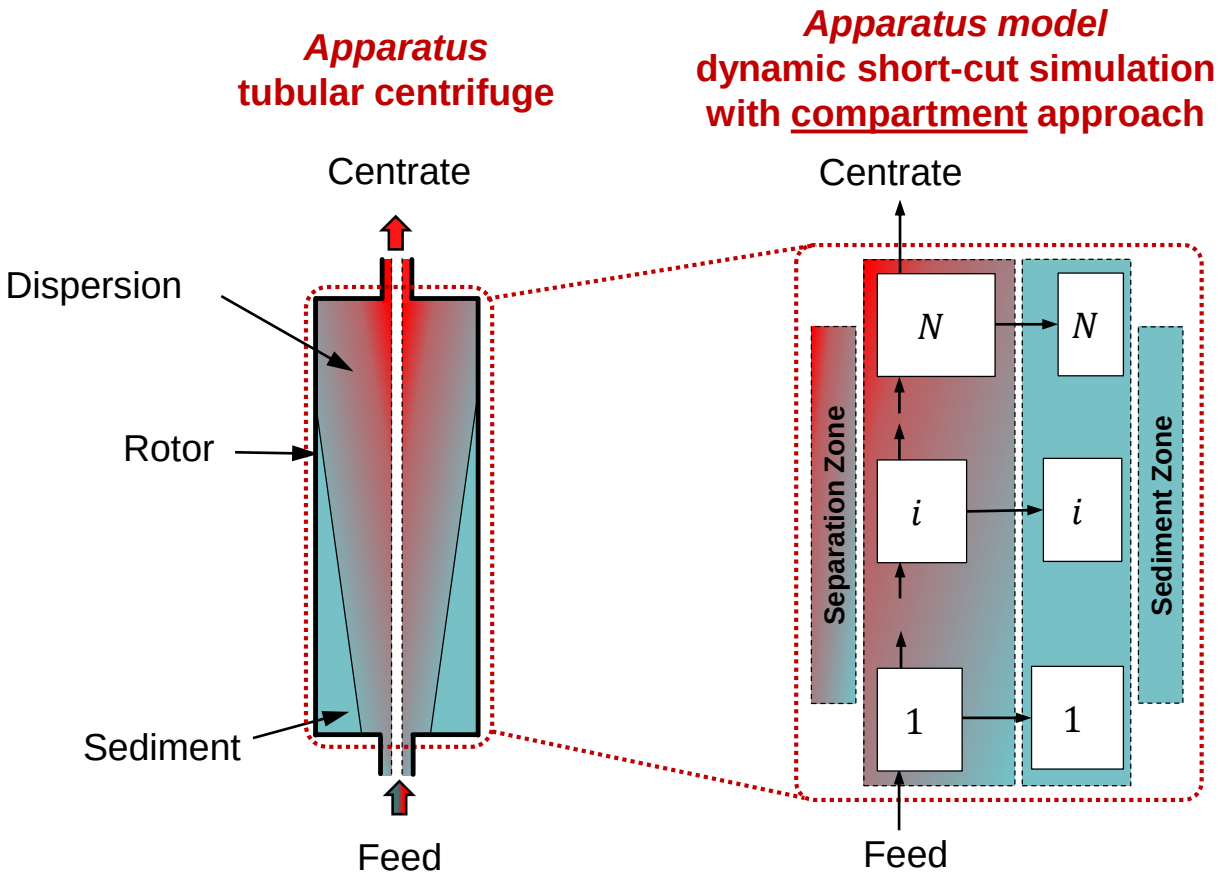


Centrifuge Real-Time Model

- Spatial discretization



- Algorithm for every compartment
  - mass balances
  - population balances

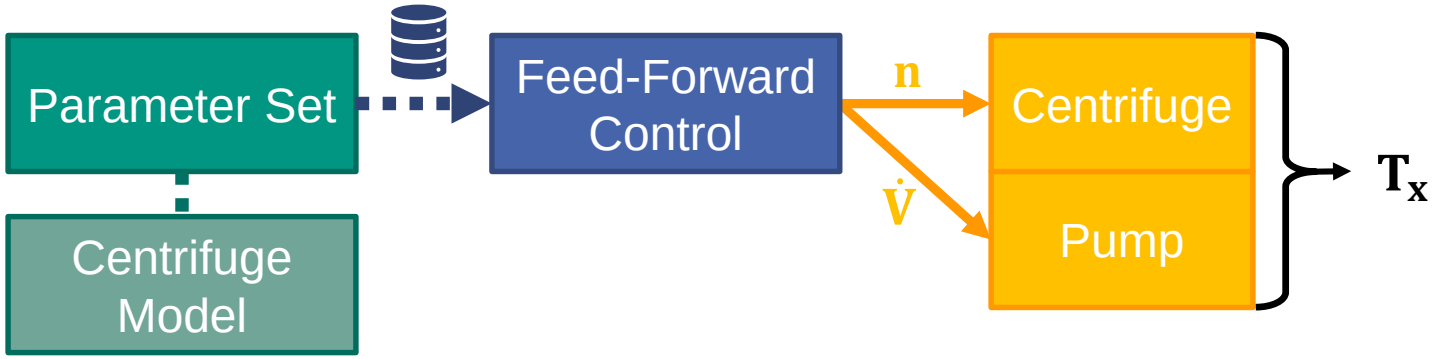
- Specific material behavior (settling and sediment formation) covered by short-cut equations

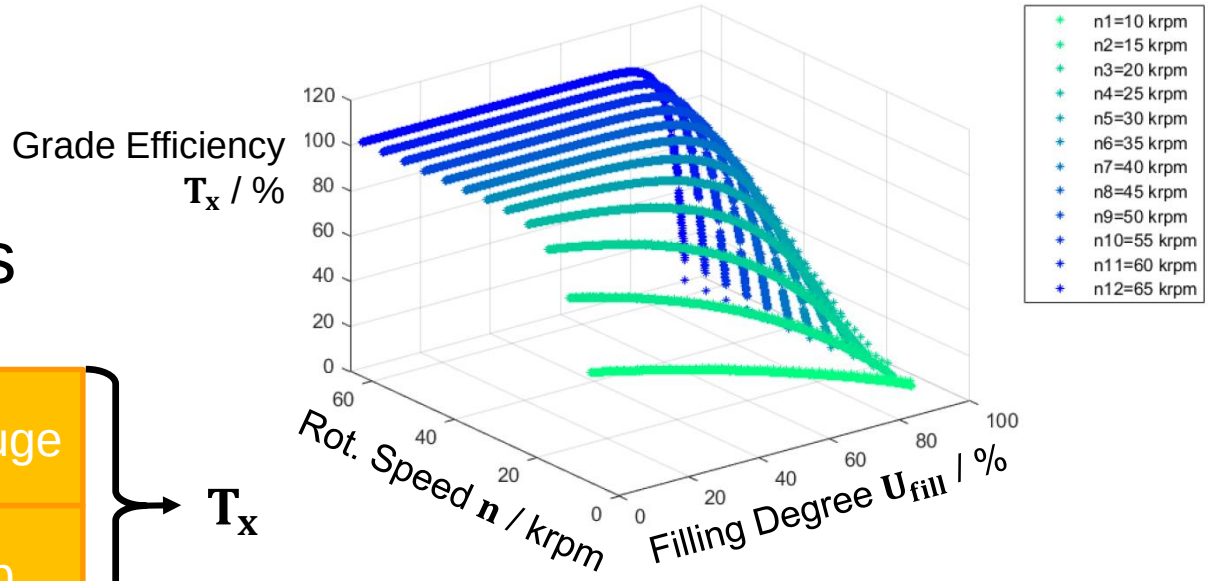
→ Computationally efficient:
Faster than real time

Model-based control

- Aim: Desired separation quality – permanently

- Feed-forward control utilizing model-based characteristic curves

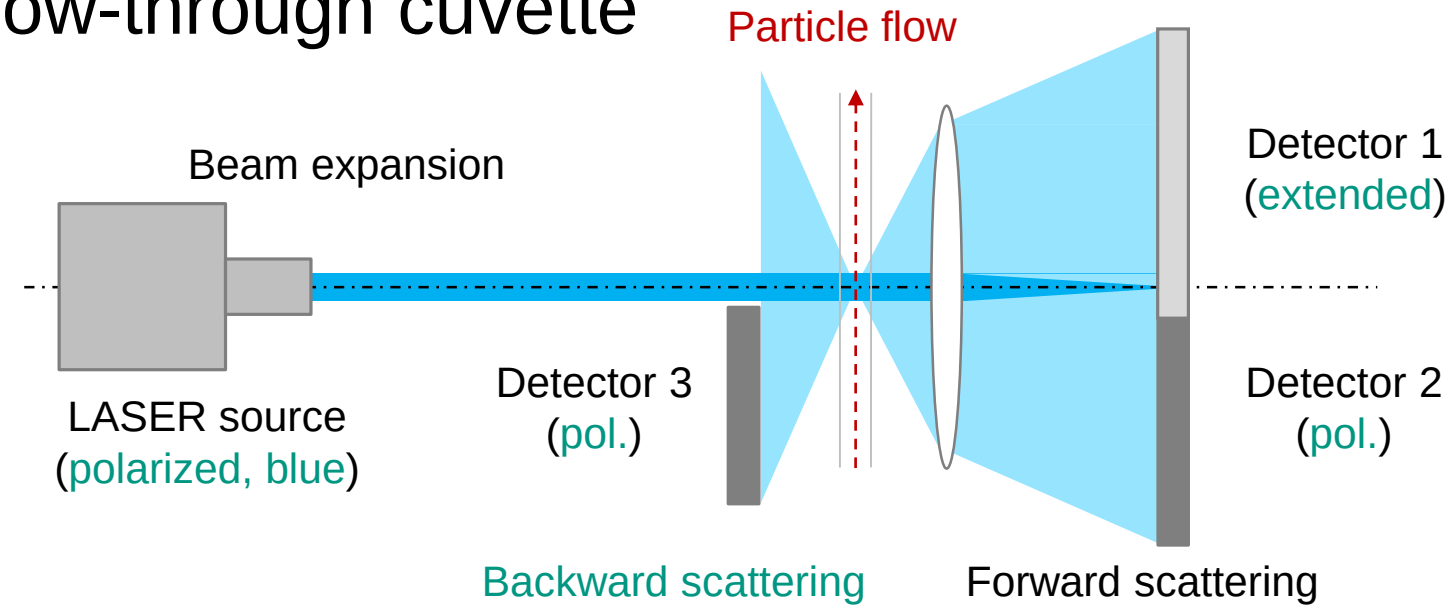




- Simulative study on different algorithms for future application (Internal Model Control *IMC*, Model Predictive Control *MPC*)

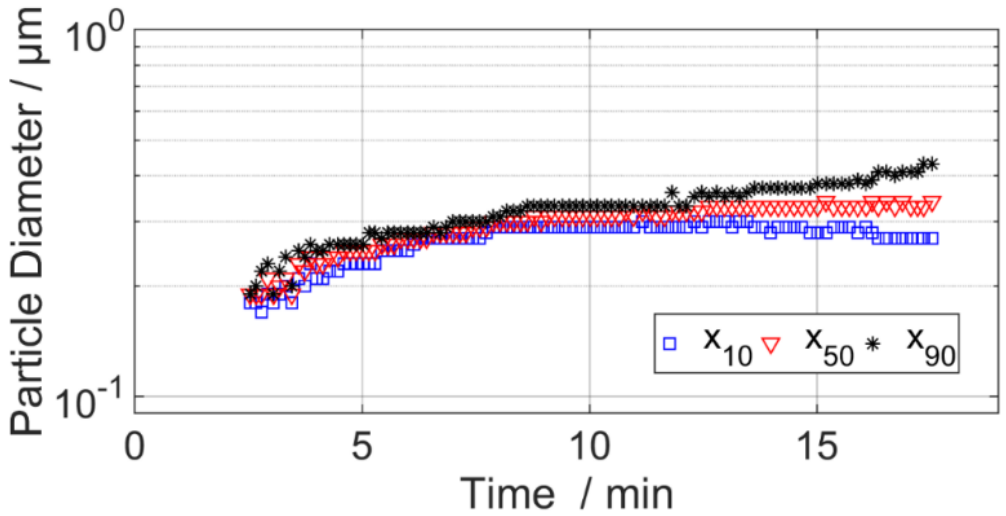
On-line PSD Measurements - New Sensor

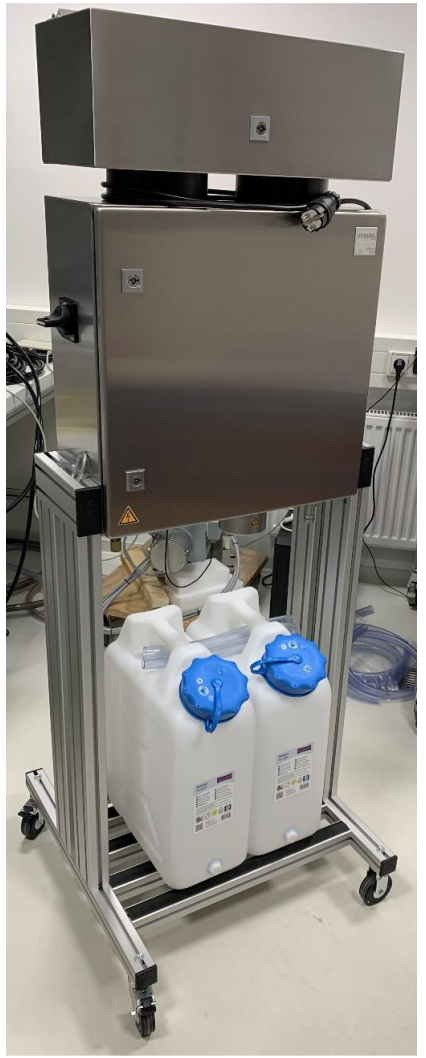
- Starting point: Sympatec‘s HELOS
- New features:
  Added and extended detectors
  → Broad size range: 20 nm to 20 µm
- Flow-through cuvette



On-line PSD Measurements - Dilution Station

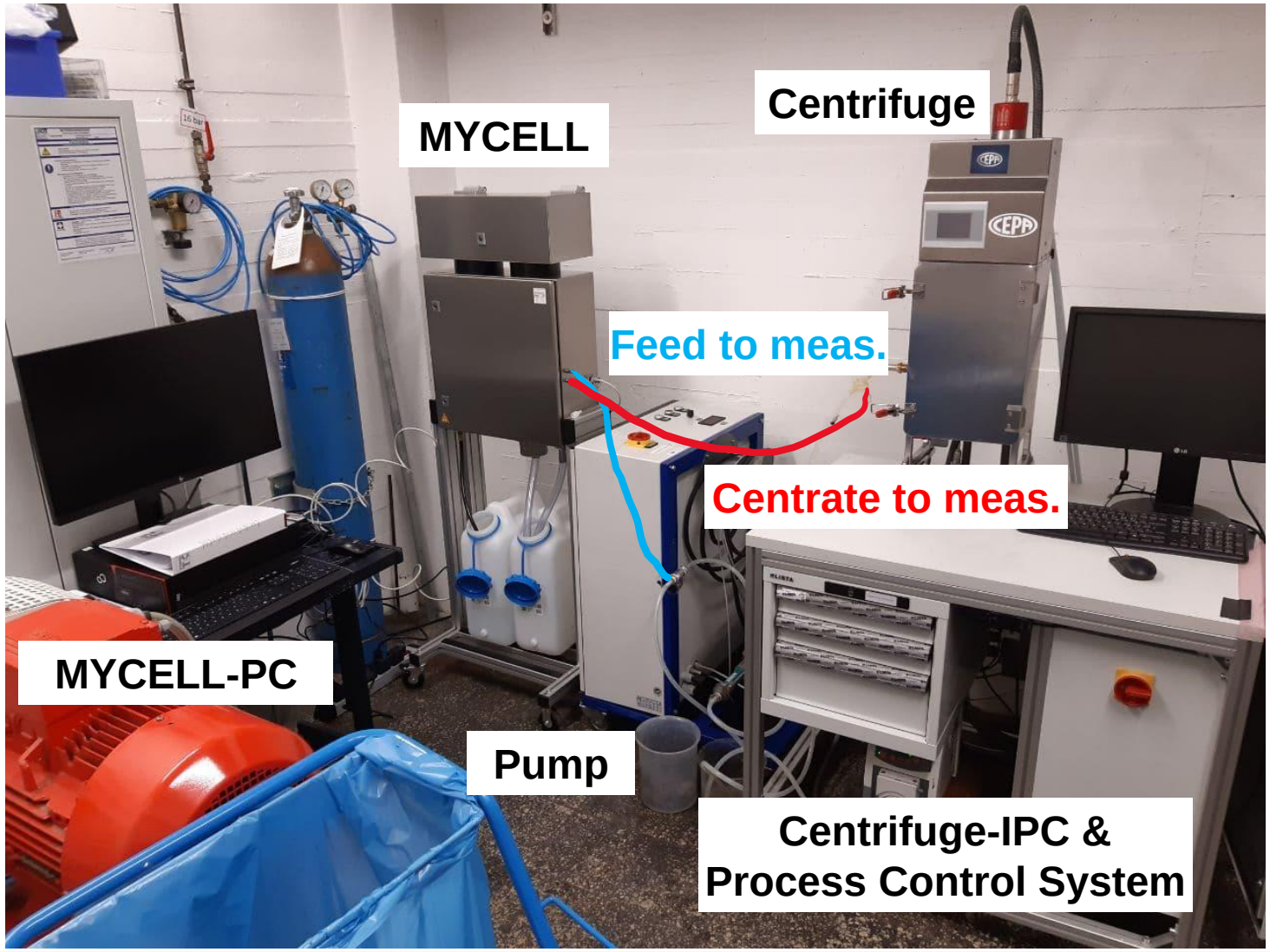
- Peristaltic pumps to convey sample and dilution water
- Automatic dilution until measurement is possible
- Exemplary results:





Complete station: **MYCELL**

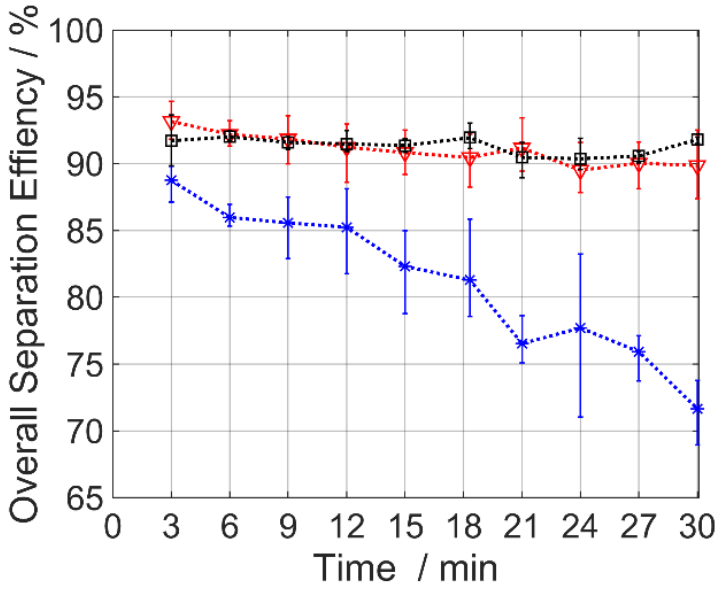
The pilot plant

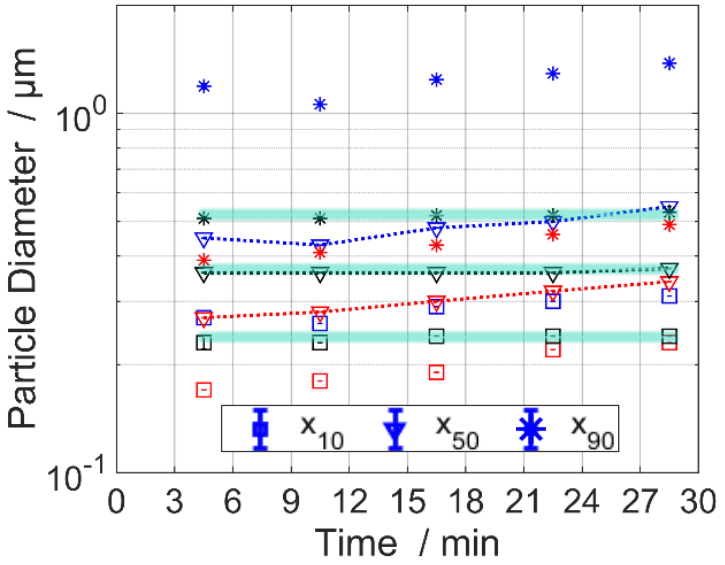


Results: Centrate

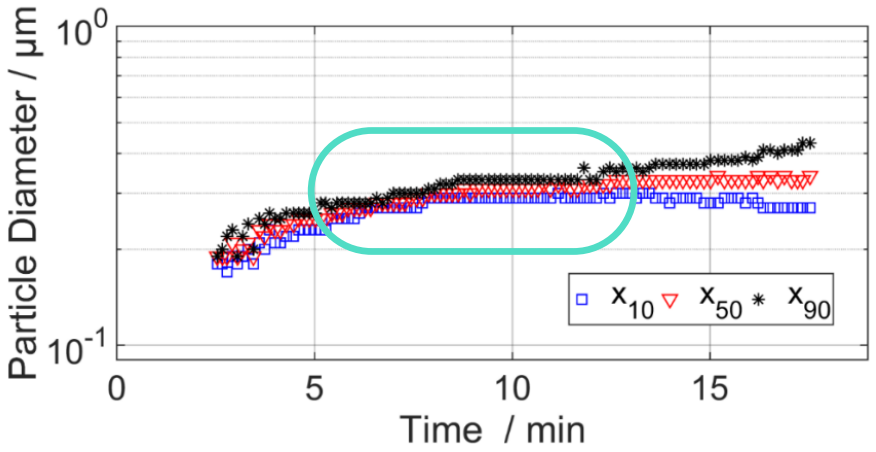
- Model-based control → high yield of LFP & nearly constant PSD

Off-line measurements:





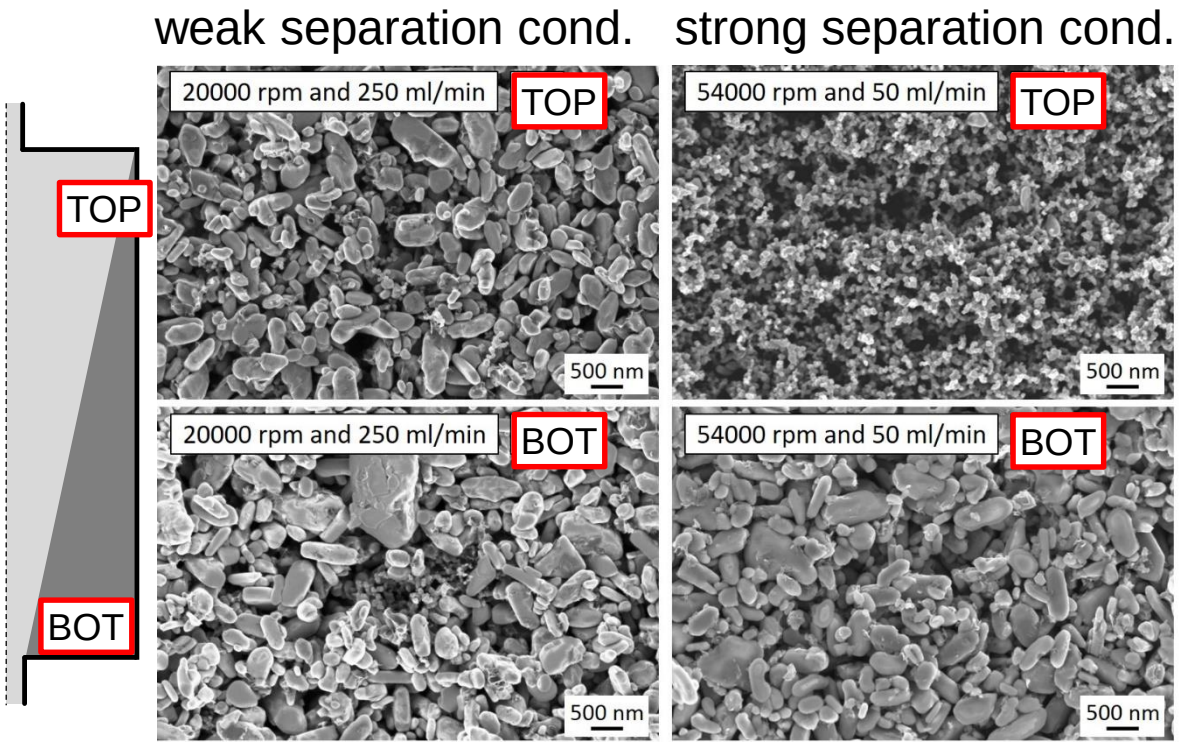
On-line measurements:



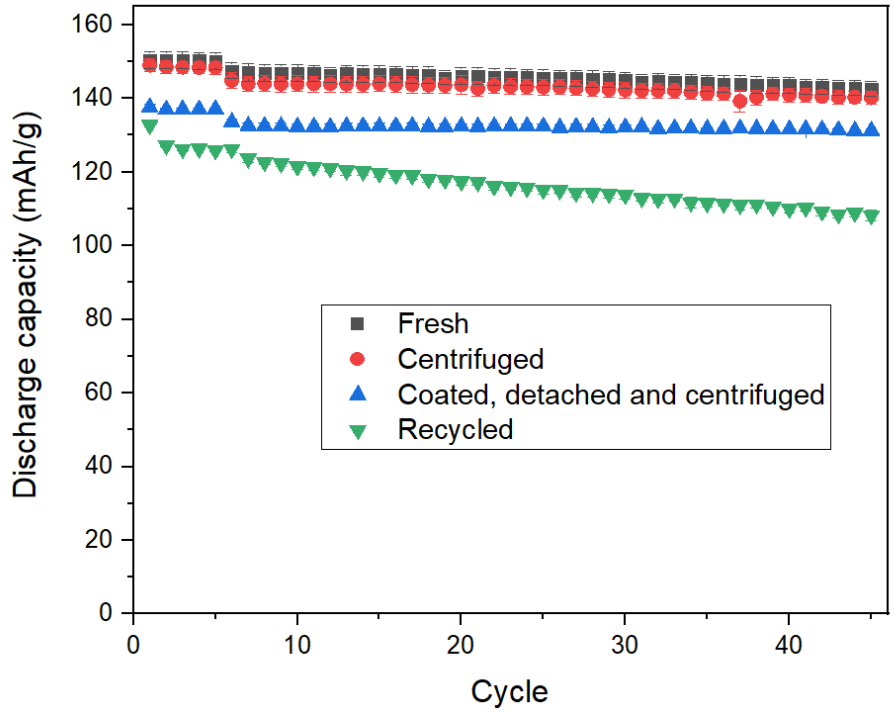
Rotational speed setting / Separation conditions:
_ const. weak _ const. strong _ **adapted rot. speed**

Results: Sediment (LFP)

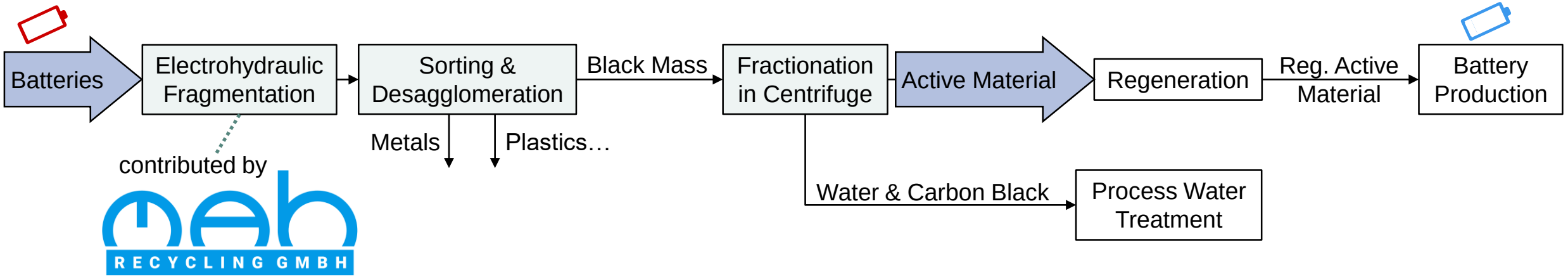
- SEM
  Pure LFP-sediment is feasible



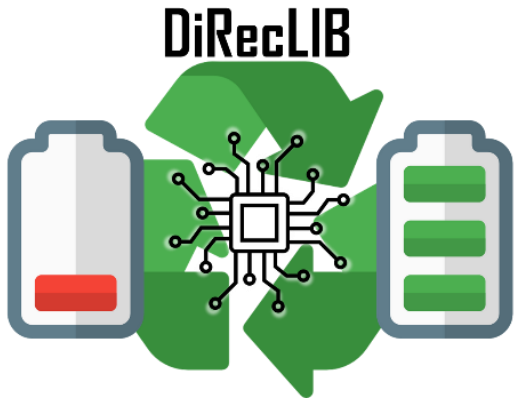
- Discharge capacities
  Centrifugation itself has no crucial effect, but agglomeration does



Outlook
(Almost) Complete Process for Direct Recycling



- New challenges on materials side:
  Process real, entire end-of-life batteries
  - Cathode & anode (& residuals)
  - Various materials (NMC…)
- Process Water: Treatment – even re-cycling?



Outlook
The way from laboratory to industry

- **Continuous** centrifuge type

- Include more **on-line sensors**
- Determine quantities that are not directly measurable via a **Soft Sensor**

- Manifold materials (NMC,… , graphite) and machines require smart **data management**
  → **“learning”** process that **adapts** to new materials

Thank you for your attention…

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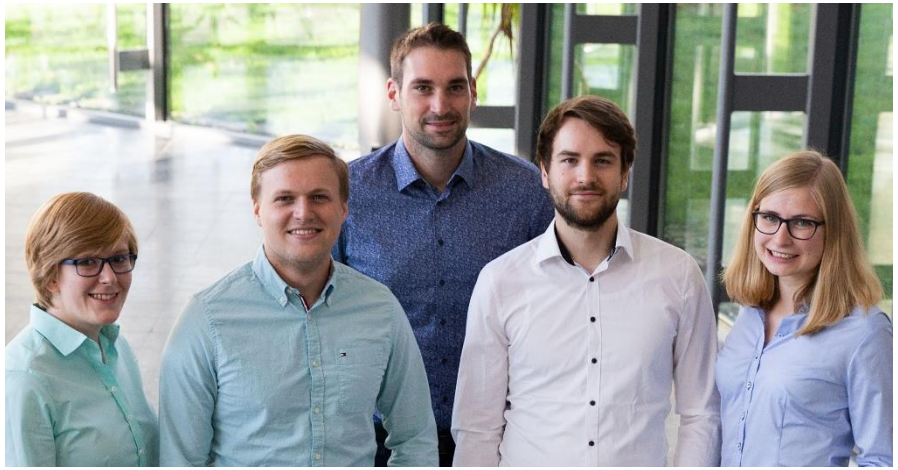

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