TECHNISCHE UNIVERSITÄT
BERGAKADEMIE FREIBERG
Die Ressourcenuniversität. Seit 1765.

INEMET

Recycling of permanent magnets



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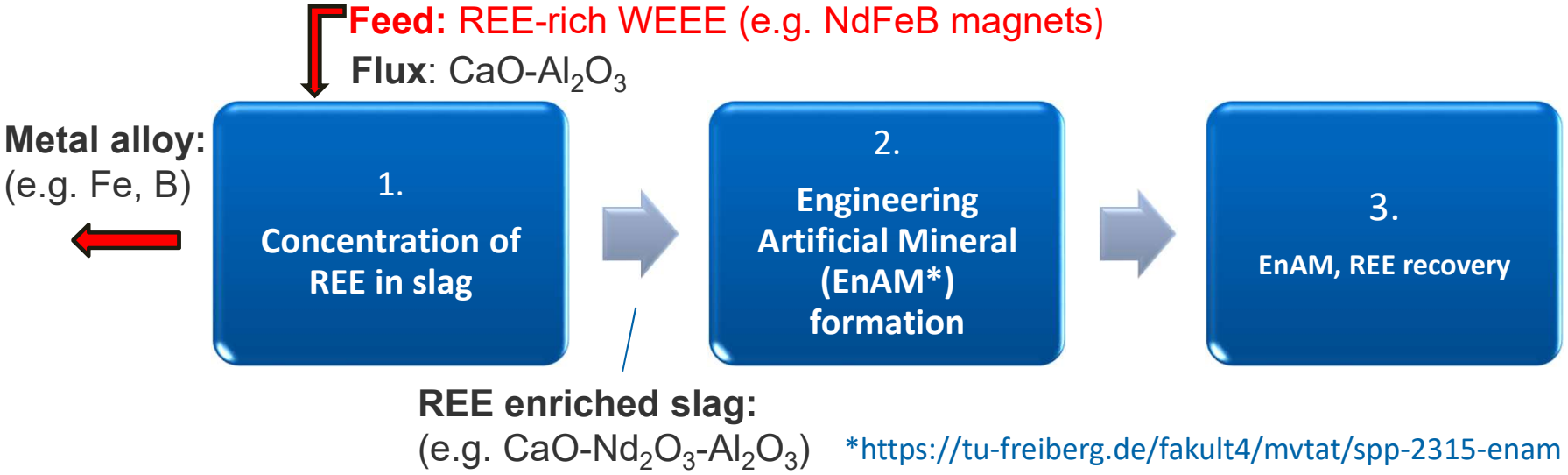
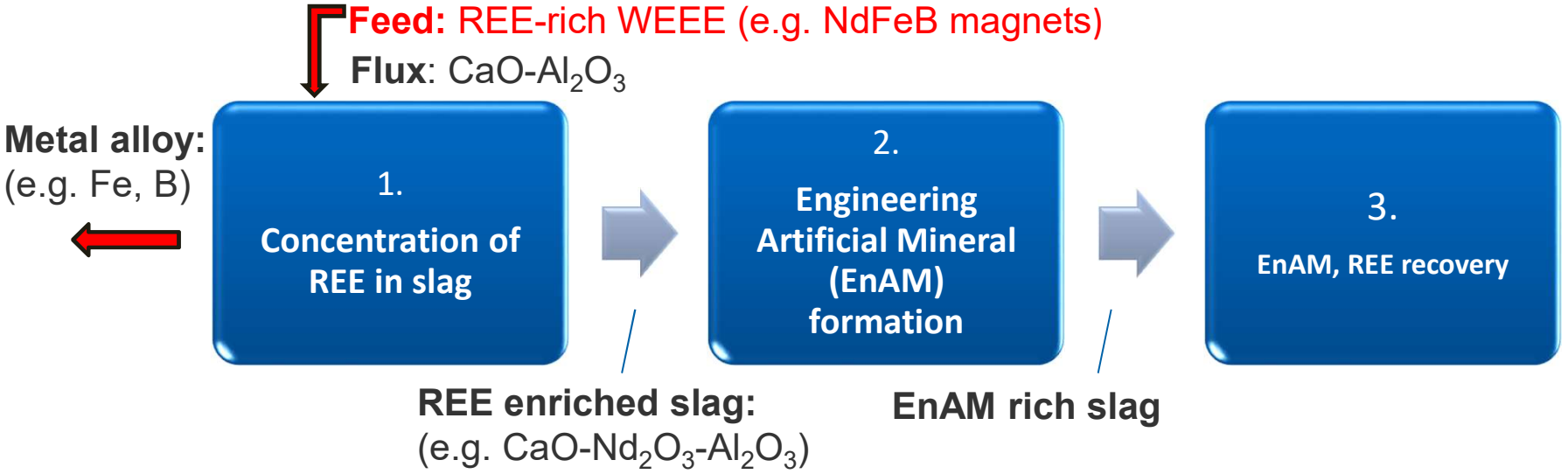
Recycling concept



- **Step 1: Concentration of REE in a $CaO-Al_2O_3$ slag**
  - REE to slag phase at low oxygen partial pressure
  - Rest metals to an alloy (e.g. Fe alloy for NdFeB magnets)

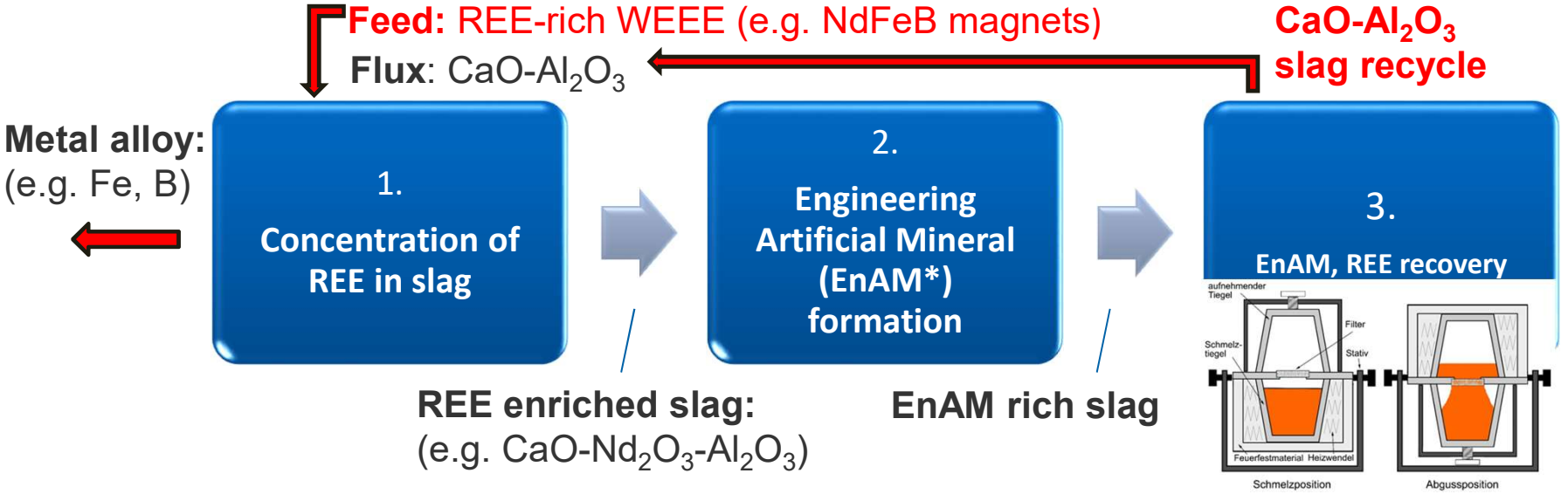
Recycling concept



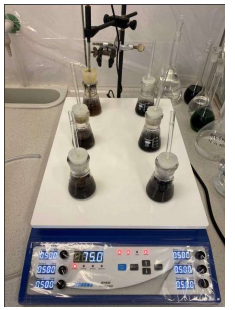
- **Step 2: Engineered Artificial Mineral formation (REE rich phases)**
  - At high temperatures > 1500°C or during solidification
  - Compounds: e.g. $NdAlO_3$ (NdAP) , $NdCaAlO_4$ (τ_1), $NdCaAl_3O_4$ (τ_2), P addition*

*Ellis et al. 1994

Recycling concept

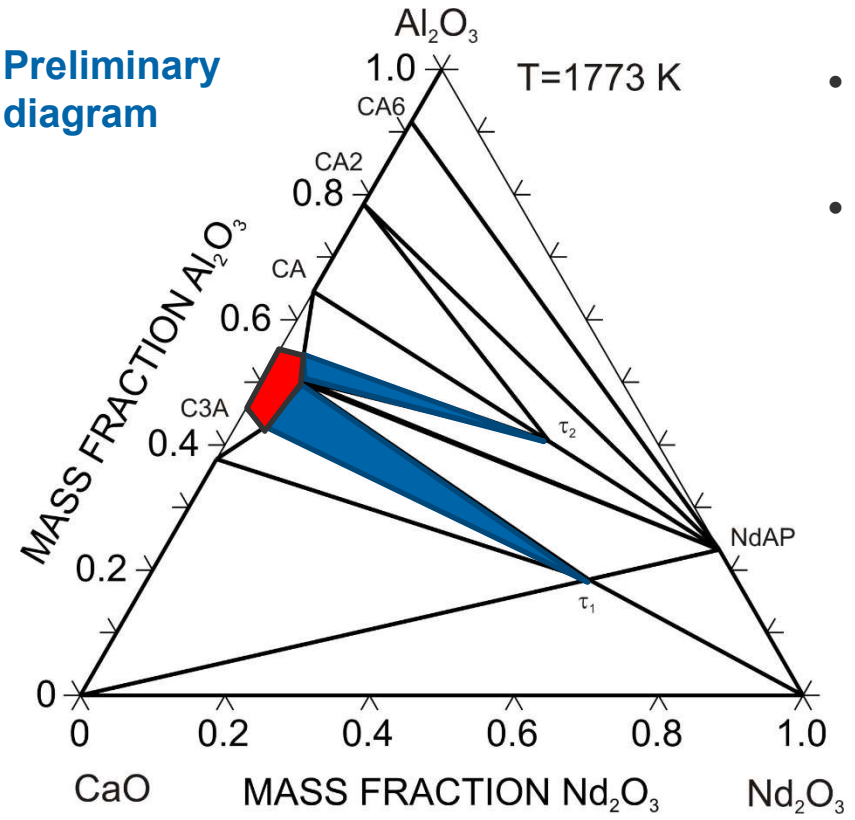


- **Step 3: EnAM, REE recovery**
  - High temperature filtration
  - Acid leaching and precipitation
  - $CaO\text{-}Al_2O_3$ slag recycle



REE recovery

Preliminary diagram



- **Red region:**
  Liquid Slag
- **Blue regions:**
  2 phase solid EnAM-slag

EnAMs

τ_1: $NdCaAlO_4$
τ_2: $NdCaAl_3O_4$
NdAP: $NdAlO_3$

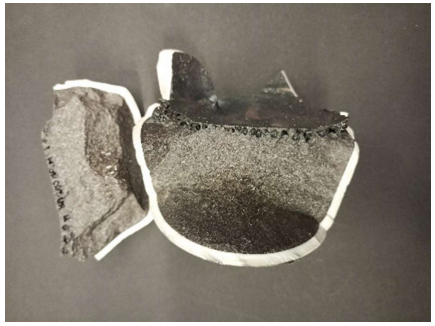
✓ Operating in blue regions allows us to obtain rich-solid phases (EnAMs) and an Nd-lean CaO-Al_2O_3 slag

Step 1: Concentration of REE

- **Option A:**
  - First slag WEEE feed (NdFeB) – high partial pressure of oxygen
  - then remove metal alloy (e.g. Fe-B) – low partial pressure of oxygen

NdFeB magnets

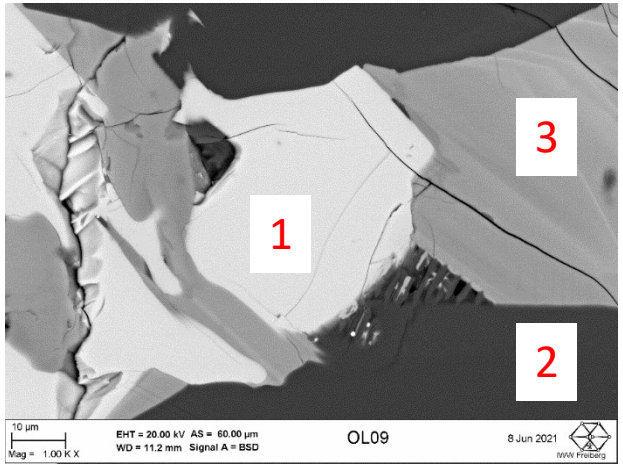
- Demagnetization, grinding
- Mixing 100 g NdFe B magnet with 500 g of CaO-Al2O3
- 1773°K in air



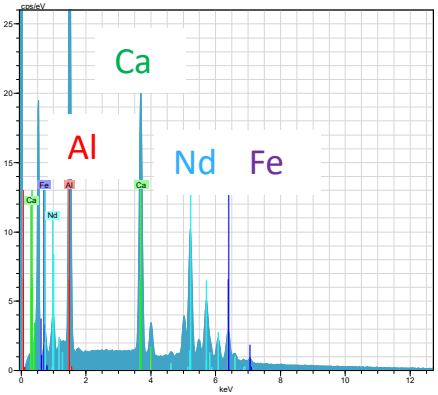
Nd_2O_3: 5.7 wt.-%
Dy_2O_3: 0.2 wt.-%
CaO: 43.8 wt.-%
Al_2O_3: 35.2 wt.-%
B_2O_3: 0.6 wt.-%

- **Option B:**
  - In one step operate at low partial pressure of oxygen
  - Make a EnAM-REE rich slag and metal alloy in one step

SEM-EDX of REE-EnAM rich slag



For EnAM-REE rich phase (1)



1. **EnAM-REE phase:**
   - Nd: 37 wt.-%,
   - Ca: 12 wt.-%, Al: 24 wt.-%, Fe: 5 wt.-%
   - Nd well concentrated
   - Is the τ_2 compound: $NdCaAl_3O_4$

2. **$CaAl_2O_4$ phase:**
   - Almost no Nd: < 0.3 wt.-%

3. **Fe-rich phase:**
   - Nd: 8 wt.-%,
   - Ca: 28 wt.-%, Al: 9 wt.-%, Fe: 29 wt.-%

   ✓ Nd will be recovered after FeO_x reduction

Conclusions & Outlook

- **REE recycling will continue to be important:**
  - e.g. Nd, Dy demand may increase by 700 %, 2600 % up to 2037 (2012 basis)*
  - listed in all four Critical Raw Materials List of the EU between 2010-2020

*Alonso et al. 2012

- **The process proposed is based on:**
  - Concentration of REE from WEEE-rich material in a slag (e.g. NdFeB magnets)
  - Reduction of other elements to a metal alloy except REE, Ca and Al (in progress)
  - Enriched Nd-phases are formed (as τ2 $NdCaAl_3O_4$) for Nd extraction
    - Through slag filtration
    - Through acid leaching and precipitation (after slag solidification)

- **Further REE containing materials:** (containing: Pr, Pm, Sm, Tb)
- Use of more complex REE containing WEEE (e.g. cell phone speakers)

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