4th Hydrometallurgy Seminar in Oslo
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Hydrometallurgical recovery of REEs from e-waste

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Overview

- Introduction: REE recycling
- Research examples
  - REE recycling from HDD shredder residues
  - REE recycling from WEEE shredder scrap
- Concluding remarks

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Introduction

- Metals are important engineering materials, but metal resources are finite and non-renewable.
- Recycling of metals contributes to the materials sustainability and circular economy.
- Bulk metals (steel & major non-ferrous) are reasonably well recycled, but minor and more critical metals are poorly recycled.
- Electrical and electronic equipment (EEE) is the main users of minor/critical metals, and WEEE (e-waste) is important secondary resource.

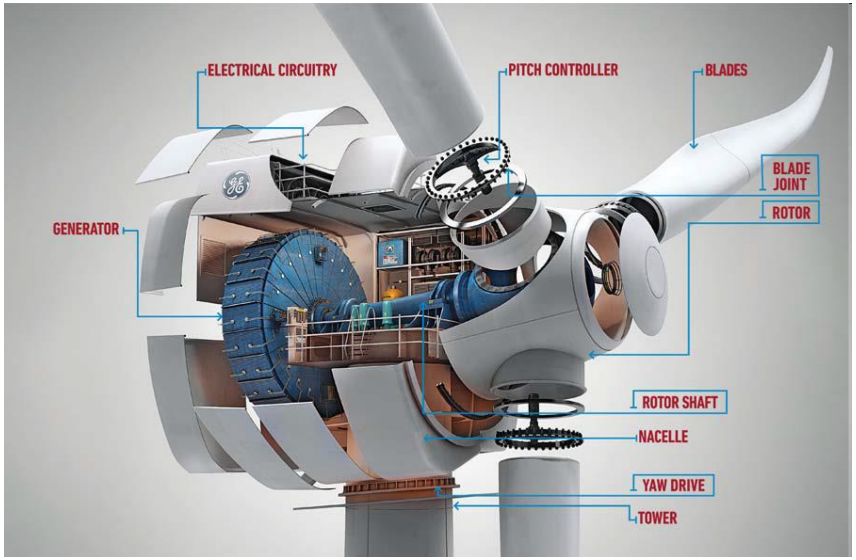
Rare Earth Elements (REEs) recycling

- REEs are the most critical metals in the world and used in many hi-tech and clean-tech applications, e.g. permanent magnet, rechargeable batteries, and catalysts.
- Demand is high and supply is limited.
- REE recycling has the significant potential as secondary supply and contributes to low carbon economy.
- Inefficient recycling technology and current low price of primary supply lead to near "zero" recycling rate.
- More efficient & low cost technologies are needed!

NdFeB permanent magnets

REE share as the permanent magnets
21% by volume & 38% by value
76% Nd, 69% Pr and 100% Dy

Generator in wind turbines
(400 kg magnet/MW)
(1.2 ton for 3.0 MW capacity)



Electric vehicles (EV/HEVs)
(1.2 kg/car)

E-bikes
(300-350 g)

Computer HDDs
(10-20 g)

REE Recycling from EoL permanent magnet in WEEE

3 steps of recycling

- Collection
- Physical processing
- Metallurgical processing

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Destinations of permanent magnets in EOL products

- **Wind turbines:** 100% collection and affordable manual dismantling
- **Conventional vehicles:** 100% collection, but go to shredder and diluted in ferrous scrap and ASRs (<300 ppm)
- **EV/HEVs:** 100% collection, manual dismantling or to shredder (diluted)
- **Computer HDDs:** 50% (or less) collection, mostly go to shredder with the whole PC, or sometimes dismantled for separate shredding
- **Small consumer electronics:** very low collection rate (~30%), no dismantling, shredding together with the whole unit

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Tech. options of REE magnet recycling

Magnet liberation

- Manual separation
  - Best but labour intensive
- Mechanical liberation
  - Hitachi process: rotating drum (shaking) for HDDs
- Hydrogen decrepitation
  - Very effective, but suitable for relatively pure magnets
- Industrial practice
  - Shredding of the whole components or the whole equipment for materials recovery
  - Not for REE recovery

REE recovery options

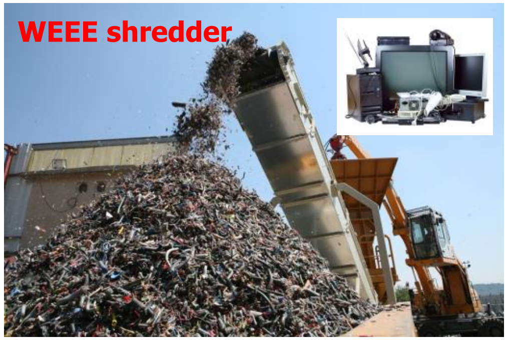
- Hydrometallurgical or pyrometallurgical processing

REE permanent magnet recycling: examples

1) REE recycling from shredded computer HDDs (Van Gansewinkel project)

2) REE recycling from mixed WEEE shredder scrap (EU FP7 project REEcover)

www.recover.eu



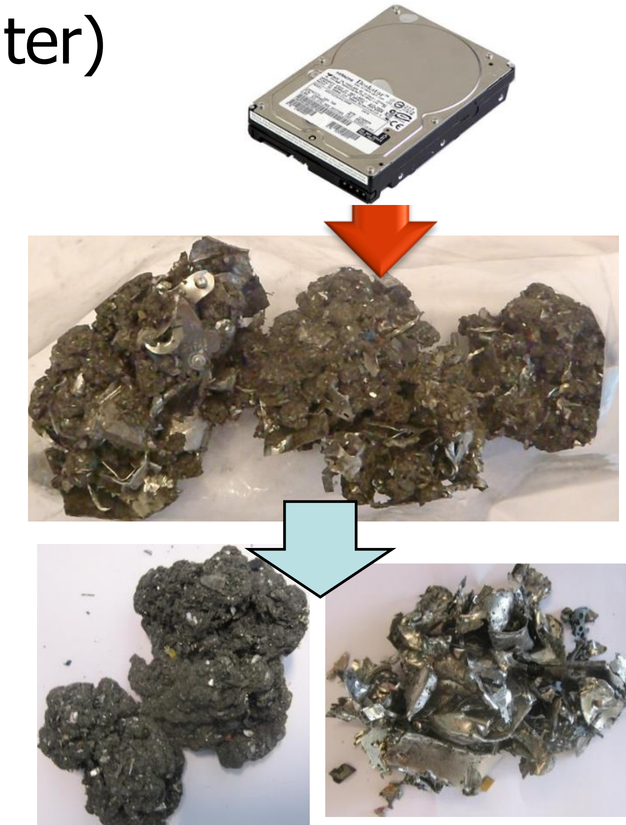
Metallurgical extraction

- **Hydrometallurgical methods**
  - Selective leaching or complete leaching (H_2SO_4 or HCl)
  - REE selective precipitation (hydroxide or oxalate)
  - REO preparation for RE metal production (electrolysis)
- **Pyrometallurgical methods**
  - Liquid metal extraction: using Mg or Ag
  - Molten salt extraction: using $MgCl_2$ or AlF_3, ZnF_2, FeF_3
  - Molten slag extraction: CaO-CaF_2, B_2O_3 etc. (for leaching)
  - Roasting for selective leaching (pyro- hydro combined)
- **Rare earth metal production**
  - Molten salt electrolysis (chlorides or REO-fluoride)
  - Metallothermic reduction

Example 1: REE recovery from HDD shredder residues

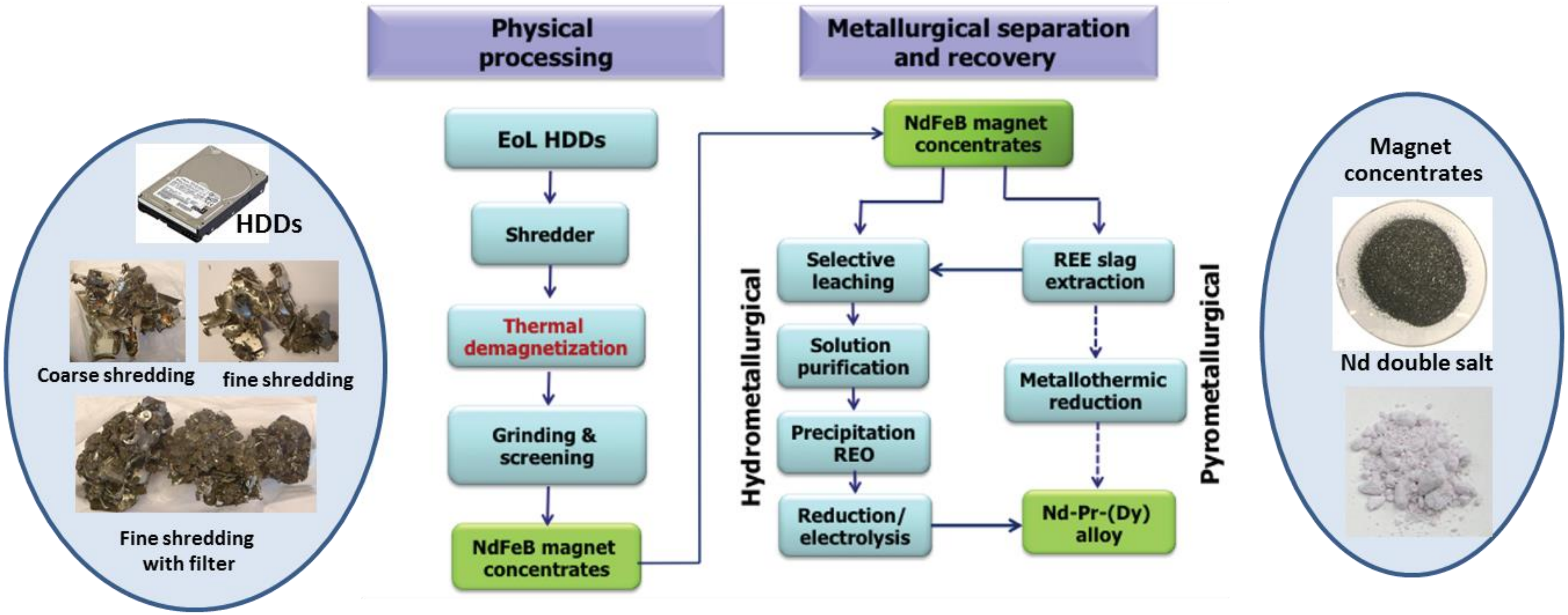
- Residue from fine shredding (with filter)
- Magnet recovery: ~70%
- Magnetic fraction in residue: ~70%

Abrahami and Yang, Mineral processing and extractive metallurgy, 2015.



Ratio (Mag./Non-Mag.) ~ 2.2

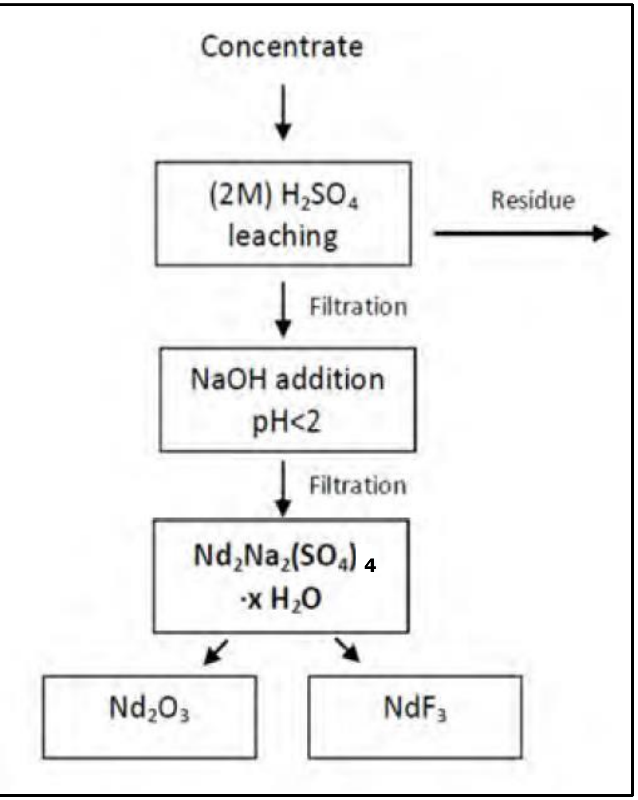
Physical upgrading and metallurgical extraction (TU Delft flowsheet)



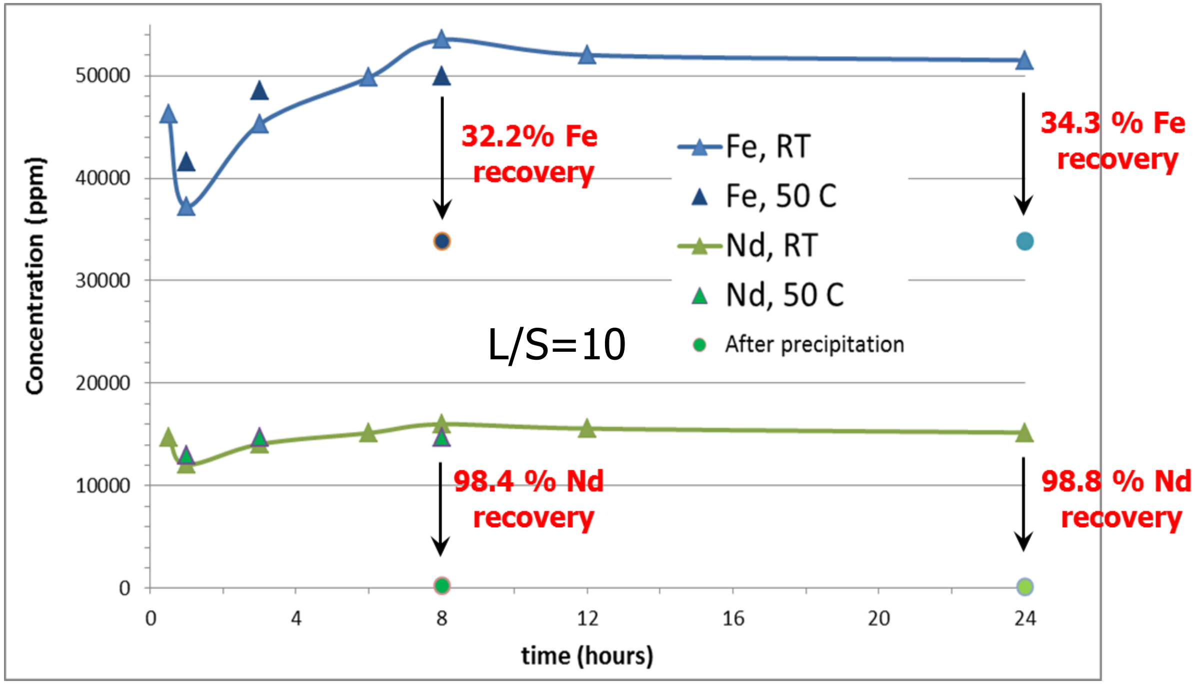
- Pure hydrometallurgical route
- Pyro – hydrometallurgical combined route

Hydrometallurgical processing

Leaching kinetics and REE recovery



$$2Nd_{(s)} + 3H_2SO_{4\ (aq)} \rightarrow 2Nd^{3+}_{(aq)} + 3SO^{2-}_{4\ (aq)} + 3H_{2\ (g)}$$



Enriched magnet concentrate (Nd+Pr=20-25 wt%)

Hydrometallurgical extraction: direct H_2SO_4 leaching

- Efficient, but iron removal is still needed
- Total REE recovery rate
  - Hydrometallurgical route: 80 – 85%
- Efficient separation of Nd(Pr) and Fe is achieved
- Good quality $NdNa(SO_4)_2 \cdot \times H_2O$ and NdF_3 /Nd_2O_3 can be produced for further metal production.

Slag treatment of the magnet waste caused low rate in REE leaching (~80%) due to gypsum formation using H_2SO_4.

REEcover (EU FP7: 2013 – 2016)

Recovery of REEs, from magnetic waste in the WEEE recycling industry and tailings from the iron ore industry

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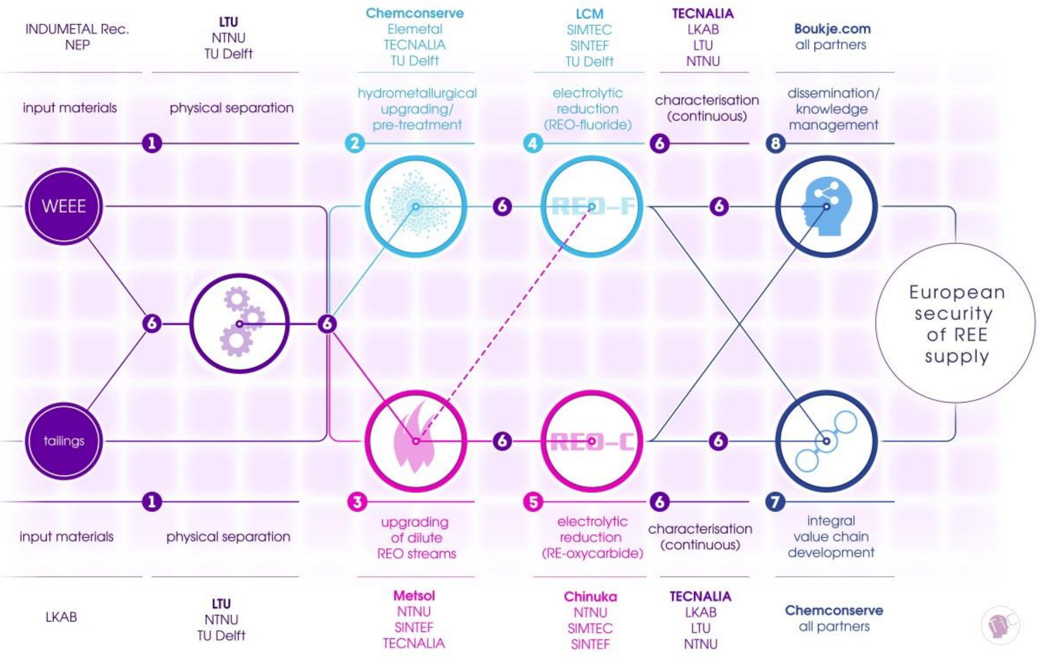
REEcover aims to

- Improve European supply of the critical Rare Earth Elements Y, Nd, Tb and Dy.
- Strengthen European SME positions in REE production & recovery value chain.
- Study two different routes for hydro- & pyro-metallurgical recovery of REEs: as Rare Earth Oxides (REO) or Rare Earth Oxy-Carbides (REOC) for electrolytic reduction.
- Demonstrate and compare viability and potential for these routes on two different resources: magnetic scrap & iron ore mine tailings.

Consortium: 15 partners
Coordinator: NTNU



2 main metallurgical routes
Hydrometallurgical up-grading and pre-treatment of raw materials
Pyro- and hydrometallurgical combined routes

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REEcover: REE recycling from WEEE

Hydrometallurgical processing route

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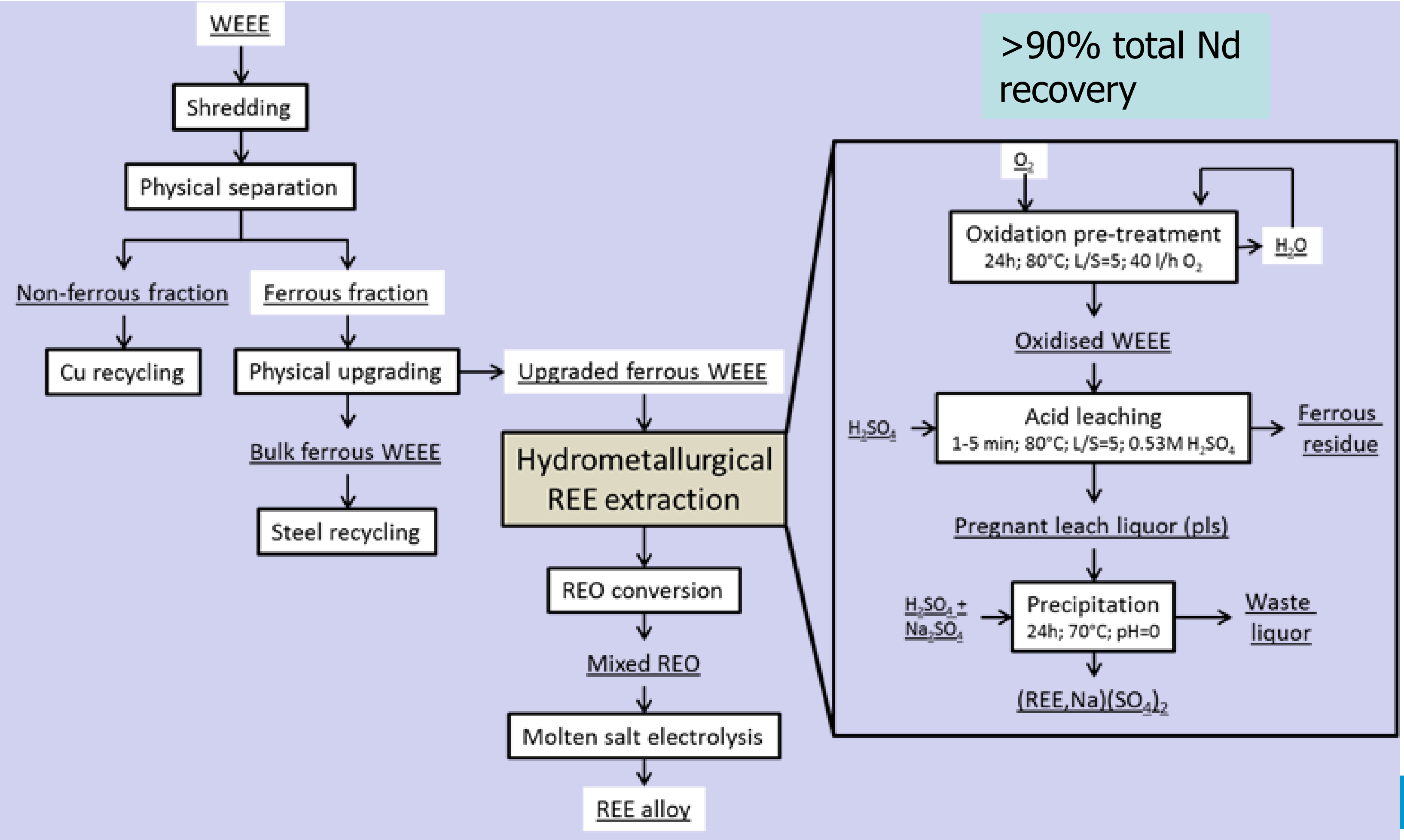

(Peelman et al. 2017, TU Delft)

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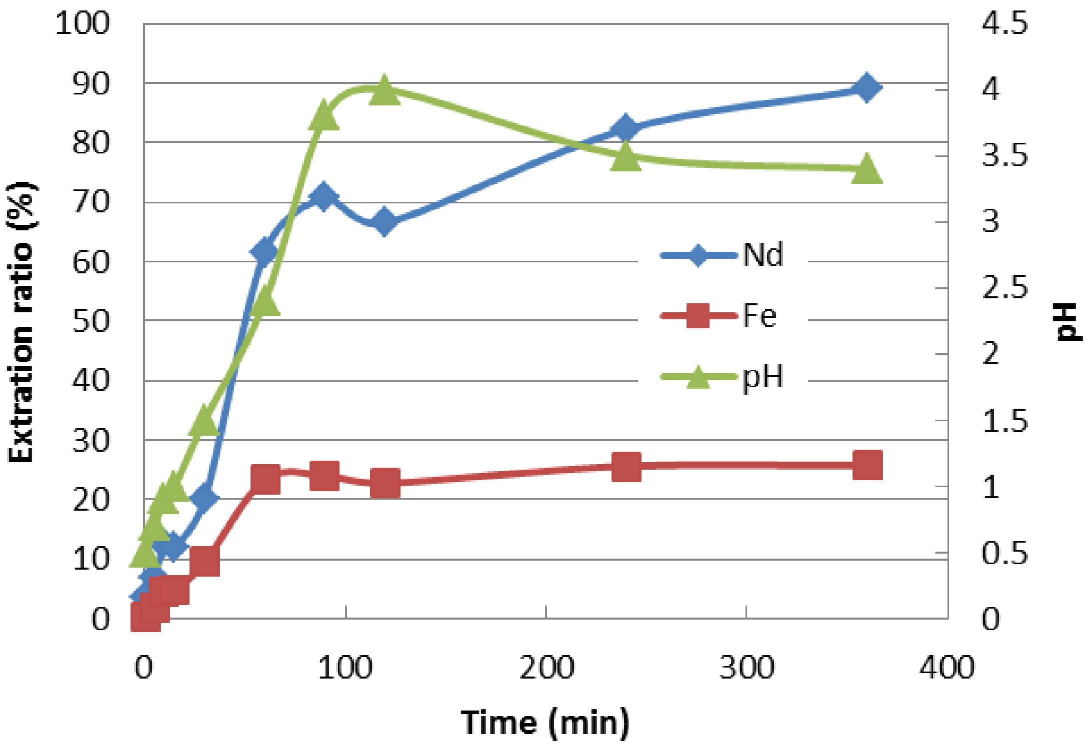
WEEE hydrometallurgical route

Leaching behaviour of oxidised WEEE with diluted H_2SO_4 at room temperature



Main challenge:
- Selective leaching of REE over Fe
- Total REE recovery

Peelman 2017, TU Delft

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REEcover: REE recycling from WEEE

Pyro- & hydrometallurgical combined route

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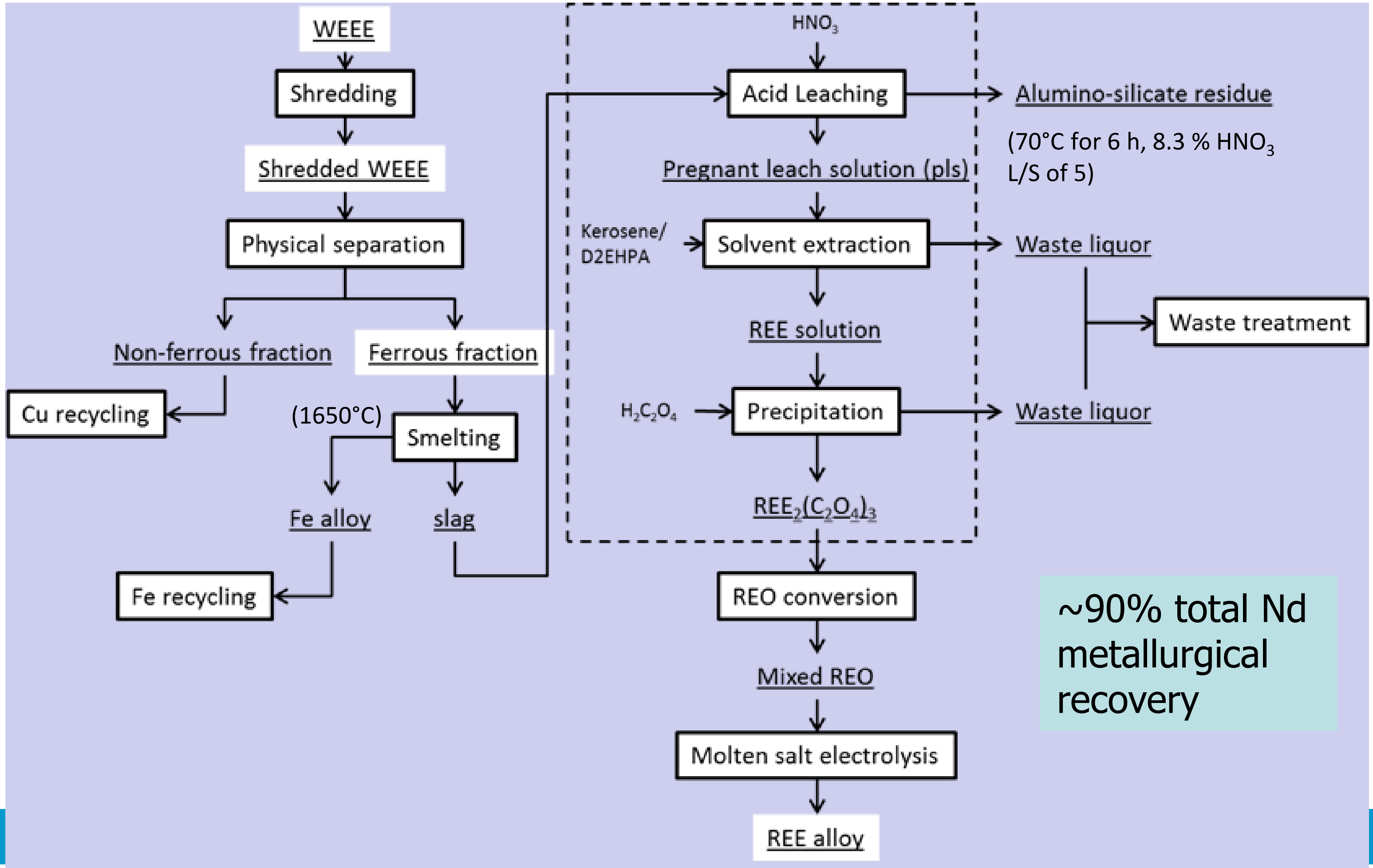

(Peelman et al. 2017, TU Delft/Elemetal/NTNU)

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Concluding remarks

1) Hydrometallurgy is a flexible and efficient technology, already used in many non-ferrous metals production and refining.
2) It is being used more and more for treatment of low grade and complex ores and secondary raw materials.
3) Hydrometallurgy can be effectively used for REE recovery from concentrated or dilute waste streams from WEEE industry.
4) Proper physical separation is needed to reach an efficient metallurgical recovery.
5) Quite often, a combined route of pyro- and hydrometallurgical processing is a better option.

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van Gansewinkel

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Thank you for your attention!

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