# Recovery of Rare Earth Elements from permanent magnets

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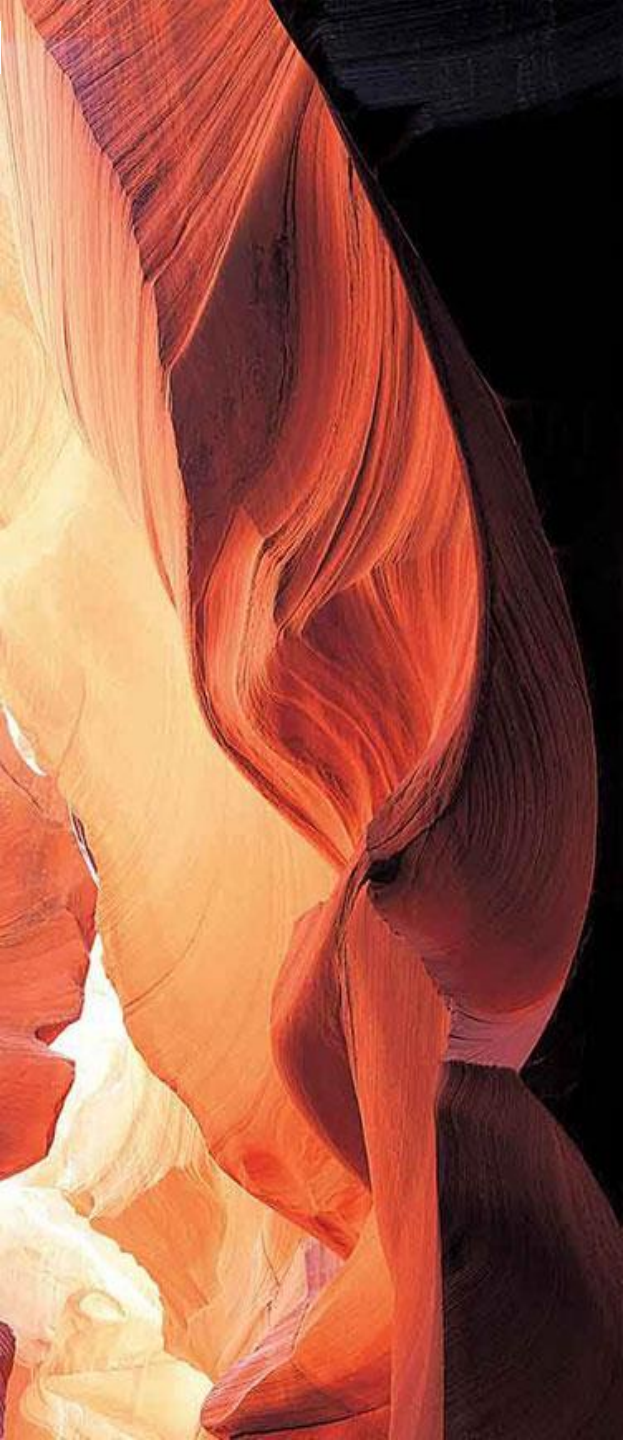
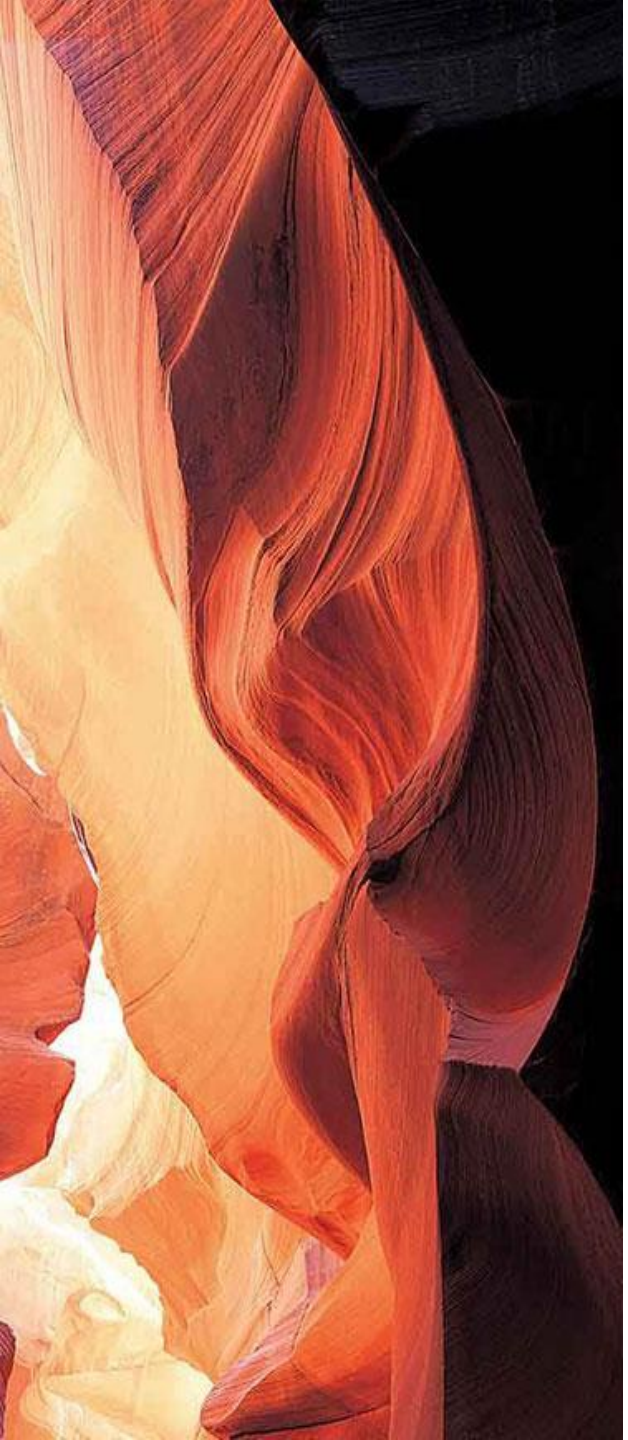
**Prometia Scientific Seminar**
**Lisboa, Portugal**
**28-30 November 2023**



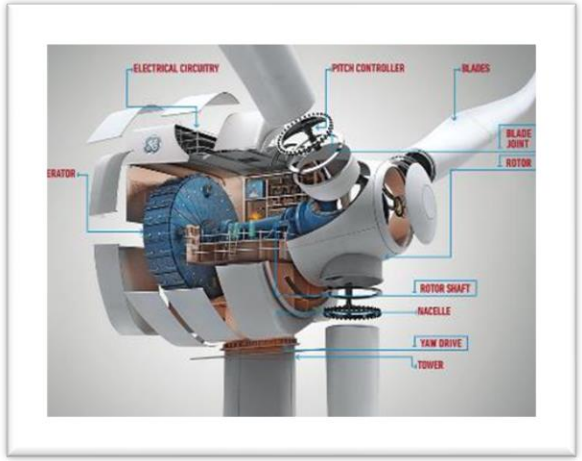
CONTEXT

# Research guidelines

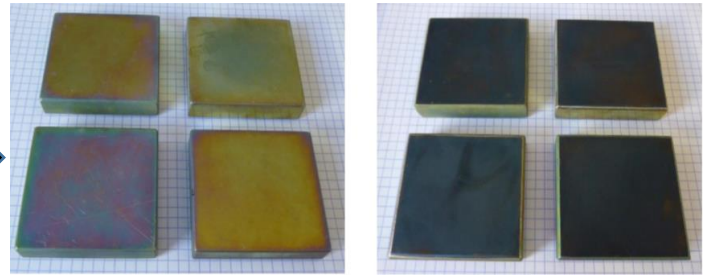
- High content of REEs (strategic metals) in permanent magnets contained in WEEE (secondary resources)
- Development of innovative mechanical sorting process to recover magnets from HDD which is not actually industrialized
- Development of alternative route to short loop allowing fragmented and polluted magnet valorization using soft and green chemistry
- Implementation of developed processes at pilot scale



# PERMANENT MAGNETS



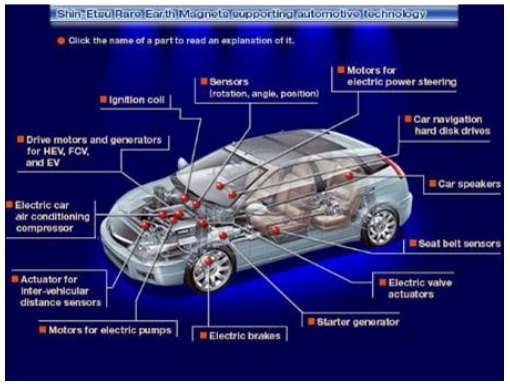

*Wind Turbine Magnets*



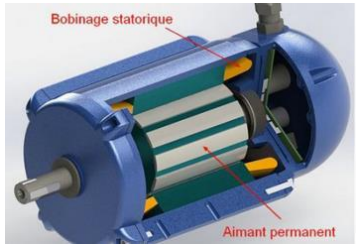
*Hard disc drives from computers*


*Electric scooter*

*Electric vehicles*




*Electrical motors*



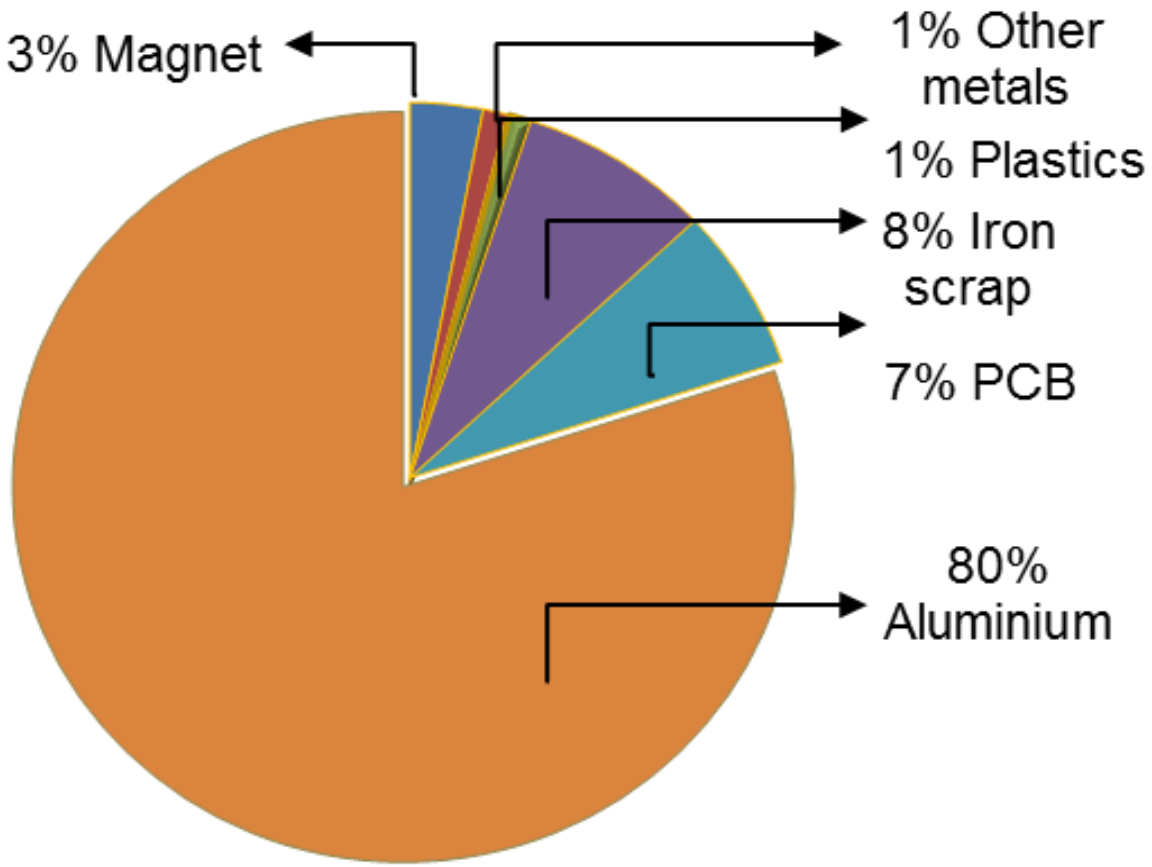
# THE HISTORY OF THIS RESEARCH AT BRGM IN A FEW FIGURES

- 8 years of research

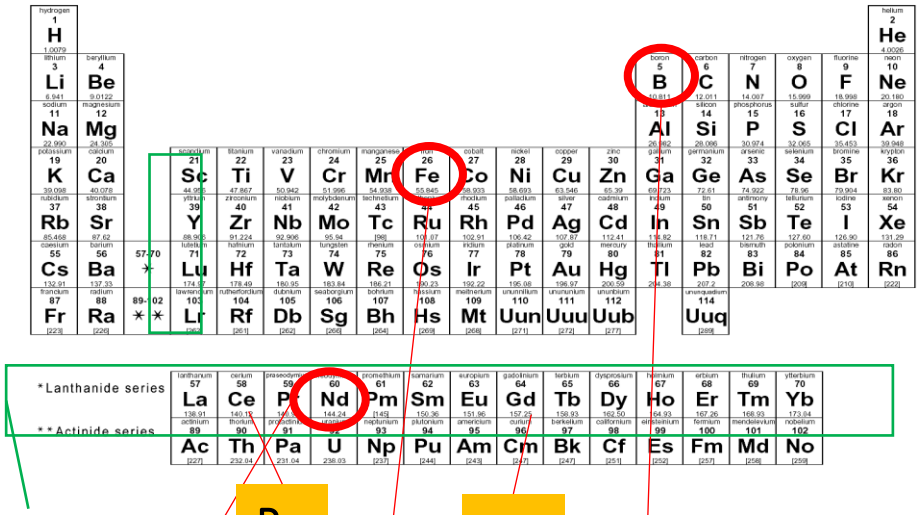
- 3 Research projects
  - ✓ EXTRADE (completed) — French funding — (2014-2017)
  - ✓ VALOMAG (completed) — EIT RM — (2020-2022)
  - ✓ PEPR Strategic metals (starting) — French funding — (2023-2025)

- 13 partners where 6 research centres, 1 eco-organism, 6 companies

# HARD DISC DRIVE COMPOSITION

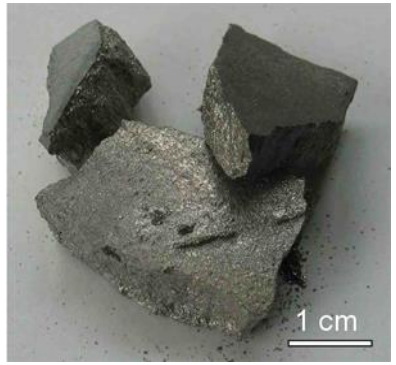


# PERMANENT MAGNETS



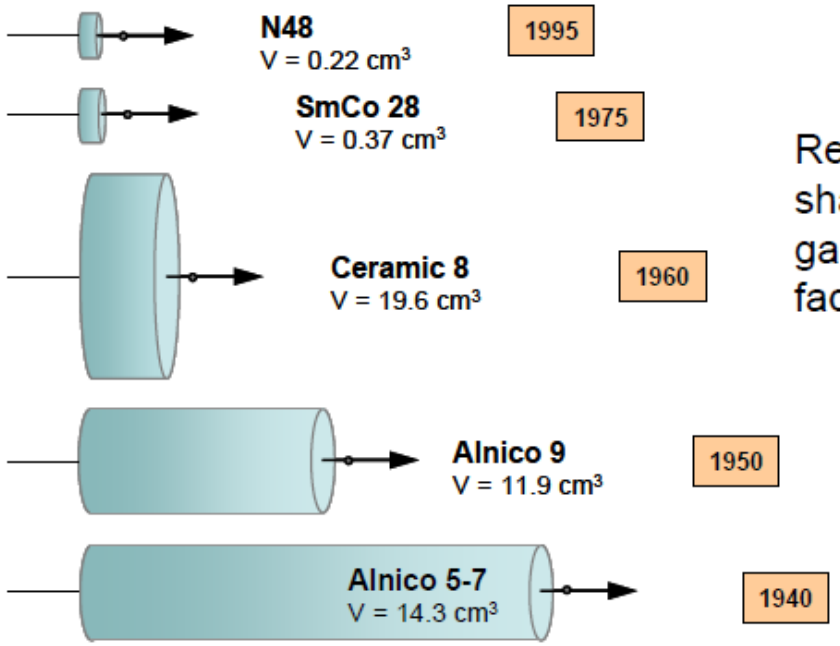

Rare earths : 17 elements

60 **Nd** Neodymium 144.24 — 26 **Fe** Iron 55.847 — 5 **B** Boron 10.811

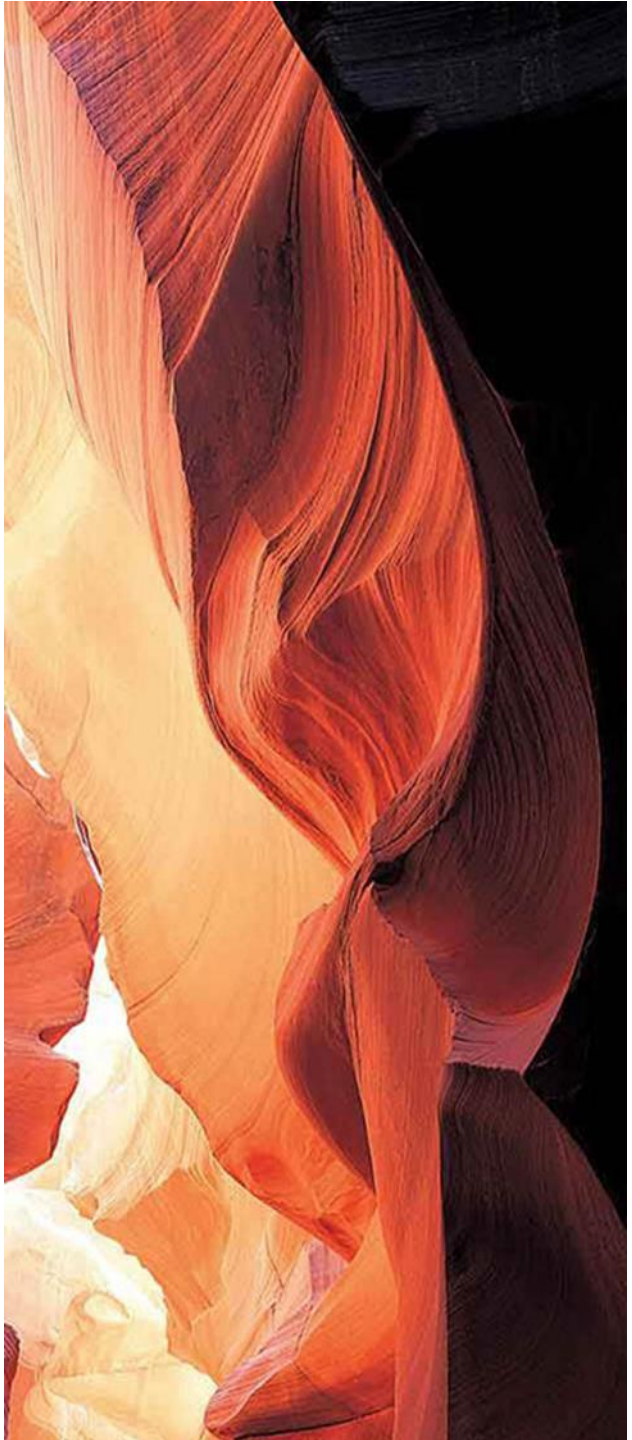



Nd-Fe-B ingot produced by arc-melting

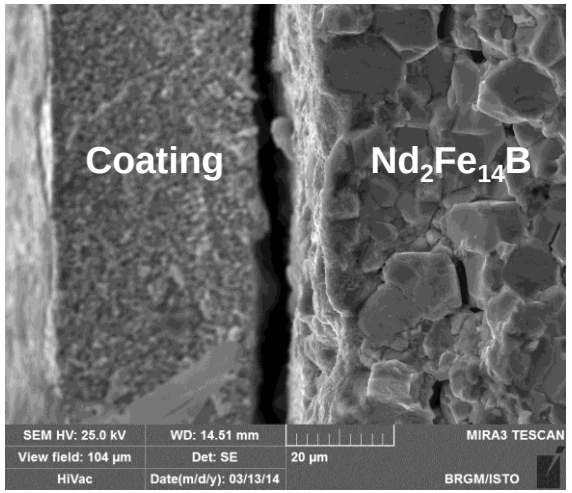
Nd-Fe-B magnets with nickel plating



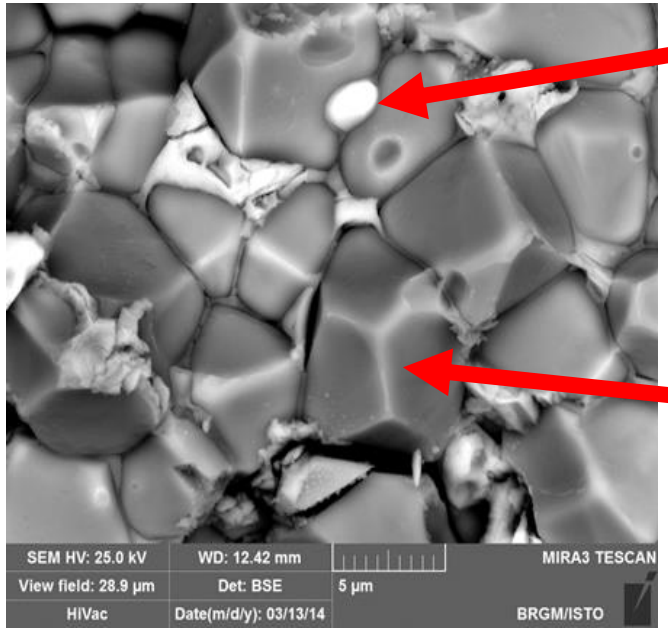

Relative magnet size and shape to generate 1000 gauss at 5 mm from the pole face of the magnet.

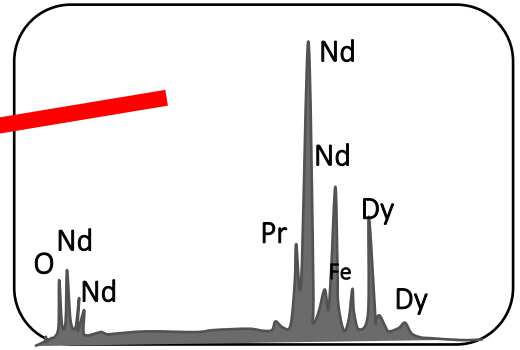


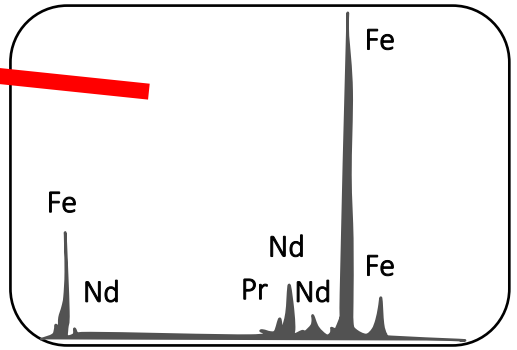
# CHARACTERISATION



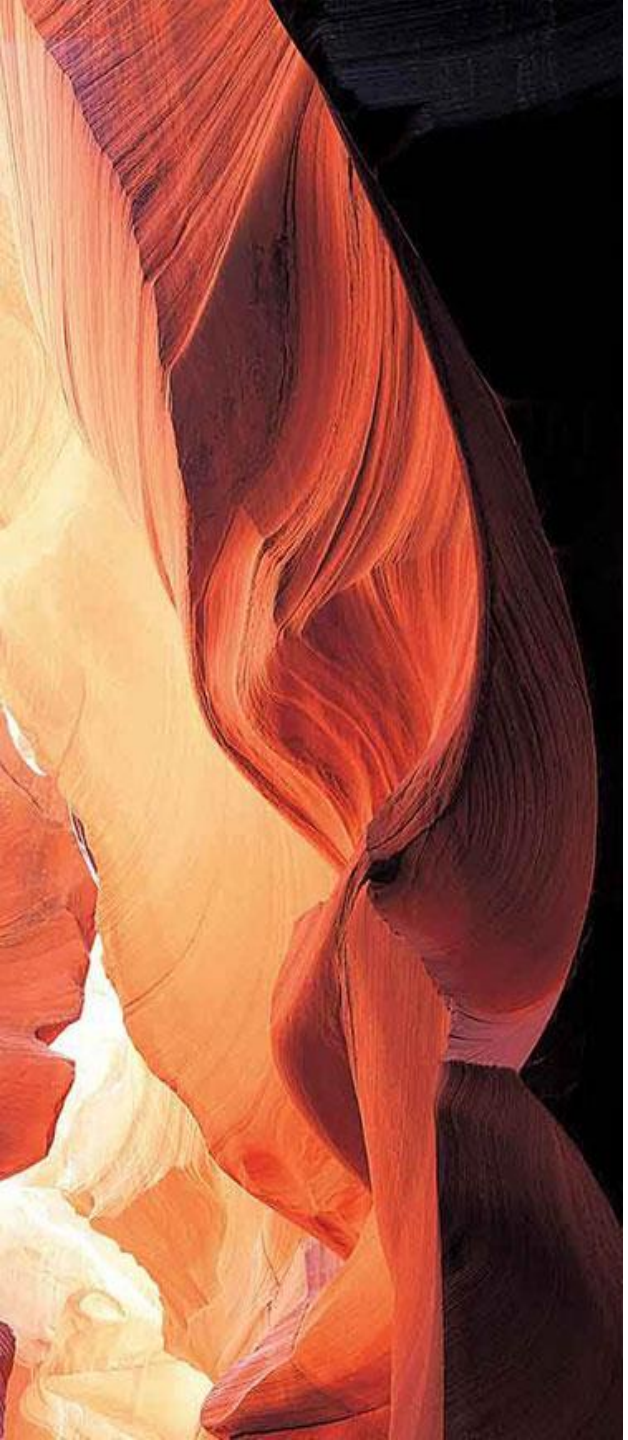

- $Nd_2Fe_{14}B$ magnet
- Coating (Ni or Ni/Cu) thickness 28µm

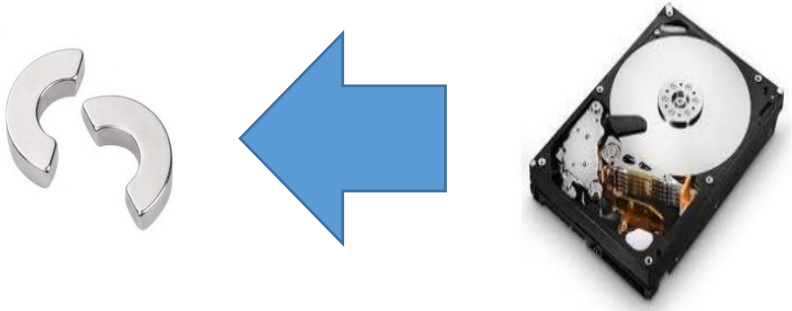



| Elem | Weight % | $Nd_2Fe_{14}B$ Theoritical |
|---|---|---|
| Fe | 69.6 | 72.0 |
| Nd | 28.1 | 27.0 |
| Dy | 2.3 | -- |
| B | -- | 1,0 |
| Total | 100.0 | **100.0** |



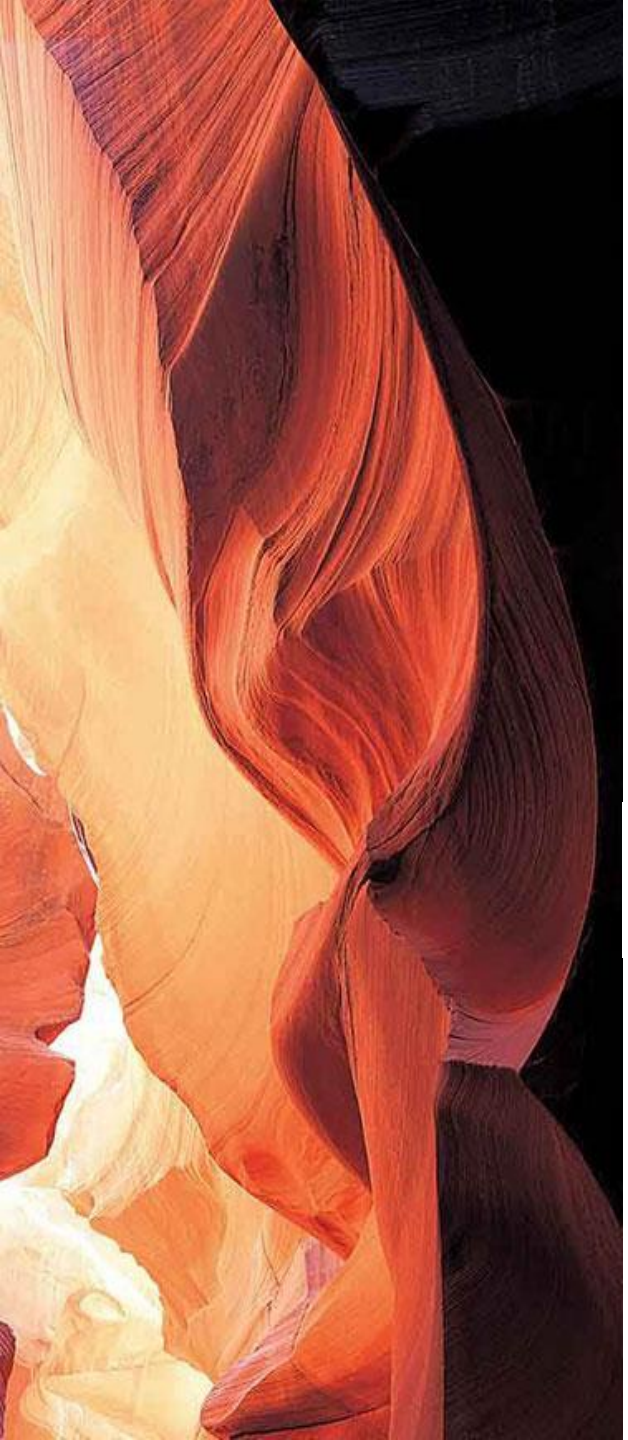


## LOCKS OF RECYCLING NdFeB MAGNETS

- ✓ Difficulties related to the dismantling of products due to their often compact and complex design
- ✓ Variation in chemical composition, even within the same IT application
- ✓ Strict requirement of the REEs market in terms of purity degree
- ✓ Difficulties related to the separation between REEs due to their similar physico-chemical properties
- ✓ Presence of other undesirable metals (coating Cu/Ni and Fe)

## OBJECTIVES

- To propose an outlet allowing REEs that can be recovered from end of life permanent magnets extracted under forms (fine powders, specific composition, mixtures) that cannot be reused in the short recycling route
- To optimize leaching procedure (nature of leaching media, residence time, concentration of the leaching agent, temperature, …);
- To improve kinetics of leaching and conversion efficiency



# MECHANICAL SORTING

**Patented results**

- ✓ 1ton HDD treated
- ✓ 350Kg HDD/day
- ✓ Recovery: 95% of magnets
- ✓ Purity: 88%
- ✓ Other fractions to be recovered (aluminum, circuit board, steel)


Dismantling and physical sorting of HDDs

## HDD Components obtained after sorting

**Al & PCB rich fraction + 40 mm**

**Iron scrap rich fraction -20 +16 mm and -40 +20 mm**

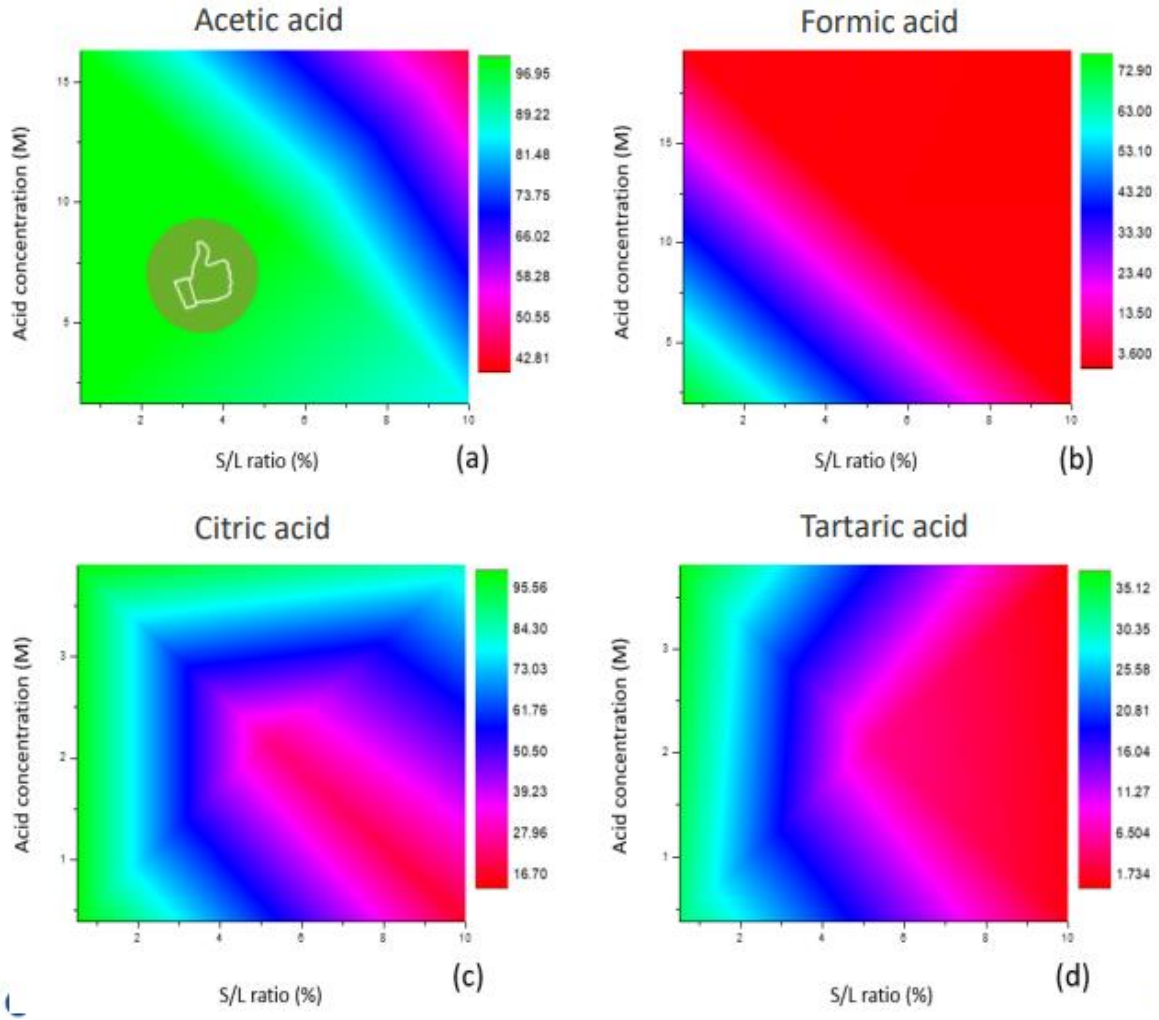
**Magnet rich fraction -16 +5 mm**

**Metal mixtures rich fraction - 5 mm**

# LEACHING OF NdFeB POWDER USING ORGANIC ACIDS

Patented results

Iso-response curves of the leaching yield (%) of Nd from NdFeB magnet powder in different organic acids at 60°C for 24 hours as a function of the S/L ratio (%) and the concentration of acids




Nd, Pr and Dy have the same leaching behavior in all tested acids

**Acetic acid:** Best candidate for leaching REEs under industrially favorable conditions; high S/L ratios and low acid concentrations

> 90% of REEs leached:
S/L ratio (%) [0.5 - 5]
Acetic acid concentration (M) [1.6-10]

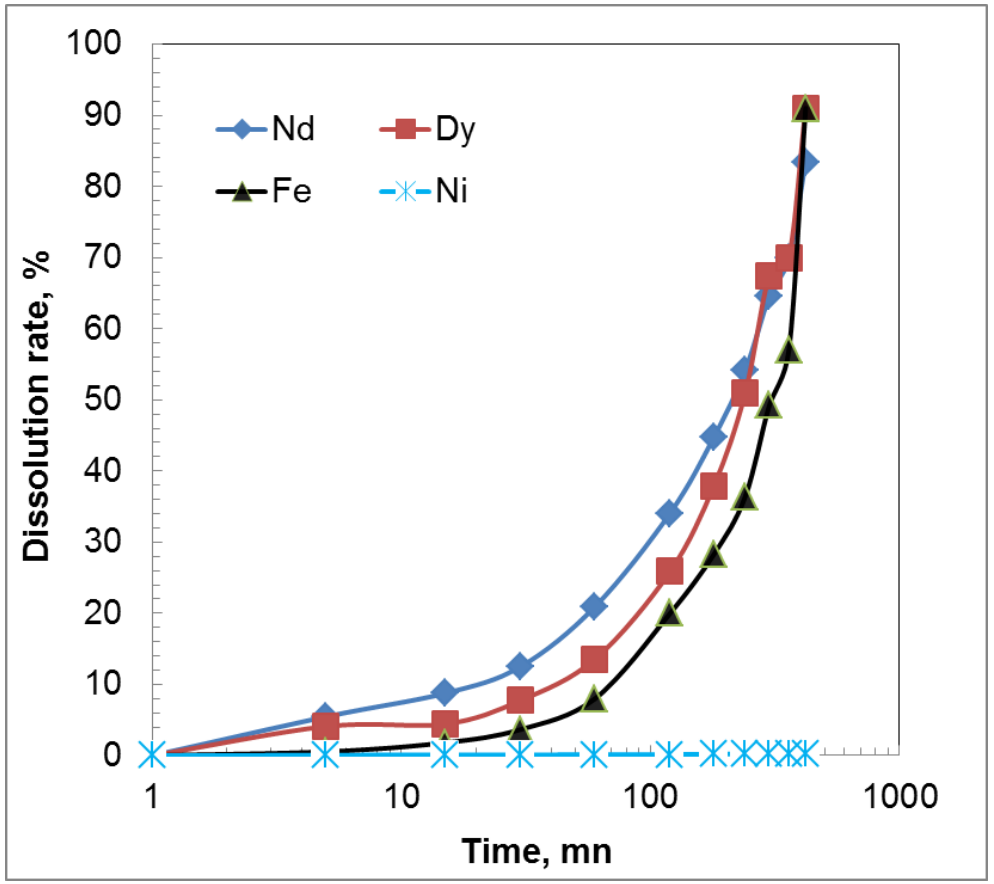
**Partial/ total co-leaching of Fe, Co and B**

**Formic acid:** Precipitation of REEs in formates
**Tartaric acid:** Precipitation of REEs in hydroxides

***Sahar Belfqeh thesis***

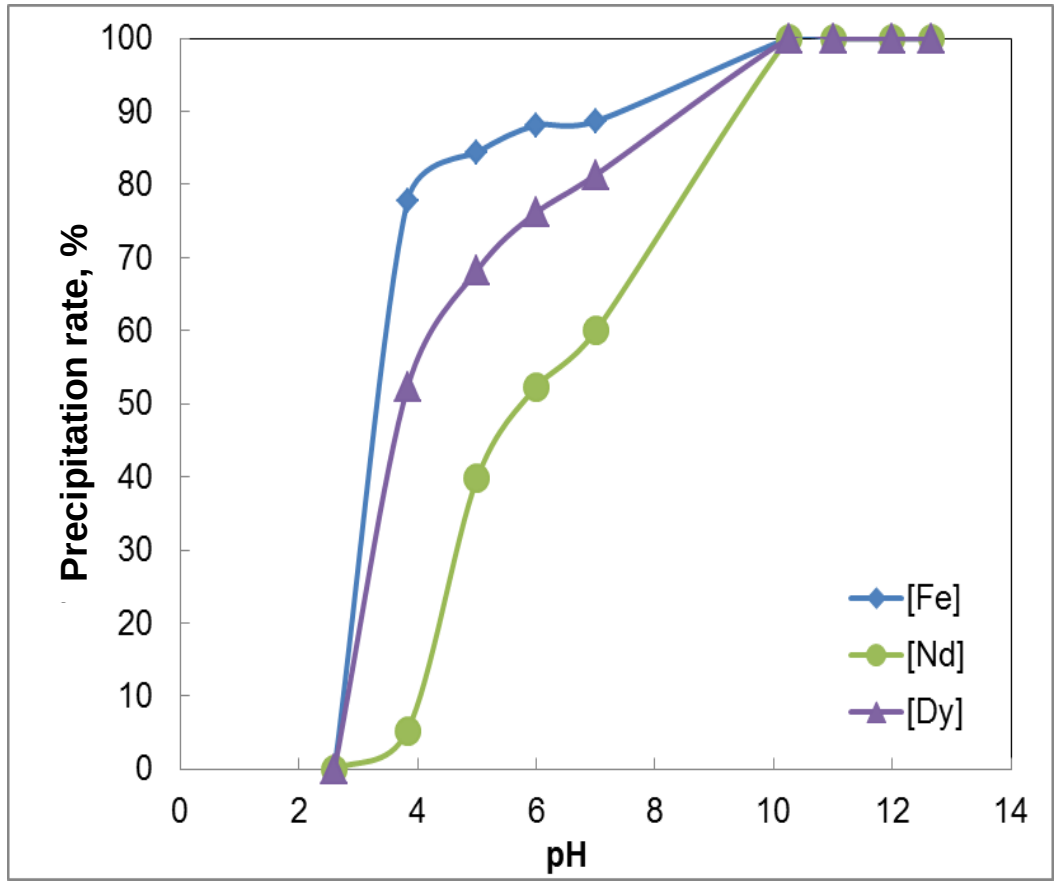
# ROUTE 2: EXTRACTION OF REES USING INNOVATIVE HYDROMETALLURGICAL TECHNIQUES

Dissolution kinetics of permanent magnets




Selective leaching of Fe, Nd, Dy

Precipitation of Fe, Nd, Dy using soda solution




Co-precipitation of Fe, Nd, Dy at pH 2-3

Look for alternative treatment to avoid iron leaching during REEs dissolution

# ROUTE 2: EXTRACTION OF REES USING INNOVATIVE HYDROMETALLURGICAL TECHNIQUES

**Patented results**

Oxidative roasting of NdFeB powder

$2NdO + ½ O_2 \rightarrow c\text{-}Nd_2O_3$

$Nd_2Fe_{14}B + 3/2\ O_2 \rightarrow 14\ \alpha\text{-}Fe + h\text{-}Nd_2O_3 + B$

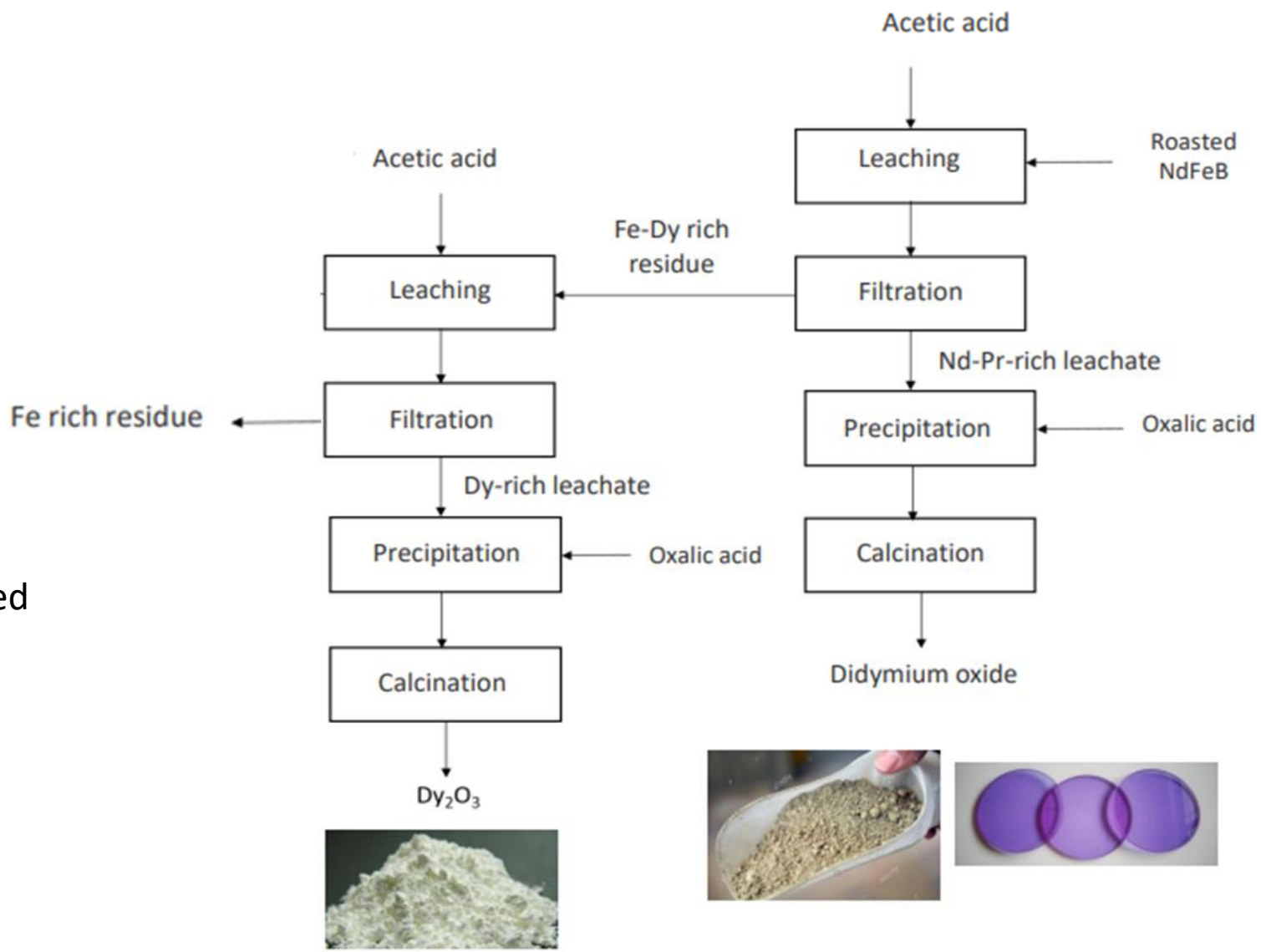
$2\alpha\text{-}Fe + 3/2\ O_2 \rightarrow \alpha\text{-}Fe_2O_3$

*From 500°C:*

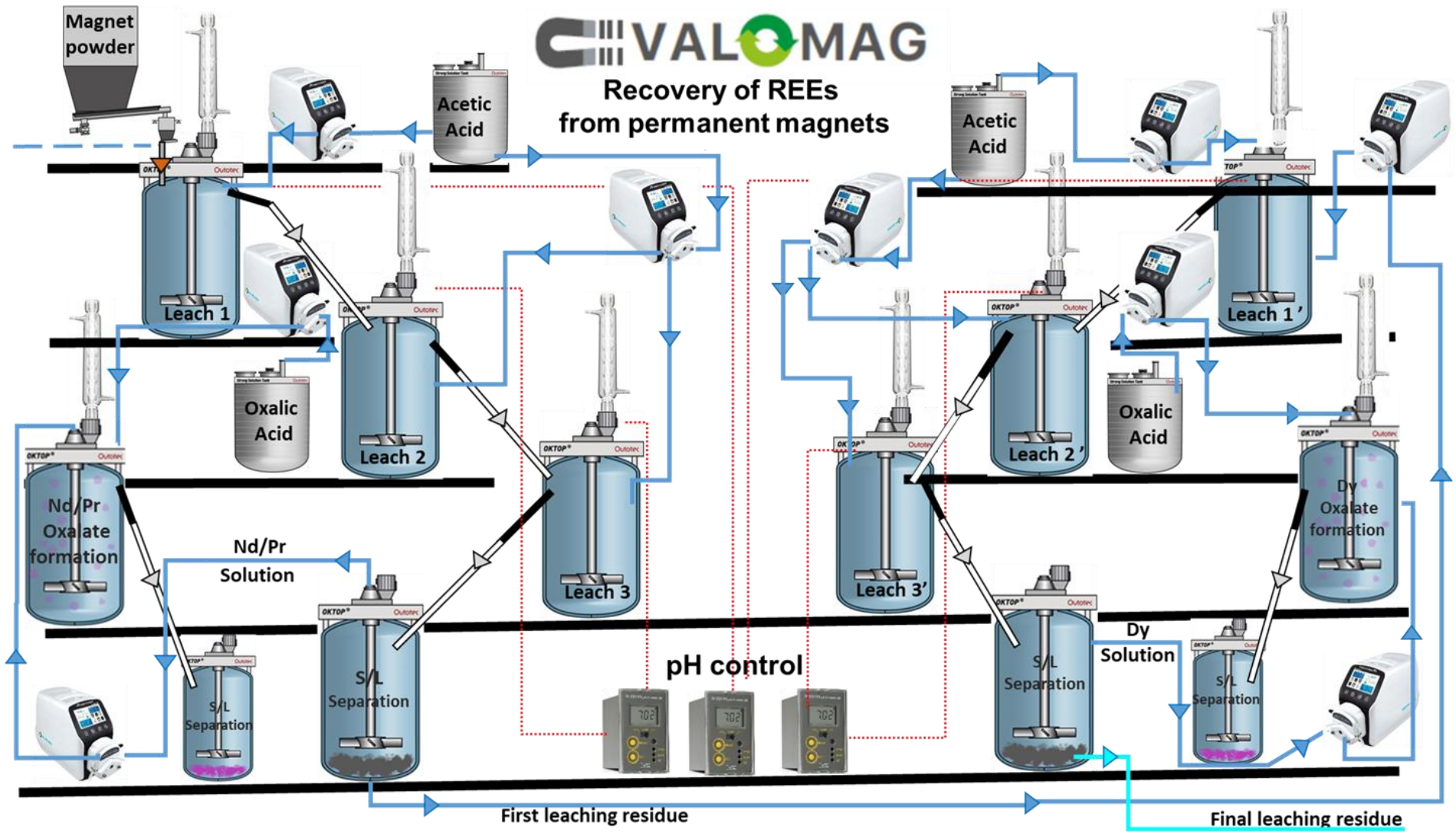
$\alpha\text{-}Fe_2O_3 + h\text{-}Nd_2O_3 \rightarrow 2NdFeO_3$

- Selective leaching of REE / Fe confirmed when starting from oxides:
- Recovery Nd, Pr, Dy > 95%
- Purity > 99%

- On going studies en NdFeB magnets



# PILOT TEST: EXTRACTION OF REES FROM MAGNETS BY HYDROMETALLURGICAL TREATMENT

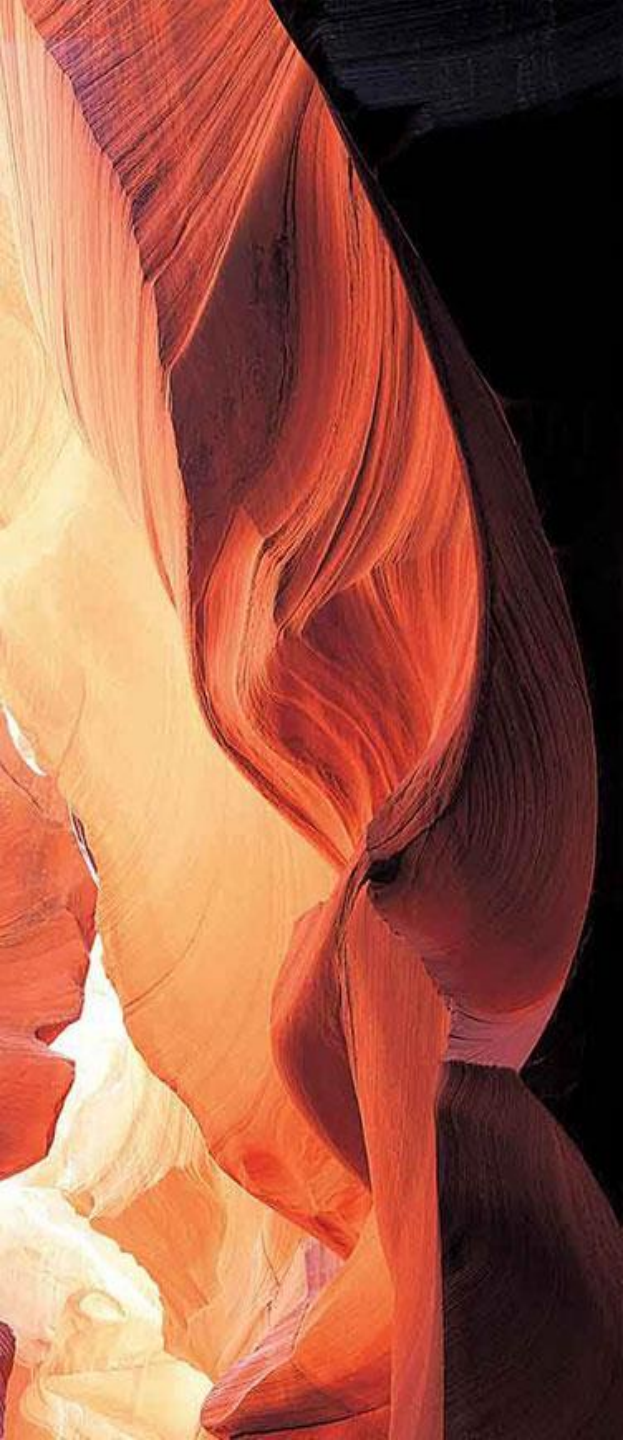



- Magnet powder
- 600g/hour
- T°C = 30°C
- Reactants
  - Acetic acid
  - Oxalic acid

*REEs precipitation using oxalic acid*

*Nd + Pr oxalate* *Dy oxalate*

Recovery by precipitation: Nd+Pr 80%, Dy 100% Residue: almost iron



# CONCLUSIONS

- The recycling of permanent magnets: an ecological solution to help reducing our dependence on REEs supply

- Identification of Nd-Fe-B magnets present in WEEE:
  - ✓ 98% recoverable in small electronic appliances feed
  - ✓ The rest is disseminated in other equipments such as fixed phones, mobiles, internet boxes (more difficult to recover)
- Two sampling campaigns were conducted on two different industrial sites to collect a representative sample of hard drives and loudspeakers
- Results of characterization, Wt% of magnet in electronic components:

  4 - 6% in the loudspeakers, 2.5 - 2.8% in fixed computer hard drives, 2 - 3% in laptops hard drives, and between 0.8 and 2% in small electric motors

# CONCLUSIONS

- Scanning electron microscopy (SEM) was used to:
  - ✓ Identify Nd-Fe-B magnets
  - ✓ Observe Nd-Fe matrice in a tetrahedral form and an inter-granular space rich in REEs (Nd, Dy, Pr).
  - ✓ Characterize the coating layer of Ni, Zn or Cu / Ni alloy (20-30µm thick).
- XRD reveals:
  - ✓ Two types of magnets: Nd-Fe-B and ferrites
- TGA shows:
  - ✓ Working T°C range of Nd-Fe-B type magnet goes from ambient to 150°C
  - ✓ Curie point is close to 300°C for Nd-Fe-B type magnet, 500°C for ferrite magnets.

- Mechanical sorting process developed and patented by BRGM allows recovering more than 95% of magnets from HDD

- Organic acid (acetic) may selectively REEs contained in magnets, and oxalic acid was used to precipitate REEs.

- Products obtained from the process developed and patented are: Didymium and Dysprosium oxides


# Thank you for your attention !


Virtual visit of BRGM Piloting Facility :
https://www.brgm.fr/fr/laboratoire-plateforme-technologique/plat-inn-economie-circulaire-entre-laboratoire-echelle