Development of an eco compatible process for the recovery of rare earths from permanent magnets

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Context

Rare earth permanent magnets:

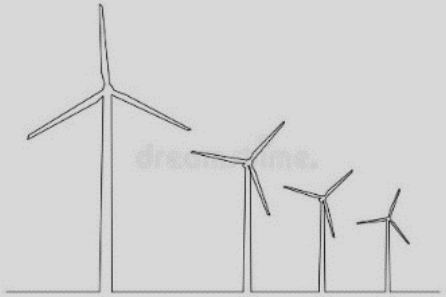
- One of the most important applications of REEs.

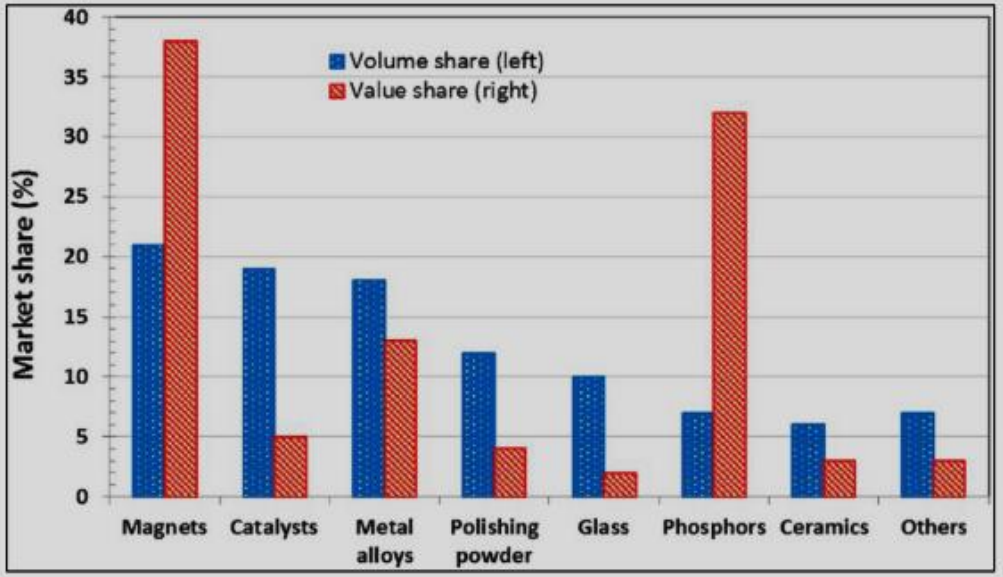
NdFeB magnets:

- Has the highest energy density.
- Used in several high-tech products, wind power turbines and electric vehicles.
- Contains: Nd, Pr, Dy, Tb, Gd.

Recycling potential of NdFeB magnets:

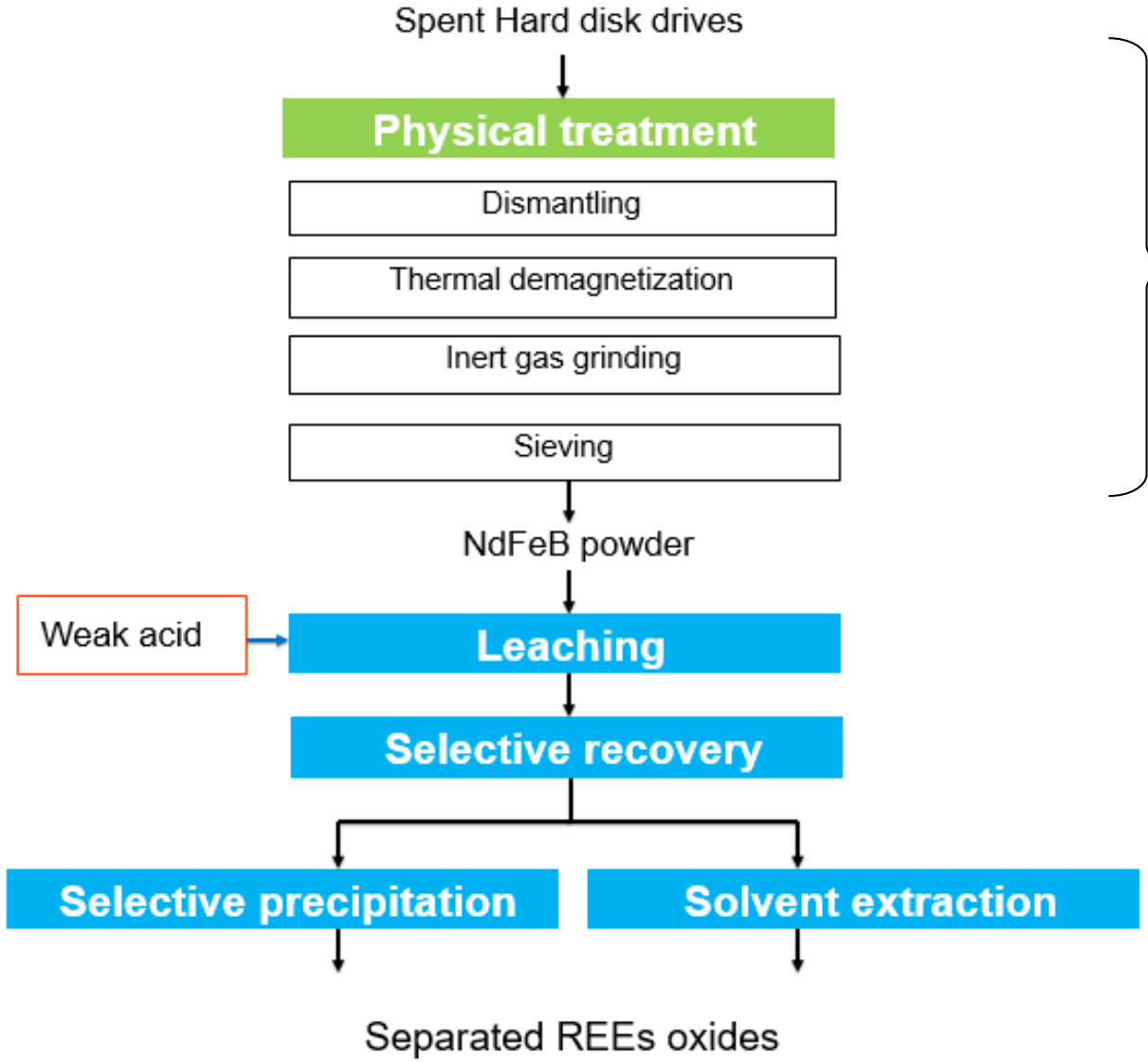
- Contains metals identified as critical by the European Commission (2011): Nd, Dy, Co, Tb.
- Importance of current stocks of spent NdFeB magnets.
- Continuous increase in stocks due to growth in the wind power and electric transportation sectors.





Market share of REEs applications.

The process



ANR EXTRADE project

Patented results FR 3 052 171 - A1

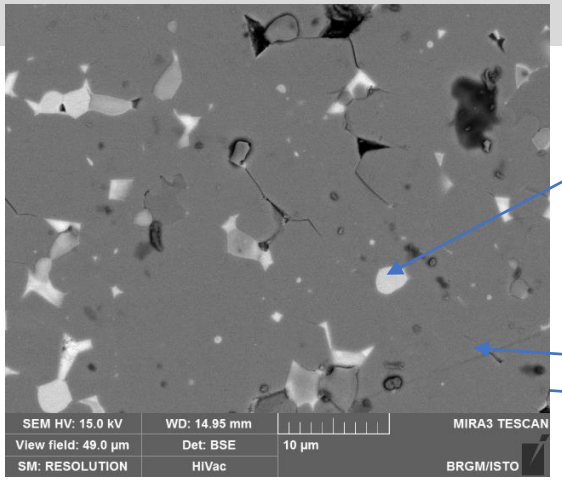
PhD's scope

Géosciences pour une Terre durable brgm

ICSM

Characterization of NdFeB Magnet

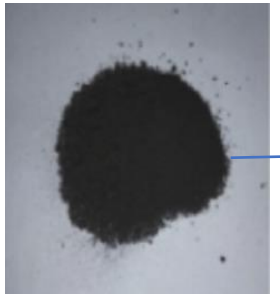
Sample study: HDD's NdFeB magnet.

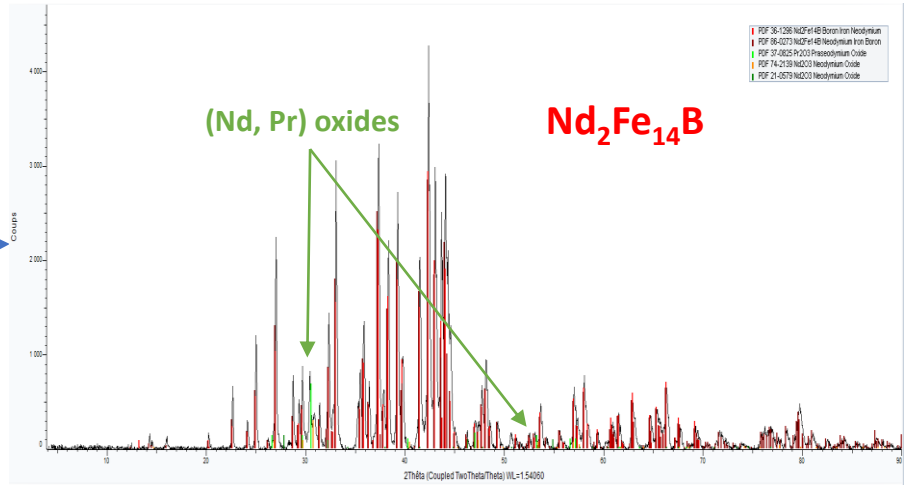


$Nd_2Fe_{14}B$

REE-rich intergranular phase

Ball milled in inert gas to avoid pyrophoric character and minimize oxidation.





Element	B	Co	Dy	Fe	Nd	Ni	Pr
% wt	0.90	1.51	1.16	62.63	22.84	0.59	3.29

Elemental composition of grinded NdFeB magnet.

Leaching

In a hydrometallurgical process, leaching is the process of dissolving certain metals from the ore or waste.

Mineral acid, such as: H_2SO_4, HCl, HNO_3

$$TR_{(s)} + 6H^+_{(aq)} \leftrightarrows TR^{3+}_{(aq)} + 6H_{2(g)}$$

$$TR_2O_{3(s)} + 6H^+_{(aq)} \leftrightarrows 2TR^{3+}_{(aq)} + 3H_2O_{(g)}$$

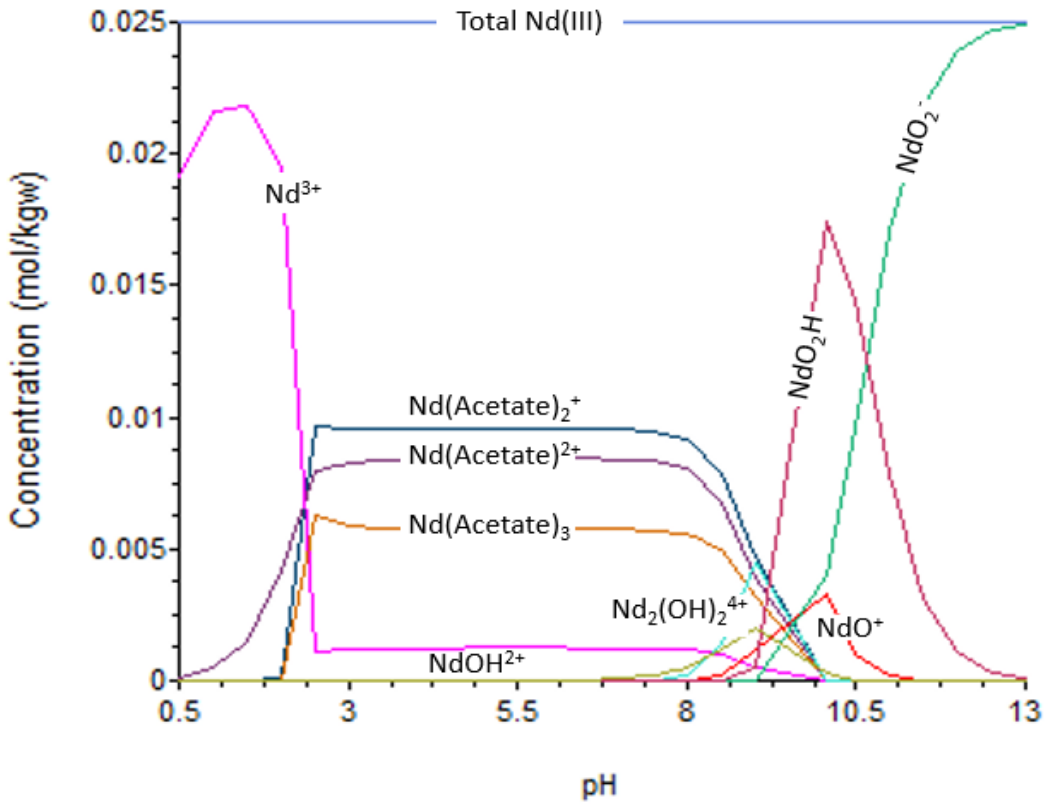
$$TR(OH)_{3(s)} + 3H^+_{(aq)} \leftrightarrows TR^{3+}_{(aq)} + 3H_2O_{(l)}$$

Eco-friendly alternatives: weak acids

Acetic acid : $Nd^{3+} + jCH_3COO^- \leftrightarrows Nd\,(CH_3COO)_j^{(3-j)+}$, j = 1, 2, 3

Citric acid : $nNd^{3+} + jH^+ + kCit^{3-} \leftrightarrows Nd_kH_jCit_k^{(3n+j-3k)}$

Presence of NdCit, NdHCit, $NdHCit_2$, $NdCit_2$ in a pH range of [2-5].

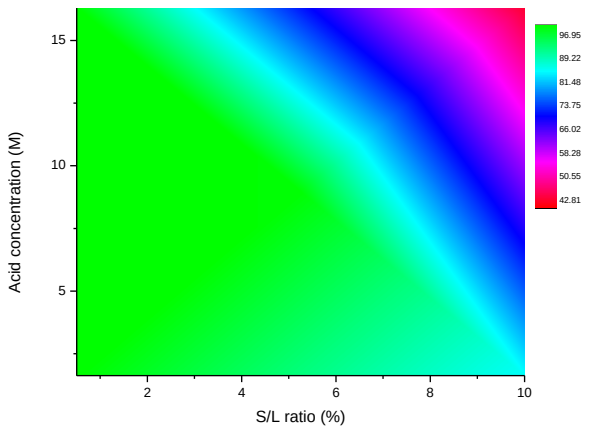


Aqueous speciation of Nd(III) as a function of pH in diluted acetic acid using pHreeqC (Database: LLNL).

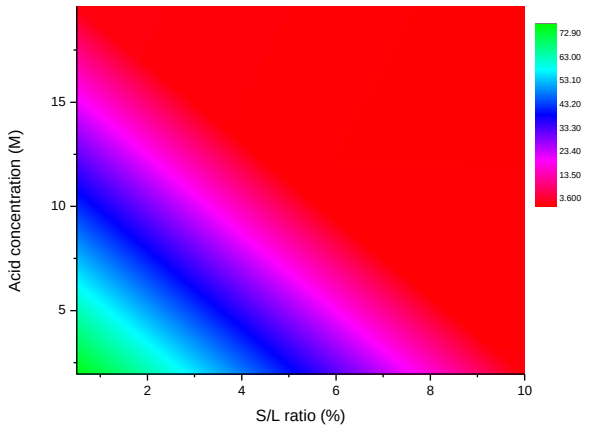
Easier to handle, form less toxic gases, easier biodegradability, possible production from agro-industrial waste…

Leaching

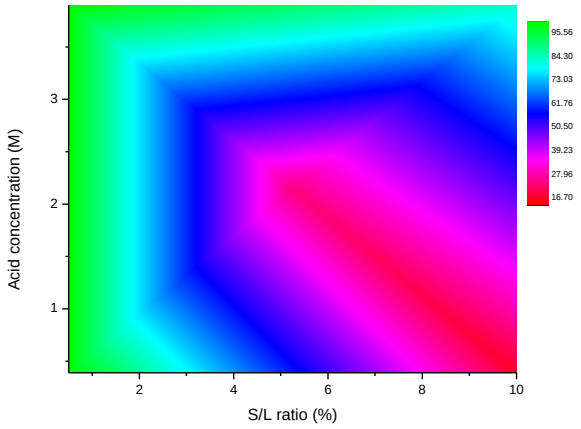
Acetic acid



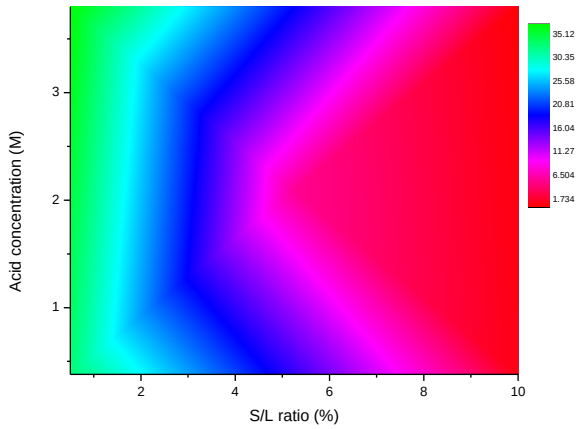
Formic acid



Citric acid



Tartaric acid



%Nd = f(C(M)**,** S/L(%)**)**

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

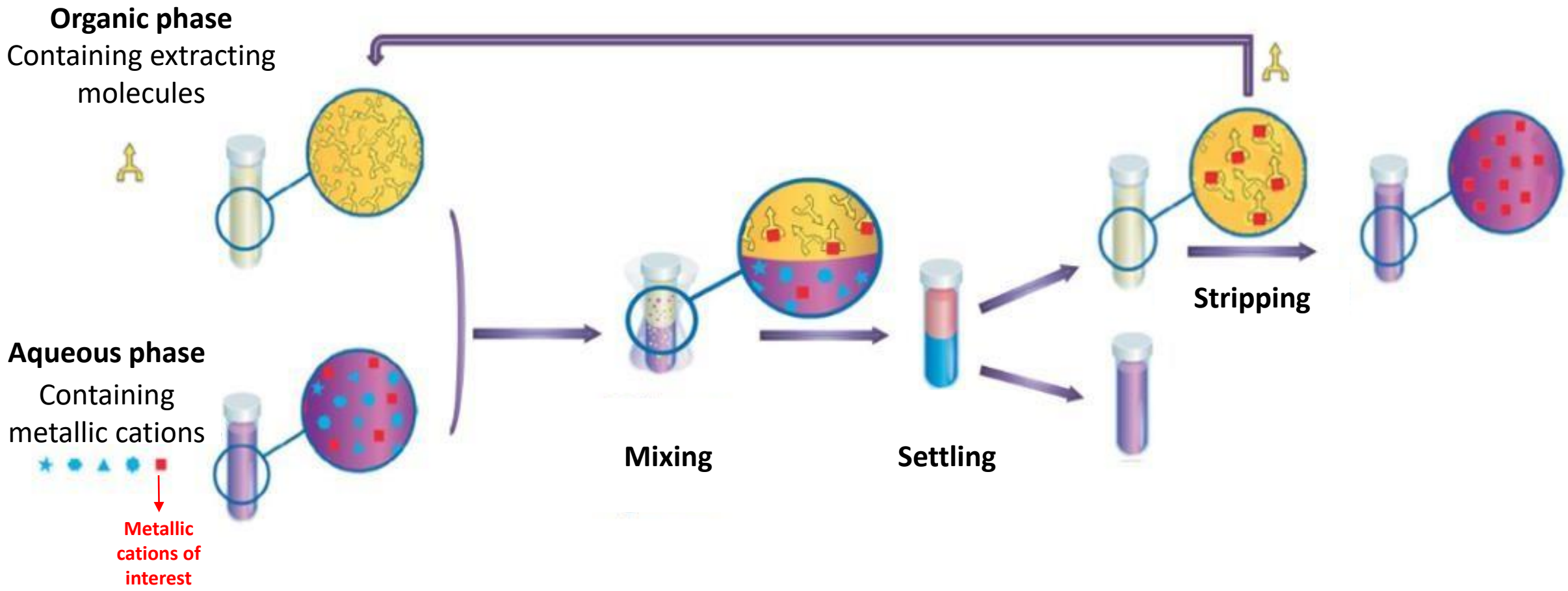
Acetic acid: Best candidate for leaching REEs under industrially favorable conditions; high S/L ratios and low acid concentrations

> 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 od REEs in formats
Tartaric acid: Precipitation of REEs in hydroxides

Solvent extraction



Summary

Characterization

- Microstructure: Matrix phase ($Nd_2Fe_{14}B$), intergranular phase (REEs oxides)
- Chemical composition: 63% Fe, 23% Nd, 1% Dy, 3% Pr, 1% B

Leaching

- Acetic acid: Efficient weak acid to leach REEs in favorable conditions.
- > 90% of REEs leached: S/L ratio (%) [0,5 - 5], acetic acid concentration (M) [1,6-10]
- Non-selective leaching

Future work

- Selective stripping, precipitation

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Thank you for your attention

Questions?