Recycling rare-earth elements from motor magnets for electric vehicles

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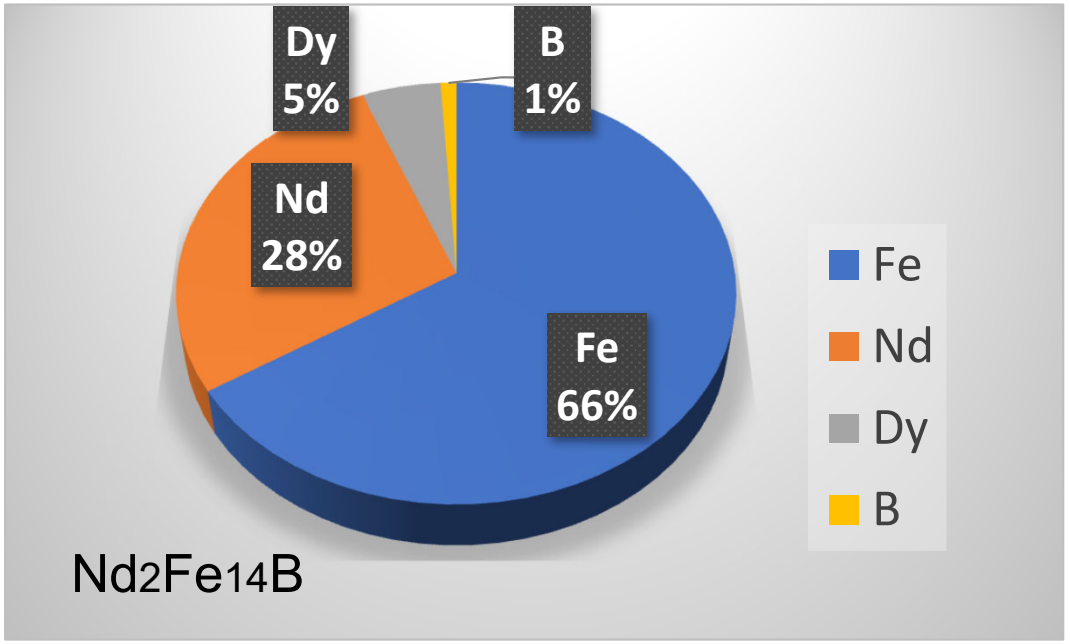
Advantages of this recycling technology

- Disassembly work can be reduced
- No need for thermal demagnetization
- Mass processing is possible
- Process time can be shortened
- Has 98% of a high recovery rate
- The recovered rare earths can be recycled horizontally.
- No special equipment required

This process has the potential to be widespread

Neodymium magnet

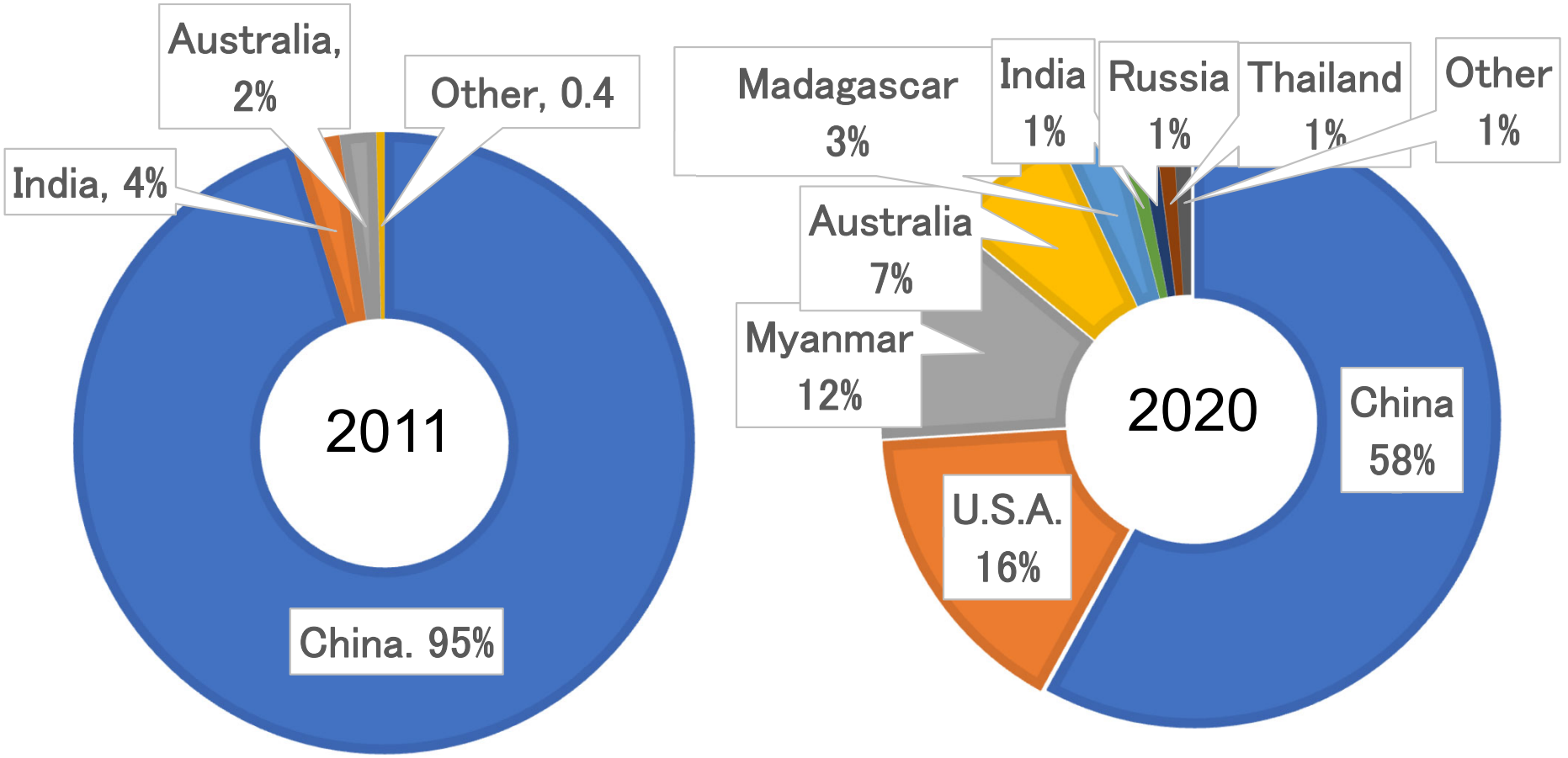
Strongest of the permanent magnets.
The magnet was developed in Japan by Dr. Masato Sagawa in 1984.



The composition of the magnet is 66 mass% of iron, about 28 mass% of neodymium and about 3 to 5 mass% of dysprosium and 1mass% of boron.
For EV, from 6 to 8 mass% of dysprosium is used.
This magnet has about 10 times strong of ferrite magnets.
The price is about 10 times of ferrite magnets.

Ref.: JOGMEC Rare metal series 2010 (in Japanese) , Takehisa Minowa

Rare earth elements, REE producing countries

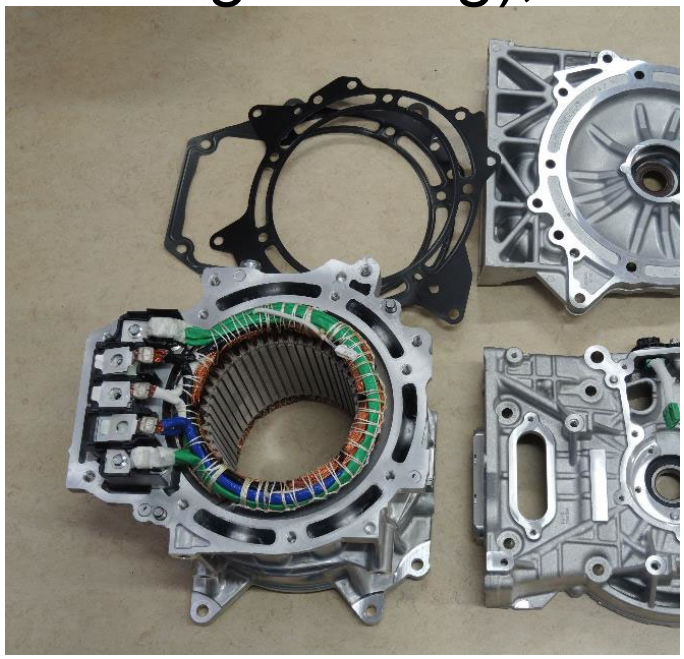


In 2011, 95% of production was in China.
In 2020, the ratio in China has dropped to 58%, but it is still high.

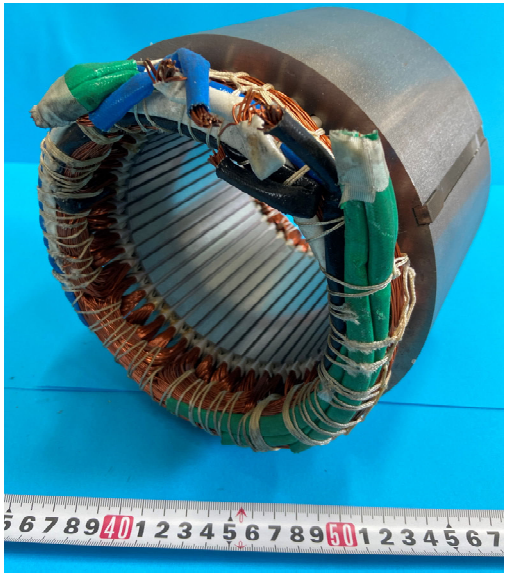
Ref.: JOGMEC Rare metal series 2010 (in Japanese) , Takehisa Minowa
JOGMEC, Mineral Resources Material Flow 2020 6. Rare Earth (REE) (in Japanese)

Component of EV driving motor

Housing（15.8kg), Stator



Rotor (15.4kg)



Stator (19.2kg)

Neodymium magnets in rotor

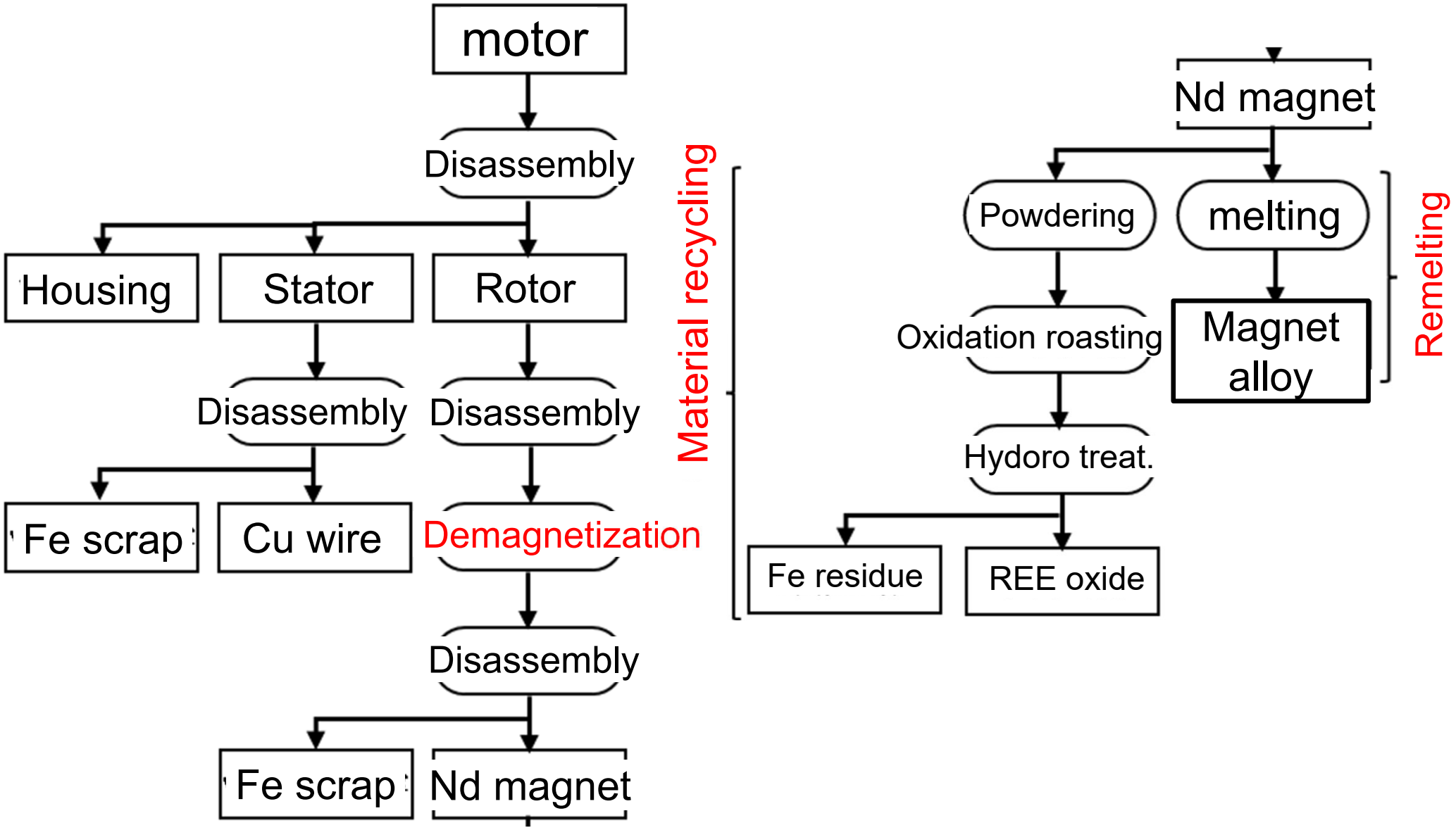
Magnet: 1.75kg

Composition of Neodymium magnets in rotor
（mass%）

Nd	Pr	Dy	Tb	B	Fe
21.0	5.0	2.5	0.4	Bal.	

Amount of REE：530g / vehicle

Current recycling process of neodymium magnets for EV motors



＜100 mass ppm of C and ＜300 mass ppm O are difficult in the remelting, horizontal recycling can not be achieved.

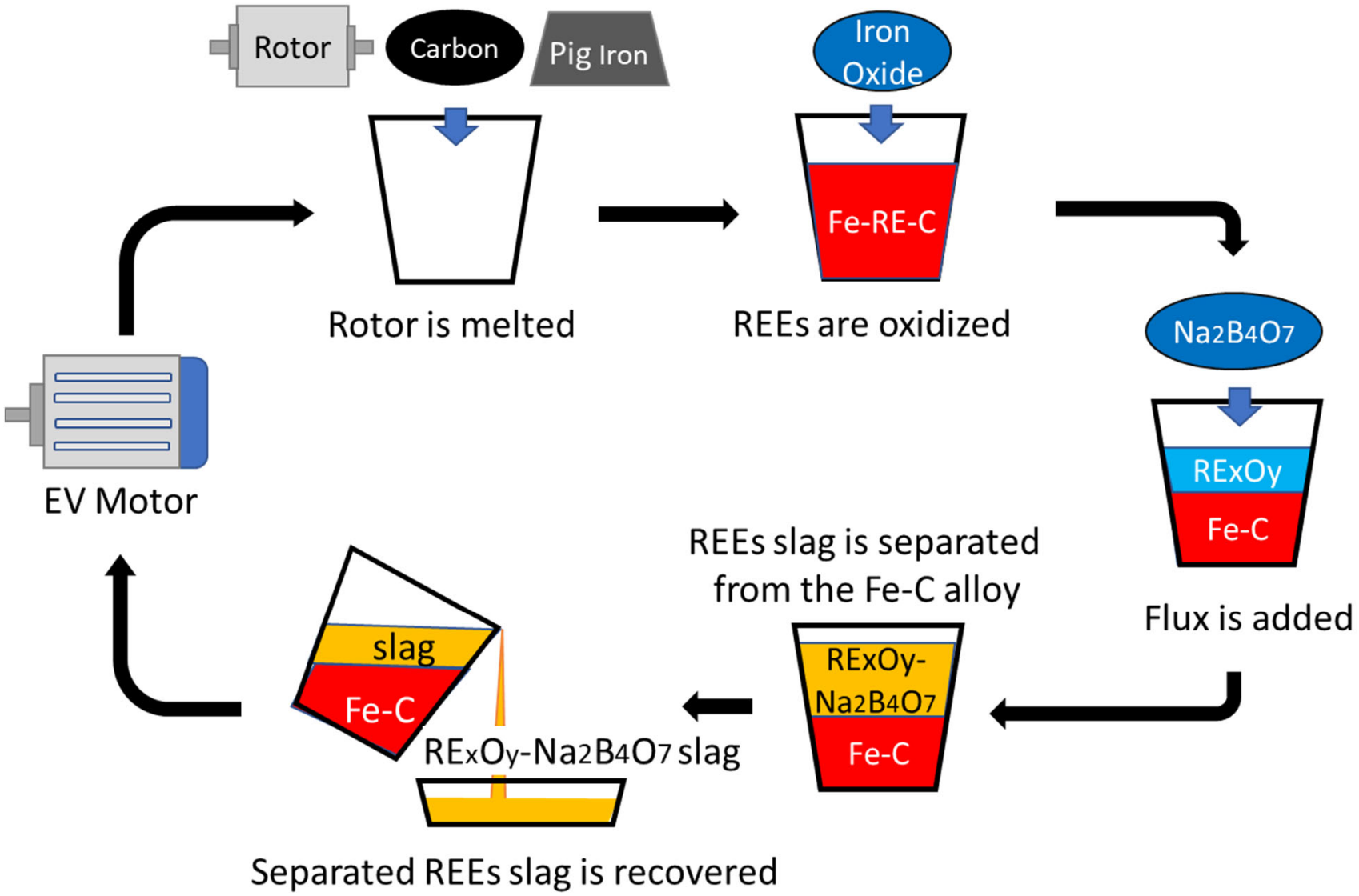
Difficulty in disassembling the motor

- The motor is strongly manufactured.
- The rotor has a strong magnetic force and requires thermal demagnetization to disassemble the motor and recover the neodymium magnet.

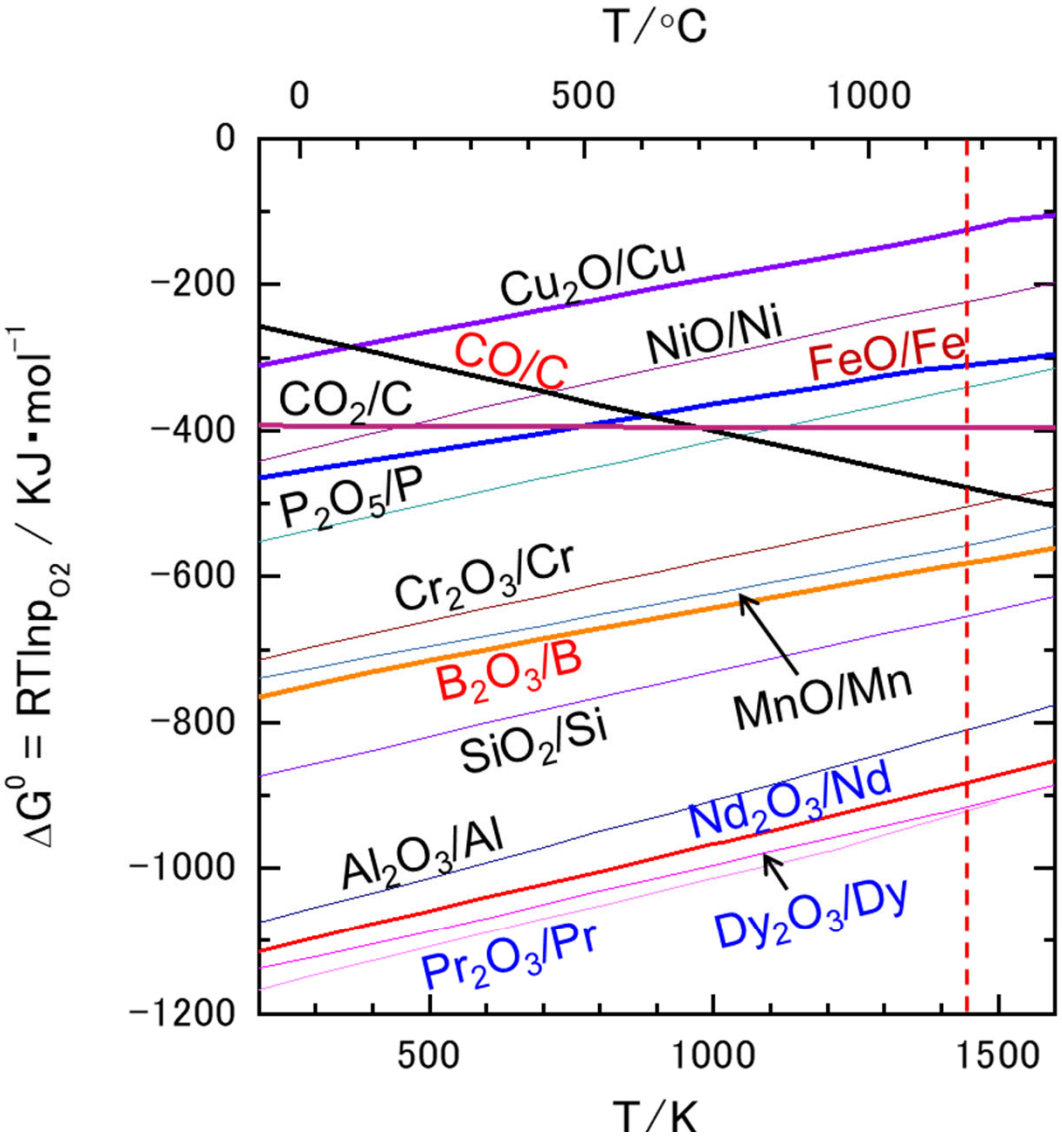
Driving rotor：15.4kg

Nissan – Waseda recycling process with Non thermal demagnetization and Non disassembly

New recycling process



Priority oxidation of REE by Fe2O3
Standard Gibbs free energy of oxides formation - temperature diagram



$$\frac{2m}{n}M + O_2 = \frac{2}{n}M_mO_n$$

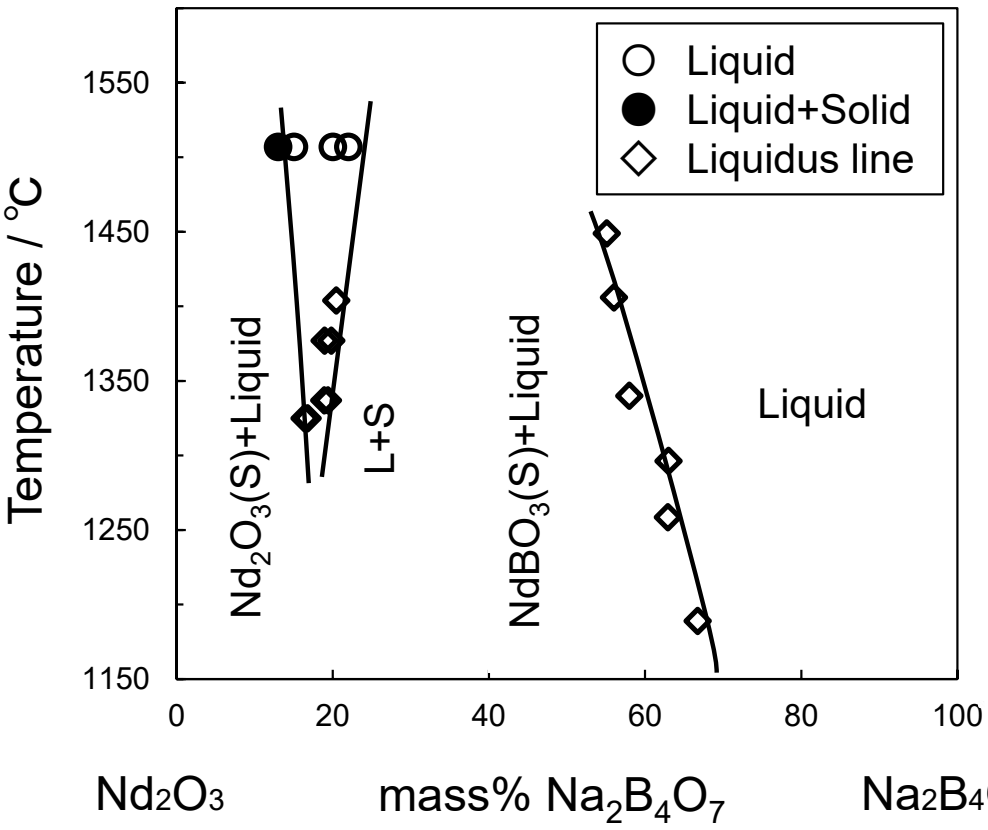
Weak affinity with oxygen

Strong affinity with oxygen

: Easy to oxidize

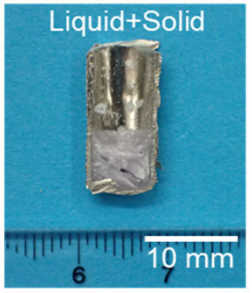
FactSage calculation by SGPS data base

Melting of RE_xO_y with $Na_2B_4O_7$ flux

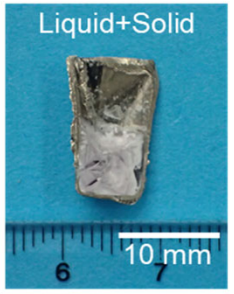


Phase diagram of the Nd2O3-Na2B4O7 pseudo binary system

Cross-sectional view of the sample after the experiment at 1350 ° C

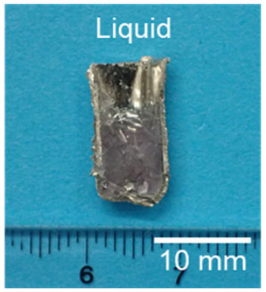


37.4 mass% $Na_2B_4O_7$

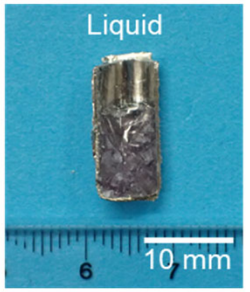


50 mass% $Na_2B_4O_7$

57 mass% $Na_2B_4O_7$



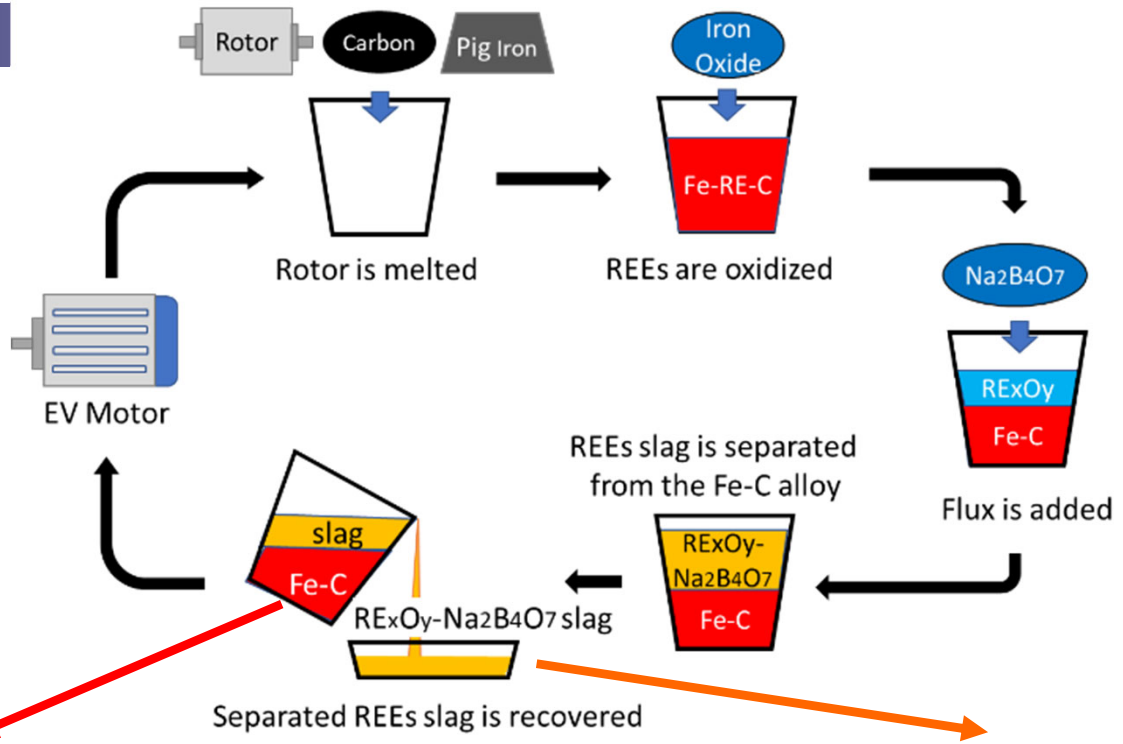
60 mass% $Na_2B_4O_7$



63.6 mass% $Na_2B_4O_7$

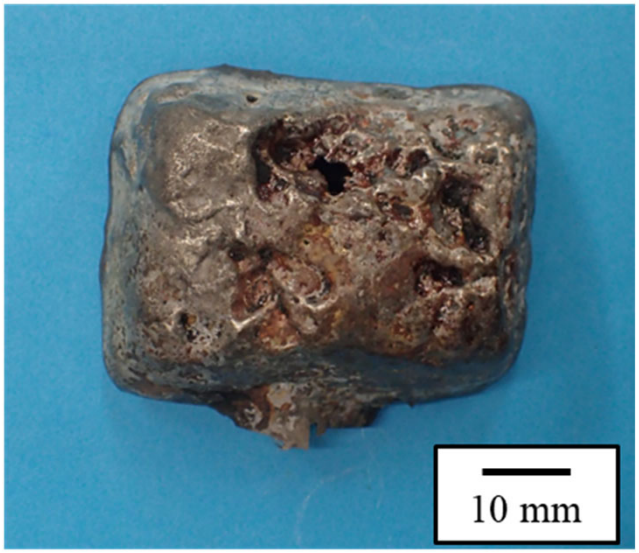
<u>Two regions of homogenous liquid</u>

- 15~22 mass% $Na_2B_4O_7$
- ＞55 mass% $Na_2B_4O_7$



Fe-C alloy

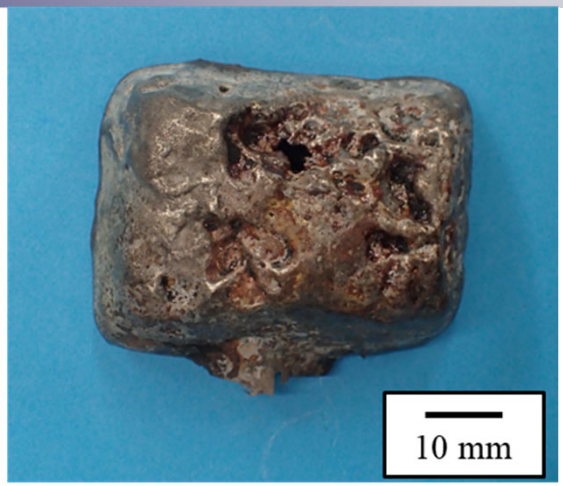
RexOy-Na2B4O7 slag



REE concentration: <0.09mass%

Recovery of REE to slag: 98%

Fe-C alloy



Substance	Nd	Pr	Dy	Tb	B	C	Fe＋Si
mass%	0.057	0.020	0.012	N.D.	0.18	6.9	Bal.

RE_xO_y-$Na_2B_4O_7$ slag

Substance	Nd_2O_3	Pr_2O_3	Dy_2O_3	Tb_2O_3	Na_2O	B_2O_3	FeO	Al_2O_3	SiO_2	Total RE_xO_y
mass%	31.5	7.0	3.8	0.59	4.7	9.6	3.9	18.2	12.5	42.9

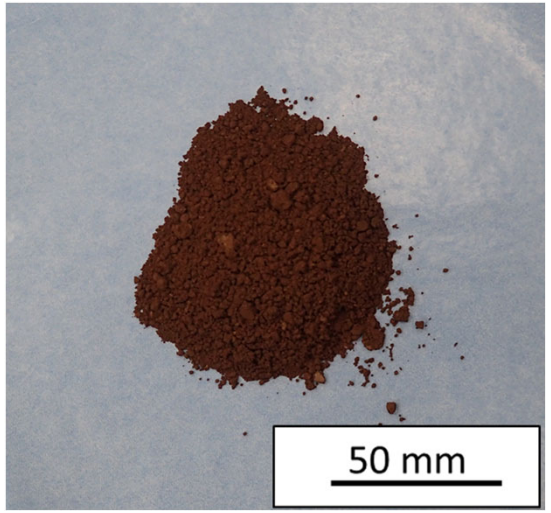
Hydro treatment

Acid leaching → oxalic acid precipitation method → calcination

$RExOy$-$Na_2B_4O_7$ slag

Hydro treatment

Recovered REE oxide

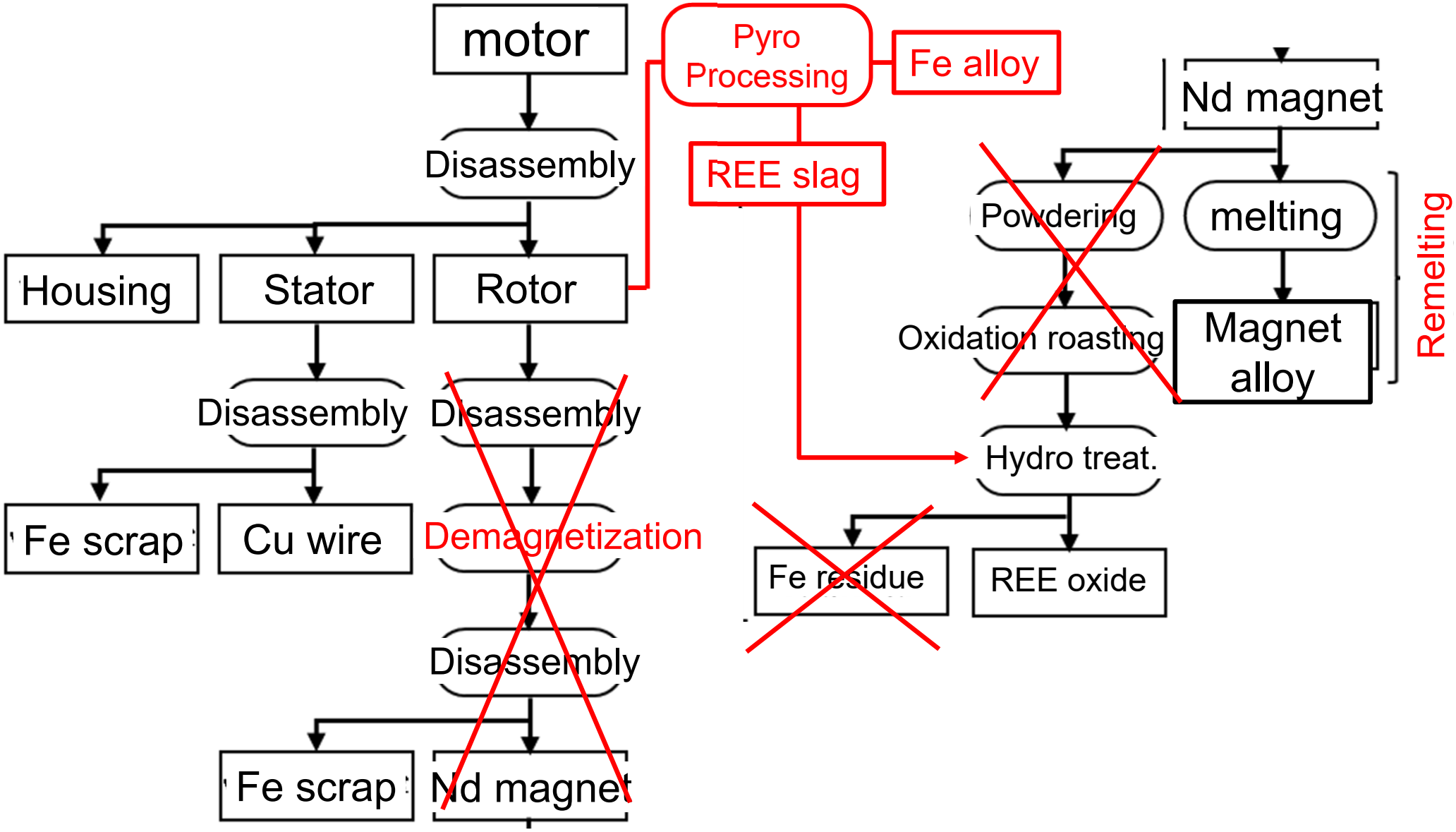


Concentration of recovered complex REE oxide（mass%）

Nd_2O_3	Pr_2O_3	Dy_2O_3	Tb_2O_3	Na_2O	B_2O_3	FeO	Al_2O_3	SiO_2
78.5	16.8	9.4	1.3	0.14	N.D.	0.071	0.46	0.09

The total concentration of Nd, Pr, Dy and Tb oxides is 99.3 mass%.

New recycling process of neodymium magnets for EV motors



New process does not require disassembly or demagnetization.
Large amount treatment of scraps is possible and simple.

Summary

- As represented by the EU Battery Regulations, we believe that the automobile industry will also be required to recycling and the use of secondary materials for products in the future.
- REEs of EV motor is not recycled. With the spread of EVs, a large amount and simple process for REE recycling from motors is required.

Thank you for your kind attention!