Neodymium

Chemistry of the Elements

04.10.2023

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Aalto-yliopisto
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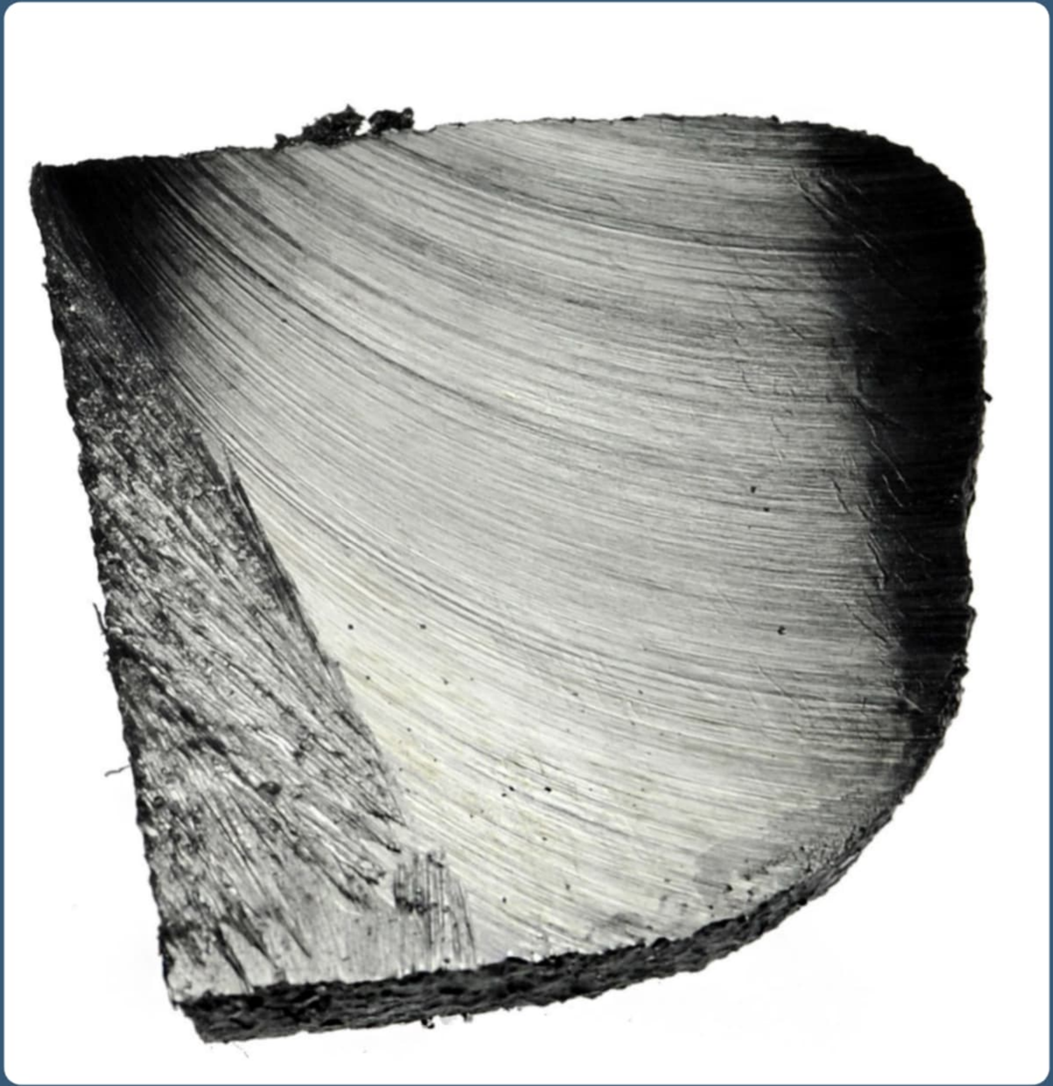


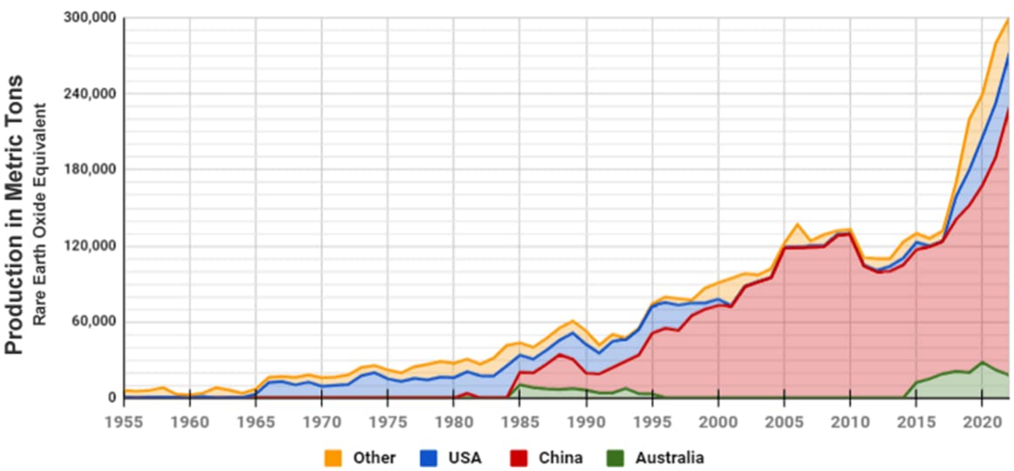
https://www.luciteria.com/elements-for-sale/buy-neodymium-metal

Discovery

- Nd is a rare earth metal discovered in 1885 by Baron Carl Auer von Welsbach.
- He separated a mineral called didymium into two new distinct elemental salts, one of which contained neodymium.
- Greek words, neos "new," and didymos "twin.“
- The principal ores : bastnasite and monazite.
- Pure neodymium metal was not isolated until 1925.

Albert Stwertka, a guide to the elements, New York 1996.

World Production



History of rare earth element production

- Historically, a mine in California produced most of the world's rare earth minerals
- Since early 90s, China has become the world's primary source
- Today China supplies 70% of the world's REEs

Hobart M. King, REE - Rare Earth Elements and their Uses, https://geology.com/articles/rare-earth-elements/

Abundance

- 28th most abundant element in the earth crust.
- Very difficult to mine because it is unusual to find them in concentrations high enough for extraction.
- 2nd most abundant element in the REEs.
- In terms of reserves, China has the most, followed by Vietnam, Brazil, and Russia.

World Mine Production and Reserves (2022 Estimates)

Country	Production (Metric Tons)	Reserves (Metric Tons)
United States	43,000	2,300,000
Australia	18,000	4,200,000
Brazil	80	21,000,000
Burma	12,000	not available
Canada	--	830,000
China	210,000	44,000,000
Greenland	--	1,500,000
India	2,900	6,900,000
Madagascar	960	not available
Russia	2,600	21,000,000
South Africa	--	790,000
Tanzania	--	890,000
Thailand	7,100	not available
Vietnam	4,300	22,000,000
Other Countries	80	280,000
World total (rounded)	300,000	130,000,000

Element	Symbol	Atomic number	Crustal abundance
Light REEs			
Lanthanum	La	57	39
Cerium	Ce	58	66.5
Praseodymium	Pr	59	9.2
Neodymium	Nd	60	41.5
Samarium	Sm	62	7.05
Europium	Eu	63	2.0
Gadolinium	Gd	64	6.2
Heavy REEs			
Terbium	Tb	65	1.2
Dysprosium	Dy	66	5.2
Holmium	Ho	67	1.3
Erbium	Er	68	3.5
Thulium	Tm	69	0.52
Ytterbium	Yb	70	3.2
Lutetium	Lu	71	0.8
Yttrium	Y	39	33

Hobart M. King, REE - Rare Earth Elements and their Uses, https://geology.com/articles/rare-earth-elements/

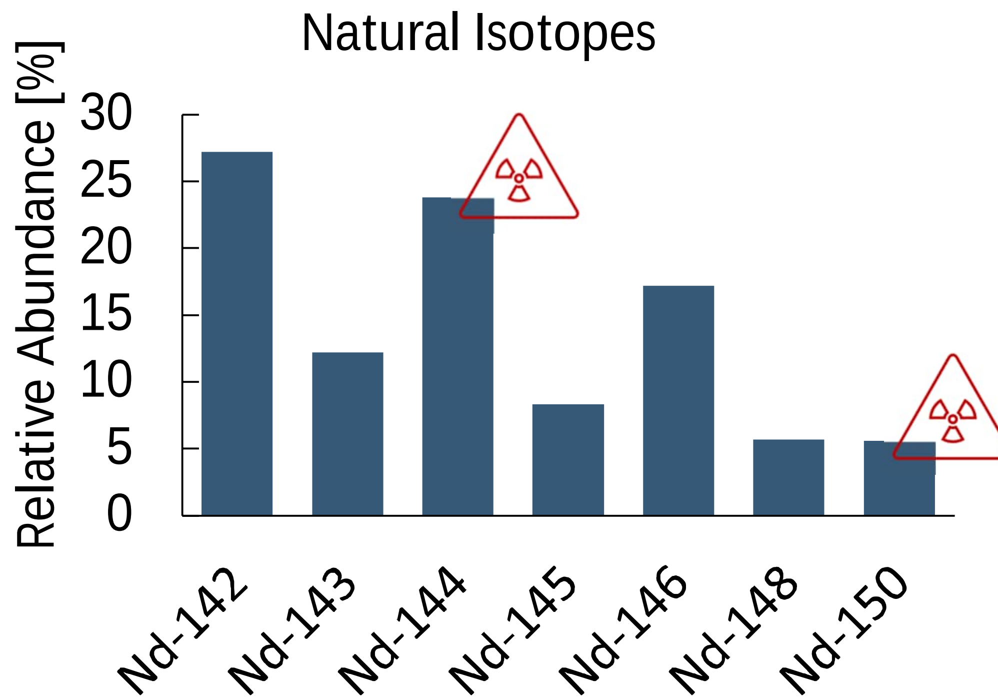
PERIODIC TABLE OF ELEMENTS

Chemical Group Block

Aalto-yliopisto
Aalto-universitetet
Aalto University

Physical Properties

Melting Point	1024 °C
Boiling Point	3080 °C
Density	7.01 g/cm³



J.H.L. Voncken, *The Rare Earth Elements*, 1st Ed., Springer, **2016**.
N. Turova, *Inorganic Chemistry in Tables*; 1st Ed., Springer, **2011**.

Chemical Properties

- Oxidation states: +II, **+III**, +IV
- Readily reacts with oxygen
- Electronegativity (Pauling): 1,14

J.H.L. Voncken, *The Rare Earth Elements*, 1st Ed., Springer, **2016**.
N. Turova, *Inorganic Chemistry in Tables*; 1st Ed., Springer, **2011**.

$Nd_2Fe_{14}B$

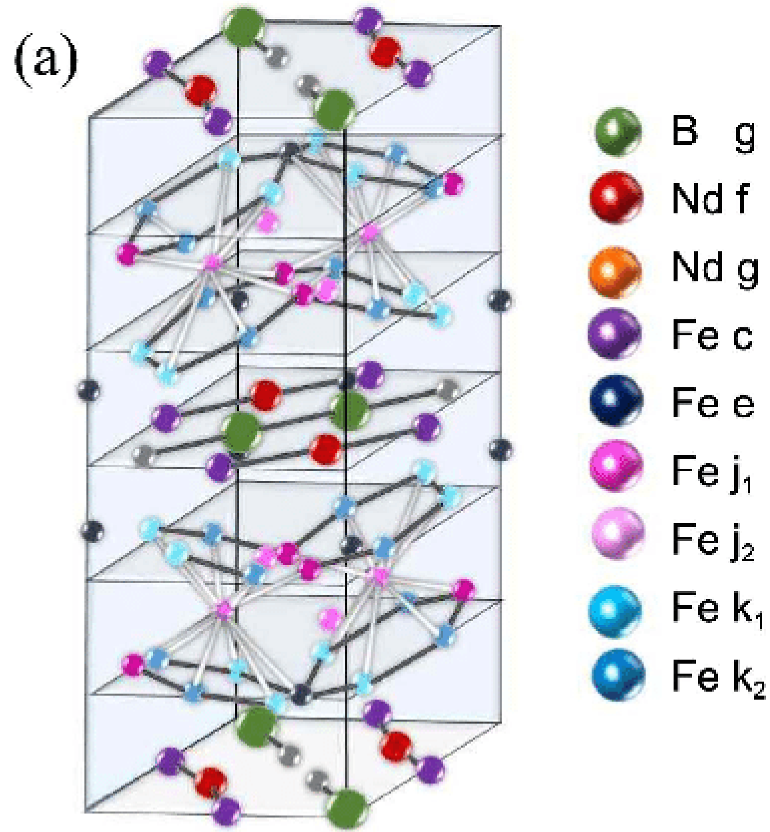
Powerful and widely used type of permanent magnet alloy

Property

- High Magnetic Strength
- Temperature Stability

Applications

- Hard Disk Drives
- Electric Vehicle Motors
- Speakers and Headphones



Schematic representation tetragonal unit cell of $Nd_2Fe_{14}B$ (P42/mnm space group)

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Abhijit P. Jadhav, Bull. *Korean Chem. Soc.* **2014**, *35*, 887.

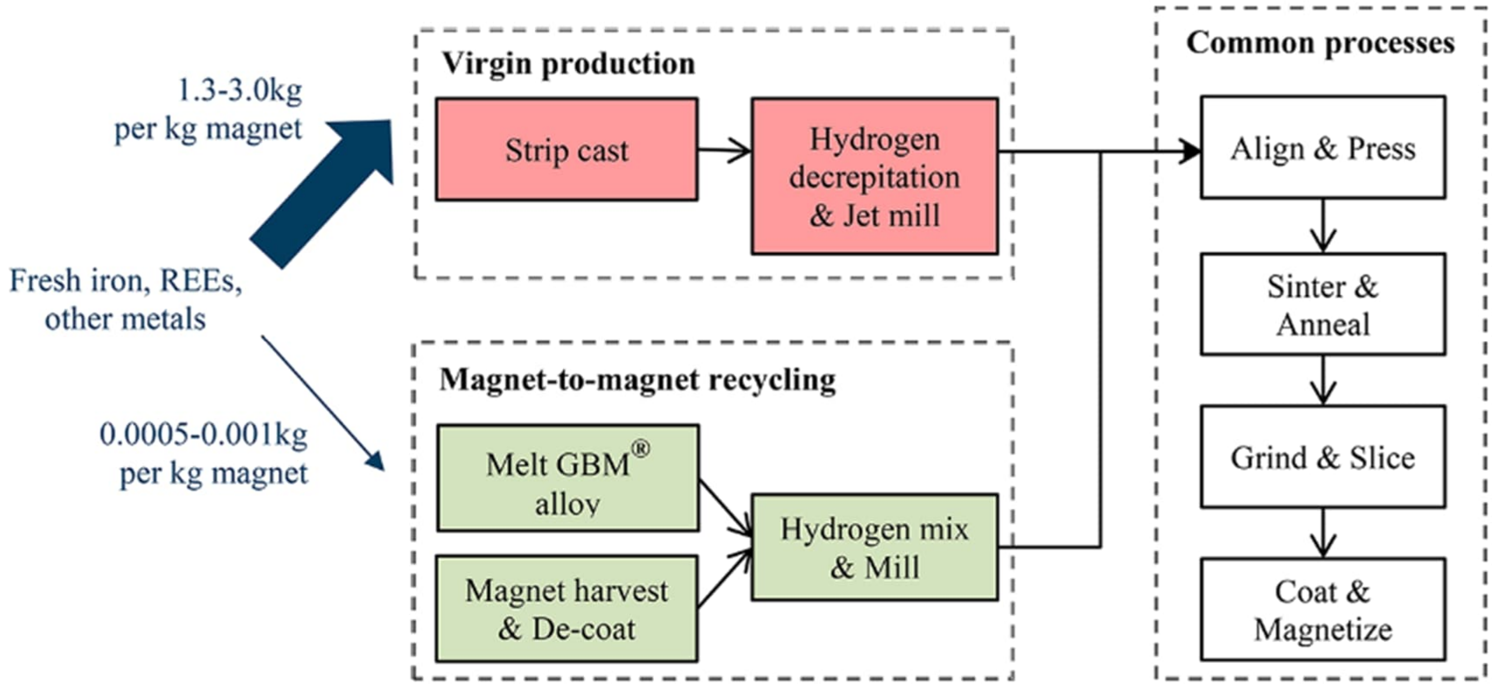
Neodymium-Iron-Boron Magnet-to-Magnet Recycling

Rare earth elements (REEs), which are the key materials for creating NdFeB magnets, have been subject to significant supply uncertainty in the past decade.

Magnet-to-Magnet Recycling

Advantage
1)Minimize waste and resource exhaustion
2)The use of mechanical processes reduces the use of chemicals and harmful emissions

Hongyue Jin, Sutherland, Environ. Sci. Technol. **2018**, 52, 3796−3802



Process flows for NdFeB magnet virgin production and magnet-to-magnet recycling

Hongyue Jin, Sutherland, Environ. Sci. Technol. **2018**, 52, 3796−3802

Properties of Virgin and Recycled NdFeB Magnets

parameters (unit)	virgin magnet	recycled magnet
B_r (T)	1.2	1.3
BHc (kOe)	11.5	12.6
IHc (kOe)	19.0	>20.0
BH_{max} (MGOe)	34.0	40.7
operating temperature (°C)	180	180

Both are suitable for high temperature applications such as electric vehicles (EVs), offer similar performance, and thus can be used interchangeably.

Life Cycle Impacts of Producing 1 kg of NdFeB Magnet through Magnet-to-Magnet Recycling

impact category	unit	virgin, China	virgin, U.S.	recycled, China	recycled, U.S.
ozone depletion	mg CFC-11 eq	12–29	13–30	0.4–0.9	0.6–1.3
global warming	kg CO_2 eq	94–222	88–207	25–56	18–41
smog	kg O_3 eq	9–21	8–19	2–4	1–2
acidification	kg SO_2 eq	0.8–1.7	0.8–1.6	0.4–0.6	0.3–0.5
eutrophication	kg N eq	1.0–2.4	1.0–2.4	0.1	0.1–0.2
carcinogenics	CTUh	4.5×10^{-06}–1.0×10^{-05}	4.8×10^{-06}–1.1×10^{-05}	6.4×10^{-07}–1.3×10^{-06}	9.7×10^{-7}–2.0×10^{-6}
non carcinogenics	CTUh	2.6×10^{-05}–5.7×10^{-05}	2.6×10^{-05}–5.8×10^{-05}	6.7×10^{-06}–1.1×10^{-05}	7.2×10^{-6}–1.2×10^{-5}
respiratory effects	kg $PM_{2.5}$ eq	0.2–0.4	0.2–0.3	0.04–0.06	0.02–0.03
ecotoxicity	CTUe	646–1,430	643–1,422	188–327	184–320
fossil fuel depletion	MJ surplus	101–240	113–267	5–10	18–39

Magnet-to-magnet recycling significantly reduces the environmental footprint of NdFeB magnet production, because it minimizes the use of fresh rare earths.

Hongyue Jin, Sutherland, Environ. Sci. Technol. **2018**, 52, 3796−3802

Recovery of Neodymium

- Hydrometallurgy
- Electrochemistry
- Gas-phase extraction
- Membrane Separation
- Biological Extraction
- Pyrometallurgy

- High processing capacity
- Low cost
- Big environmental impact

C. Liu, Q. Yan, X. Zhang, L. Lei, C.Xiao, *Environ. Sci. Technol.* **2020**, *54*, 10370-10379.

Recovery of Neodymium

Complete Leaching → **Liquid-liquid Extraction** → **Stripping/ Precipitation**

- Complete Leaching:
  - Acids/Bases
- Liquid-liquid Extraction:
  - Organic solvents
  - Ionic liquid
- Stripping/ Precipitation:
  - Acid Stripping
  - EDTA
  - Oxalic acid

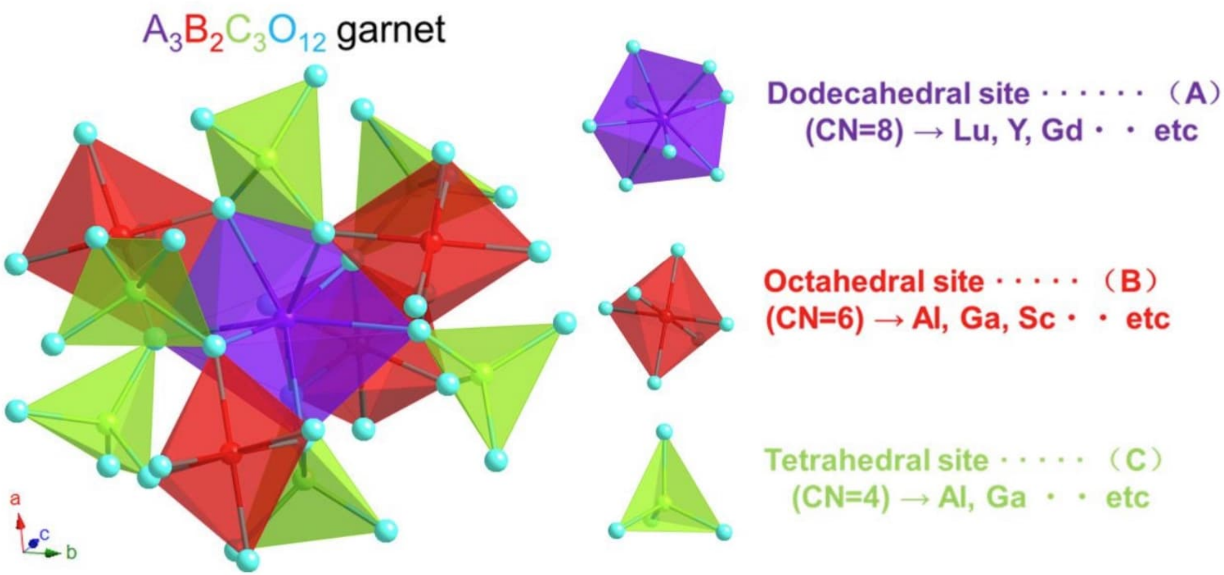
Selective Dissolution → **Precipitation**

- Selective Dissolution:
  - Deep eutectic solvents
- Precipitation:
  - Oxalic acid

C. Liu, Q. Yan, X. Zhang, L. Lei, C.Xiao, *Environ. Sci. Technol.* **2020**, *54*, 10370-10379.

Nd:YAG Laser

- Neodymium-doped yttrium aluminum garnet (Nd:$Y_3Al_5O_{12}$)



B. Denker, E. Shklovsky, *Handbook of solid-state lasers*, Woodhead Publishing, **2013**.
J.Xu, J. Ueda, S.Tanabe, *J. Am. Ceram. Soc.* **2017**, *100*, 4033-4044.

Nd:YAG Laser

- **Cutting**
- **Drilling**
- **Many more**

- **Skin treatment**
- **Ophthalmology**
- **Surgery**

- **Rangefinders**

B. Denker, E. Shklovsky, *Handbook of solid-state lasers*, Woodhead Publishing, **2013**.

Thank you !

Any questions or comments?