Circularity potential of rare earths for sustainable mobility: Recent developments, challenges and future prospects

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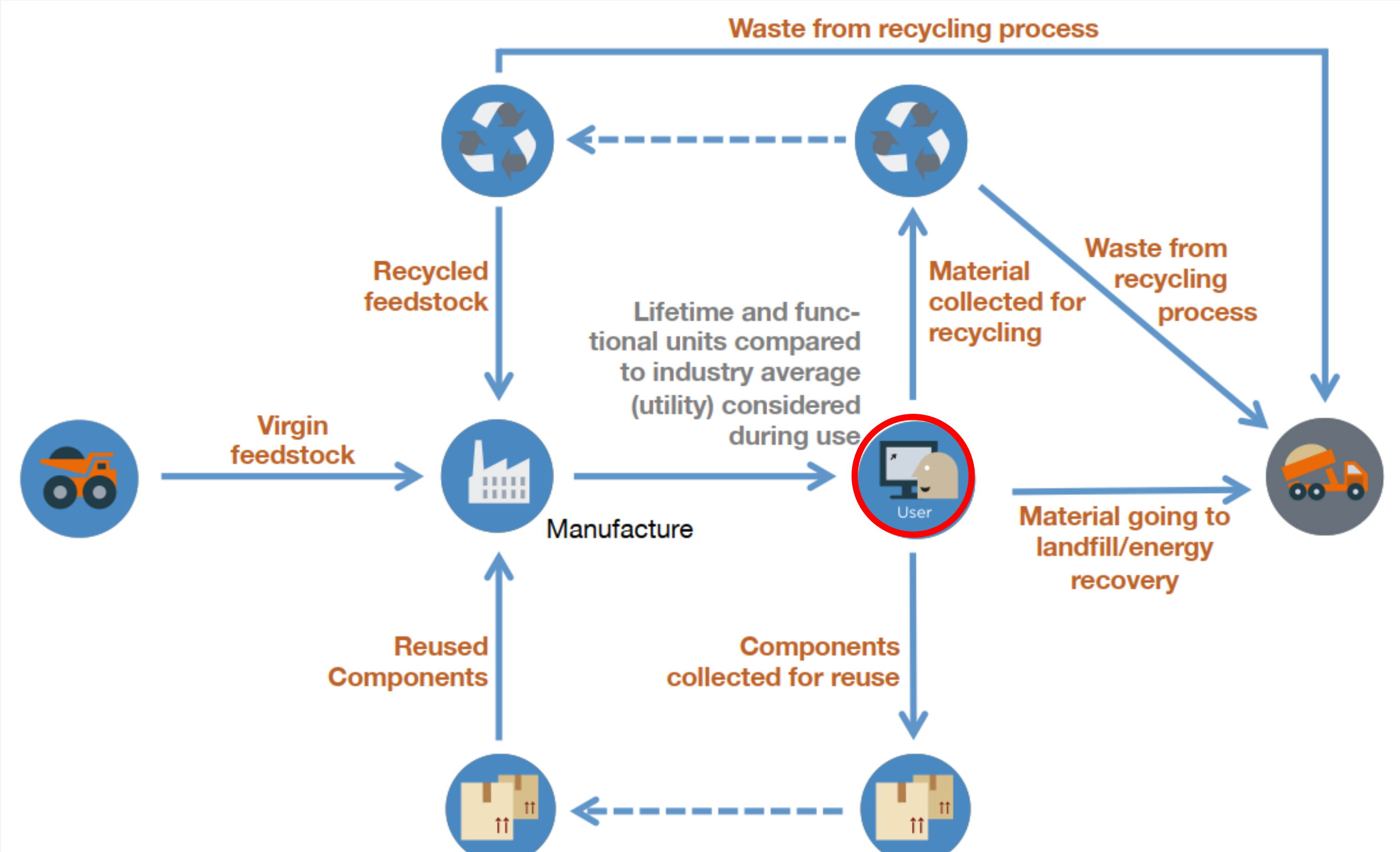
CIRCULARITY POTENTIAL ASSESSMENT FOR RARE EARTHS

- Rare earths **criticality** and supply chain risks
- **Recovery** processes of rare earths from spent batteries
- European vehicle **trade** and **Regulations**
- Modeling of a **closed-loop** CE system
- Assessment of Rare Earths **circularity potential**

What is the material circularity?

The material circularity for a **product** is the measure of:

- How much the linear flow for its component materials has been minimized;
- How much the restorative flow has been maximized; and
- How long it is possible to use them.



Ellen MacArthur Foundation, 2015

What are Rare Earths (REEs)?

17 elements:

- lanthanum
- cerium
- praseodymium
- neodymium
- promethium
- samarium
- europium
- gadolinium
- terbium
- dysprosium
- holmium
- erbium
- thulium
- ytterbium
- lutetium
- scandium
- yttrium

Rare earths are not “rare” due to their lack of natural abundance, but…

- **Cost**: It is very hard to find them in heavy concentration, making their extraction extremely expensive;
- **Strategy**: Rare earth elements are often found alongside deposits of other precious metals, such as gold and copper, or radioactive materials, such as uranium and thorium;
- **Environment**: Processing rare earths poses significant hazards to human health and the environment (acidic wastewater, radioactive waste residue, toxic gases, and dust).

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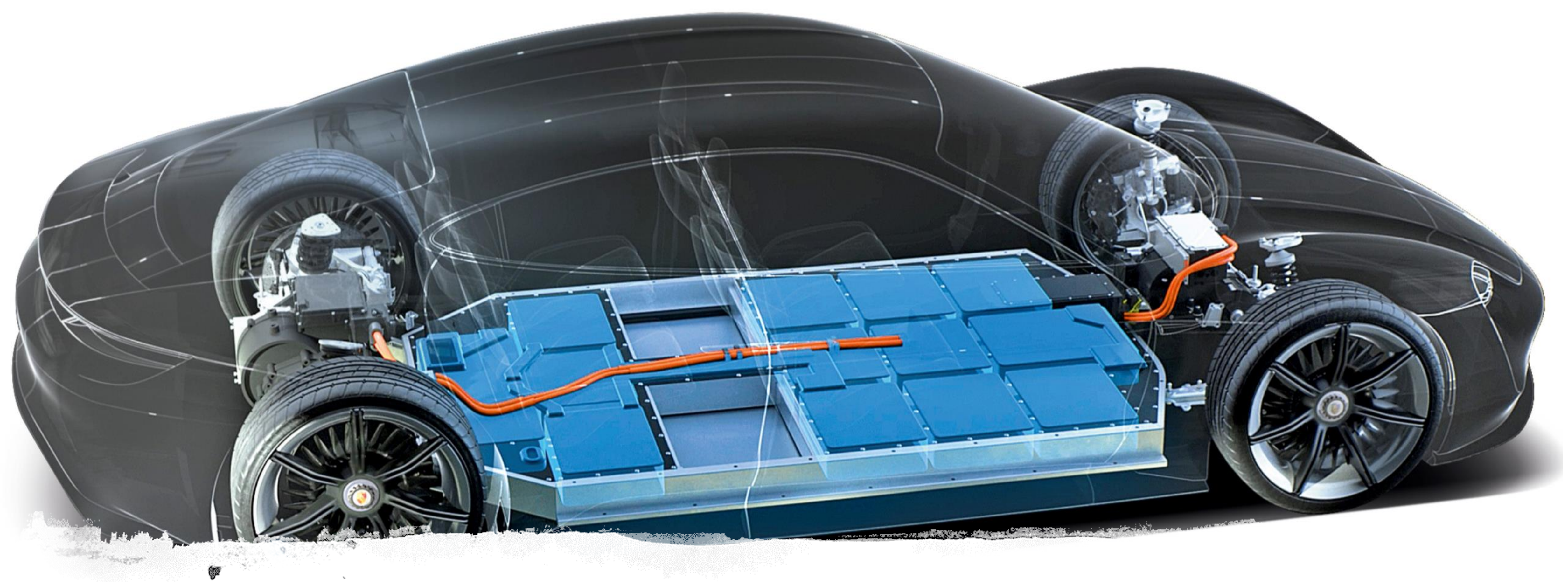
Rare earths are widely considered as critical metals, because…

- increasing in alternative "**green**" energy technologies (e.g. batteries and magnets)
- their supply chain is affected by **restrictions**, environmental implications and risk of disruption due to the market imbalances or governmental policies, such as export bans
- their production is dominated by **China** (88% of total production in 2016, excluding yttrium) and this dependency may represent one of the major issues.
- China has an excess **production capacity** and this not only results in low prices, but also reduces the chances to mine Rare Earths in others parts of the world (e.g. Canada, U.S., Malawi and Sweden).

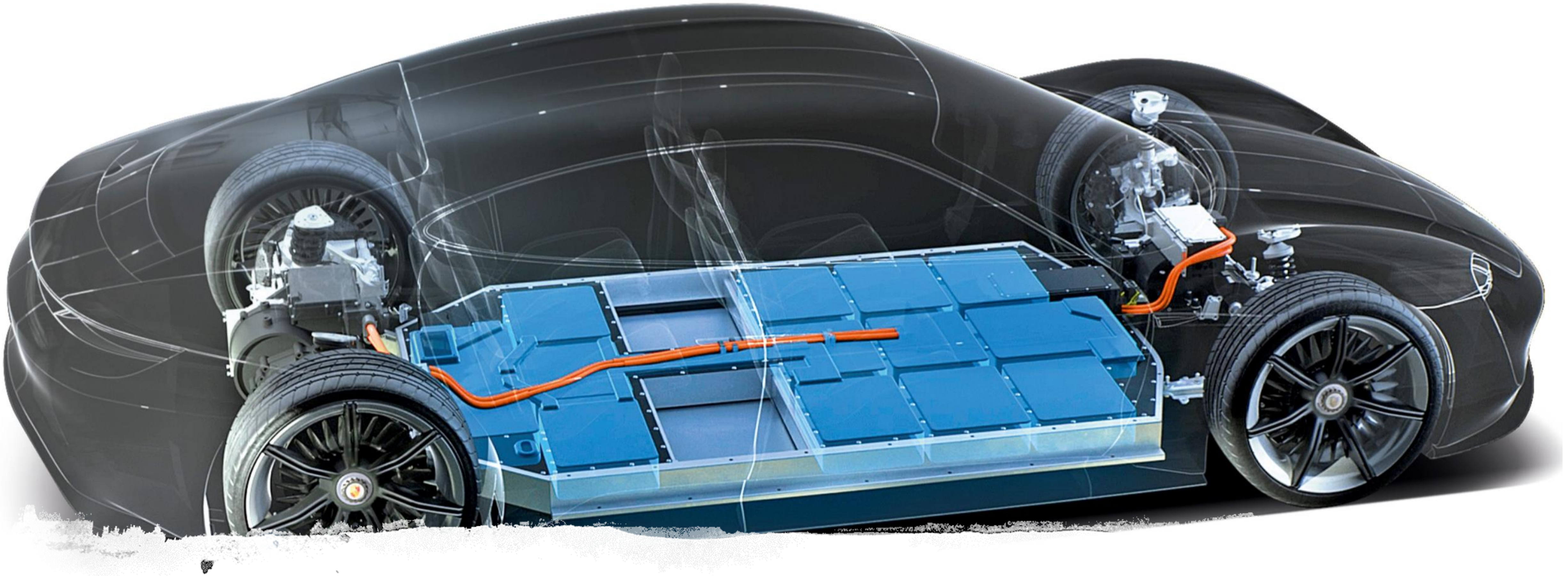


Relation between rare earths and traction batteries

Li-Ion Vs. NiMH

Lithium-ion battery

Nickel–metal hydride battery

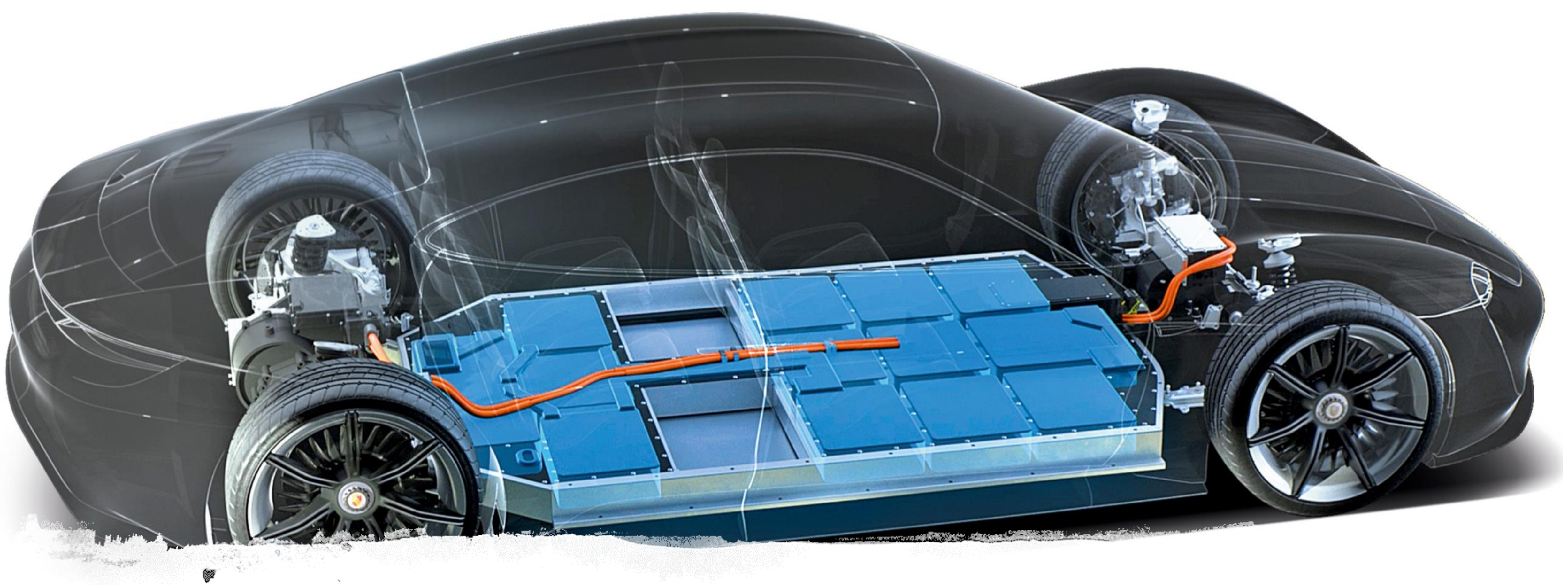


Relation between rare earths and traction batteries

~~Li-Ion~~ Vs. NiMH

Rare Earths (REEs)

- In 2016, more than half of NiMH batteries are used in hybrid electric cars (57%).
- The typical NiMH chemistry has an anode material designated as AB_5 (mischmetal-Ni5 based hydrogen storage alloy).



Relation between rare earths and traction batteries

Li-Ion Vs. NiMH

Rare Earths (REEs)

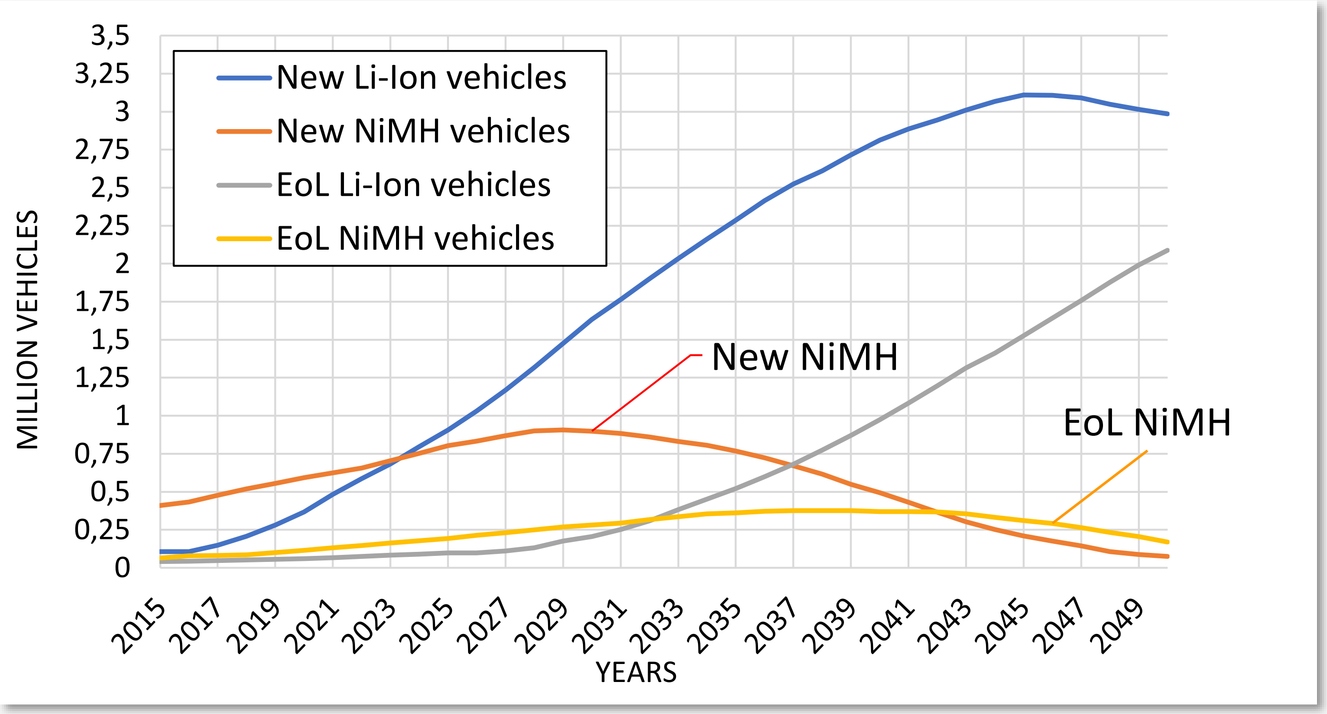
Main differences:

- Li-Ion battery has a greater power and energy density than NiMH, but inferior durability and lifetime cycles.
- NiMH have a higher self-discharge rate.

Trade of Rare Earth based battery vehicles

The tendency seems to be the gradually shifting from NiMH to Li-Ion vehicles, with a total decrease by 50% of NiMH in European applications between 2010 and 2020.

New vehicles Vs. **End-of-Life vehicles**



Mischmetal used
in NiMH batteries

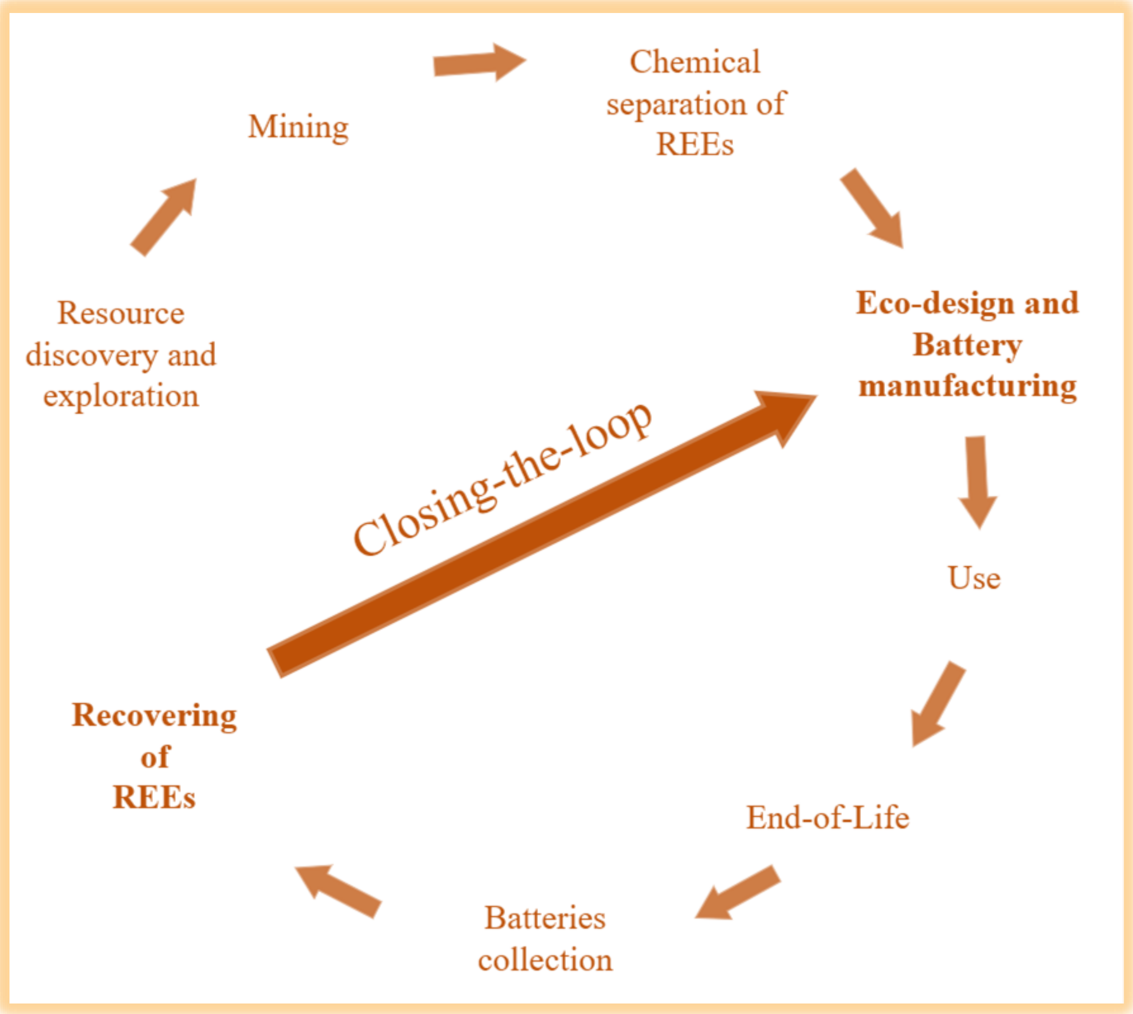
- The total amount of REEs contained in a Toyota Prius battery pack (NiMH Batteries) can be estimated in 2.5 Kg.

Assessment of Rare Earths circularity potential

Investigation of the potential of a closed-loop recycling system in the European context:

1) The state-of-art of the current technology for recovering rare earths;

2) European collection targets for spent batteries;



Recovery processes for NiMH batteries

Rhodia

Methods:

- Pyrometallurgical
- Electrochemical
- Hydrometallurgical
- Ultra High Temperature (UHT) from Umicore in Belgium

Average recovery percentages:

70% - 85% - 99%

Example of volumes (2012) in Hoboken by Umicore:

- 7000 ton/year of NiMH and Li-Ion
- 150,000 (hybrid) EV batteries or...
- 250 million mobile phone batteries
- 2 million of e-bike batteries
- 35 thousand EV batteries

SET-Plan ACTION n°7

Declaration of Intent "Become competitive in the global battery sector to drive e-mobility forward".

- The document is intended to record the agreement reached between representatives of the European Commission services, representatives of the EU Member States, Iceland, Norway, Turkey and Switzerland.

SET-Plan ACTION n°7

"Become competitive in the global battery sector to drive e-mobility forward"

European Commission

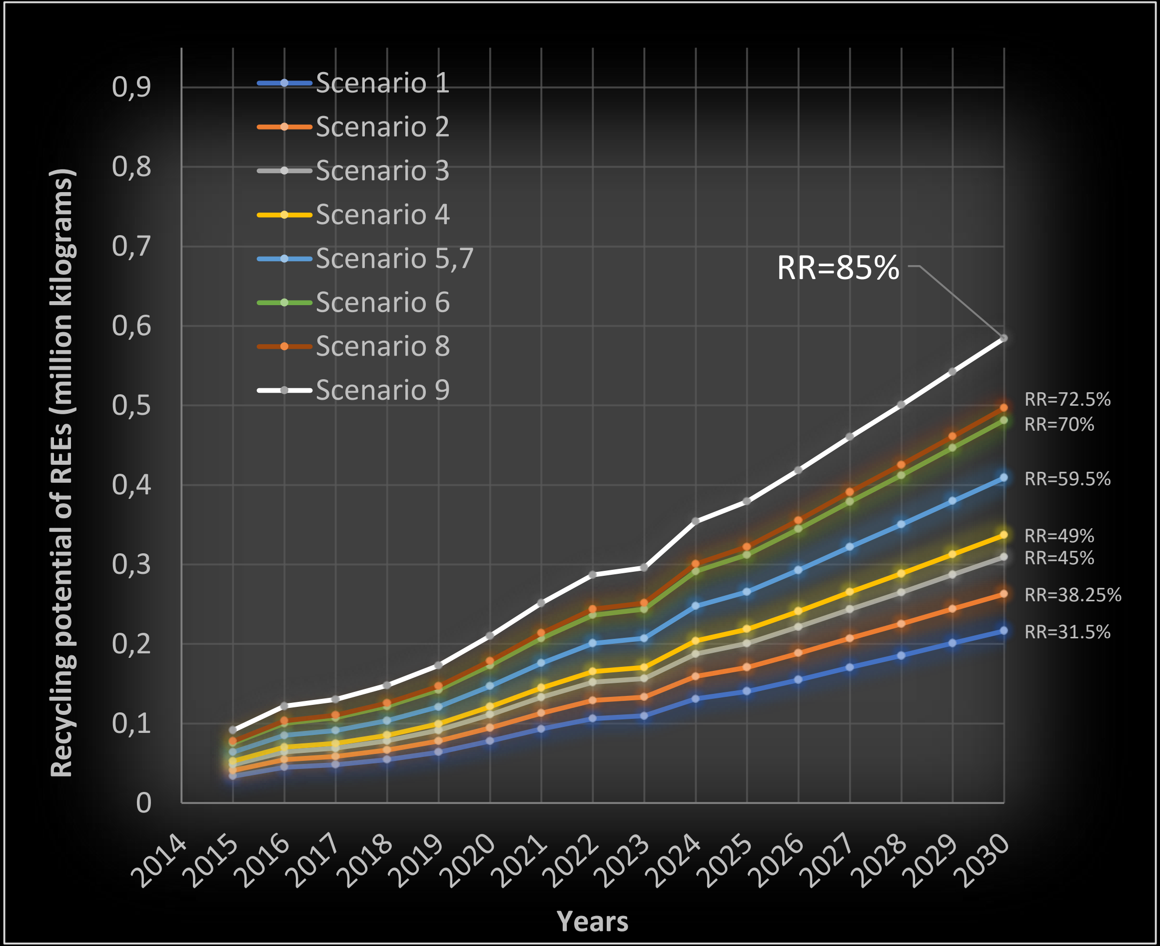
TARGETS		Current (2014/ 2015)	2020	2030
Manufacturing targets				
1	Automotive (Li-ion and next generation post-lithium) battery cell production in EU [GWh/year][1] (% supporting EU PHEV+BEV production)	0,15 – 0,20	5 (50% of the 0.5 M EVs with 20 kWh)	50 (50% of the 2 M EVs with 50 kWh)
2	*Utility Storage (Li-ion and next generation post-lithium) battery cell production in EU [GWh/year]	0,07 – 0,10	2.2	10
3	Recycling			
	**Battery collection/take back rate	45% (Sept 2016)	70%	85%
	Recycling efficiency			

Recovery rate (RR) for Rare earths

$$RR = CR \times RE \quad [\%]$$

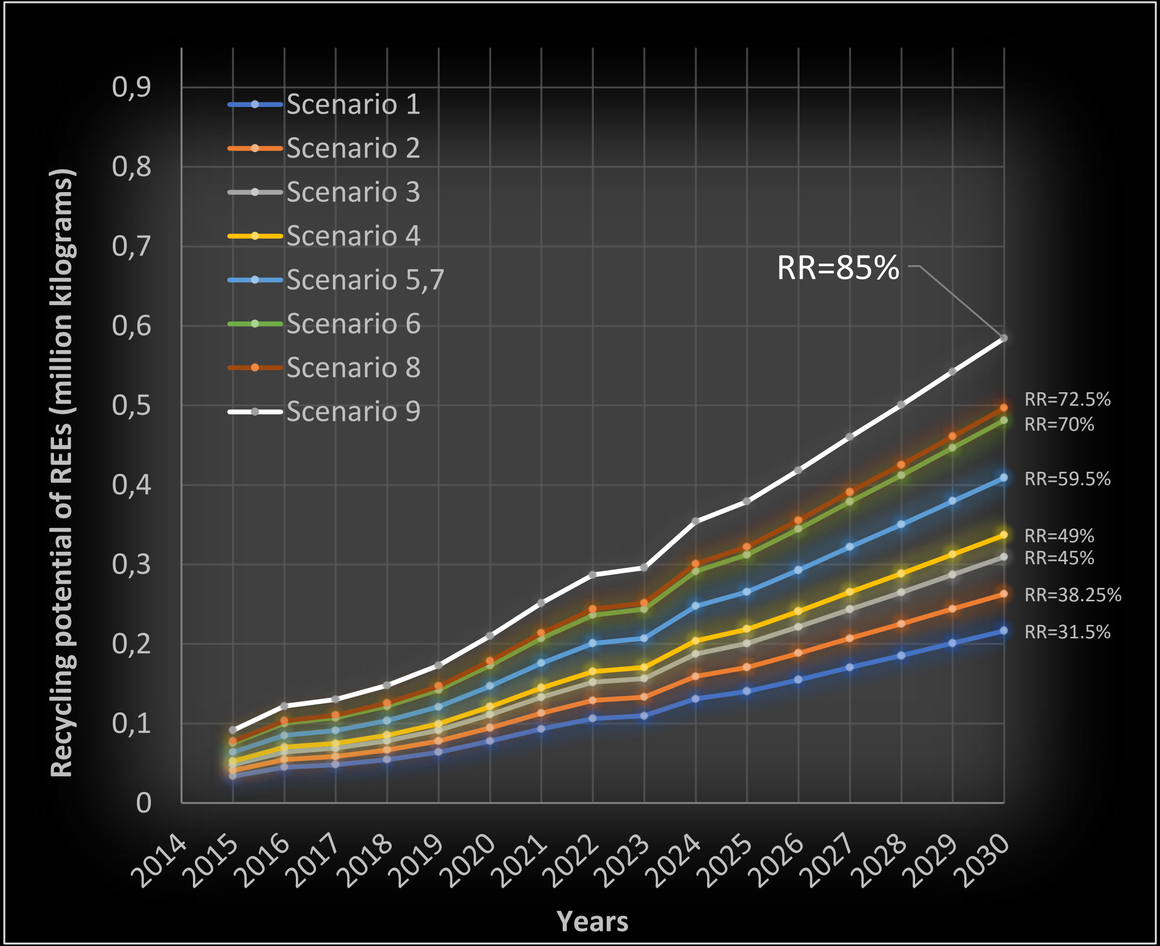
	Collection rate (CR) [%]	Recovery efficiency (CE) [%]	Recycling rate (RR) [%]
Scenario 1	45	70	31.50
Scenario 2	45	85	38.25
Scenario 3	45	100	45.00
Scenario 4	70	70	49.00
Scenario 5	70	85	59.50
Scenario 6	70	100	70.00
Scenario 7	85	70	59.50
Scenario 8	85	85	72.25
Scenario 9	85	100	85.00

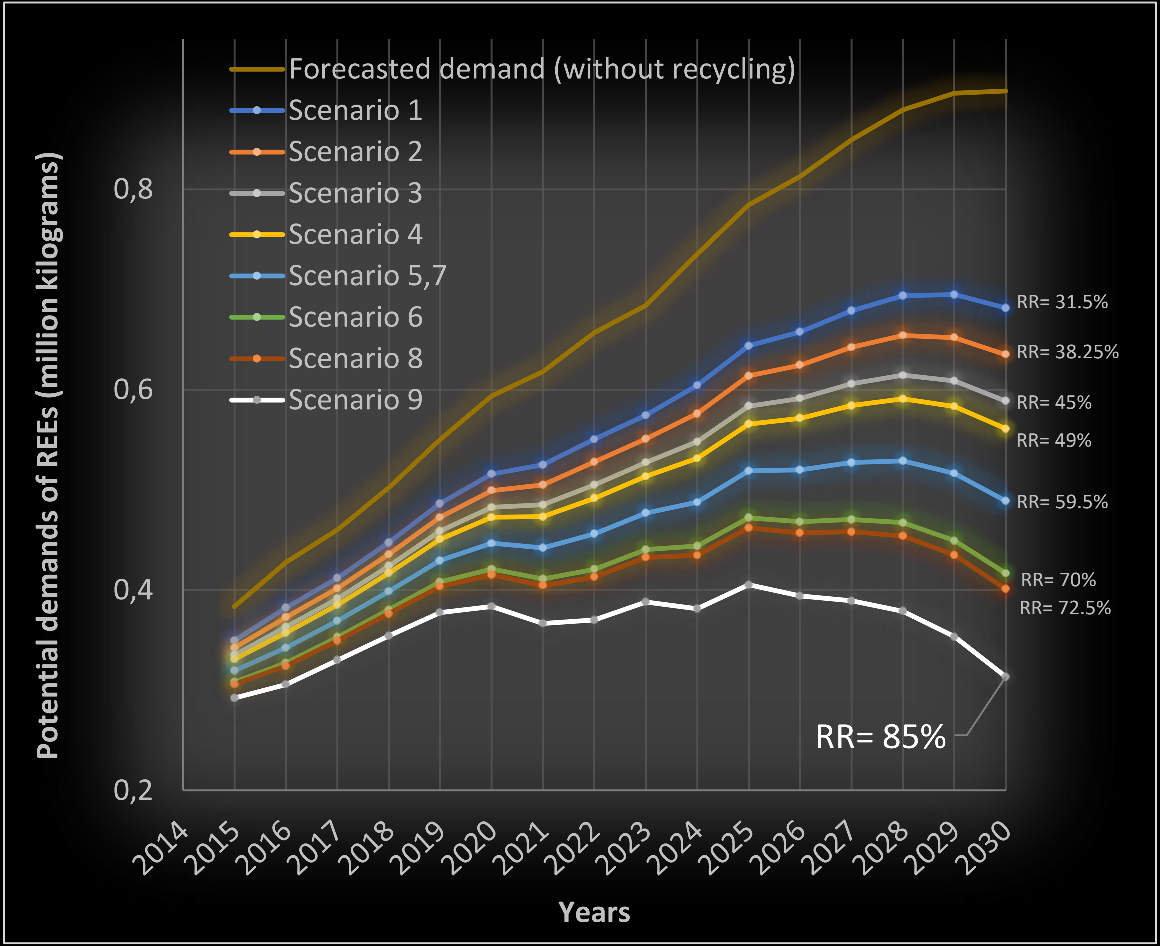
Assessment and discussion of Rare Earths circularity potential



1) The advantages of recycling scenarios with the highest recycling rates become more evident when the number of batteries considered increases;
2) High recycling potential for REEs from spent batteries is able to significantly decreases the future demand of REEs needed for new batteries, contrasting risks in REEs supply chain. In particular, an 85% recycling rate scenario would guarantee a decreasing trend in the demand of REEs for vehicle batteries starting from 2025.

Assessment and discussion of Rare Earths circularity potential





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Assessment and discussion of REEs circularity potential

The economic sustainability of the entire recycling process

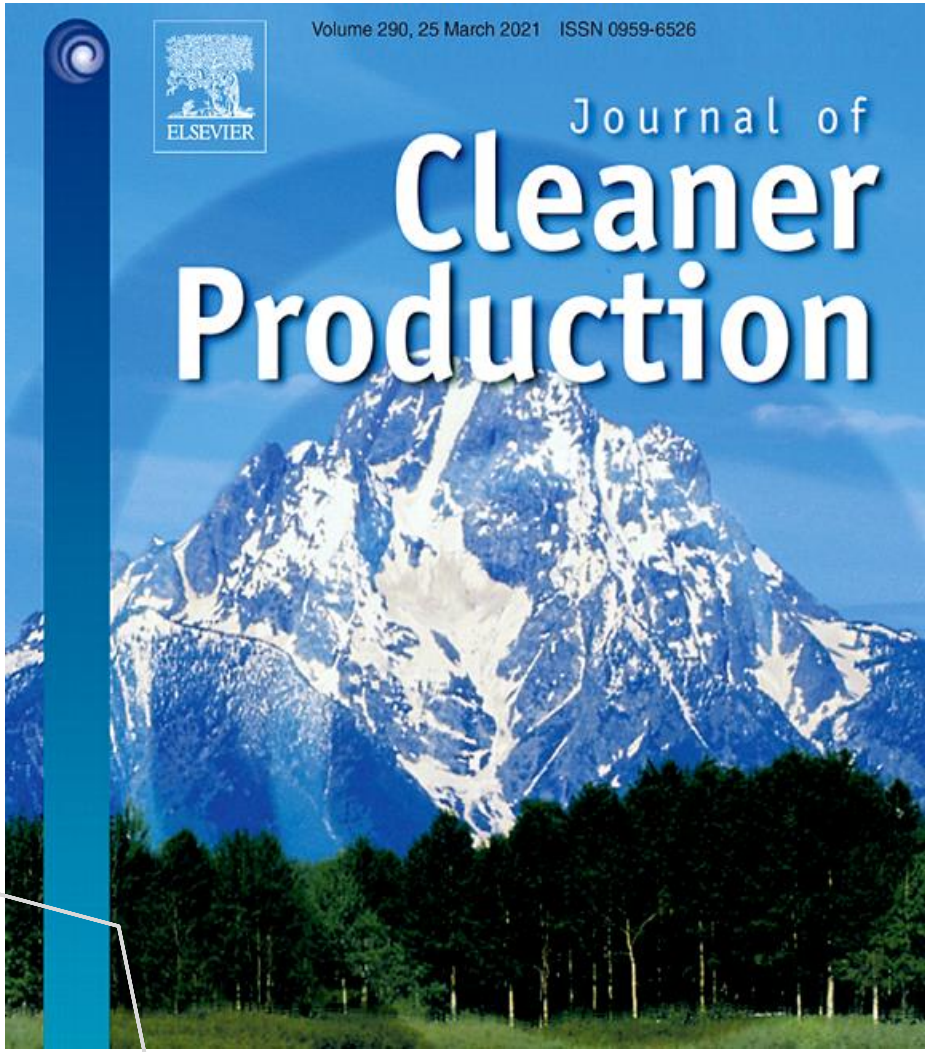
Rare earths	Relative absolute percentage	Relative percentage	Cost (€/kg)
Cerium (Ce)	2.6	22.03	3.84
Lanthanum (La)	7.4	62.71	4.12
Neodynium (Nd)	0.9	7.63	43.42
Praseodynium (Pr)	0.3	11.02	76.91
Yttrium (Y)	0.6	22.04	27.83

- The market value of the mix (mischmetal) can be calculated at 21.35 €/kg.
- The potential revenue deriving from the recovery of REEs from a ton of spent batteries can therefore be estimated at approximately € 1000 in ideal conditions.
- According to the energy required for rare earths recovering (351 kWh/ton of electricity and 1485 kWh/ton) and the European electricity and heat process (0.2 €/kWh for electricity and 0.55 €/kWh for natural gas), the economic valorization of REEs is able to compensate up to 66% of the energy costs.

Conclusions

1) The current recovery technology, along with appropriate recycling policies, is able to reduce the future demand of rare earths as early as from 2025;
2) High collection and recovery rates allow to contrast uncertainties in rare earths supply chain;
3) The recovery of rare earths is a key process to ensure the economic sustainability of the entire recycling process.

These results provide the evidence that an appropriate **circular economy system** for vehicle battery industry can lead to benefits not only in terms of **supply risk reduction** but also in relation to the **preservation of natural resources**, implying one step further towards a sustainable mobility.



Article:

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Journal: Journal of Cleaner Production

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