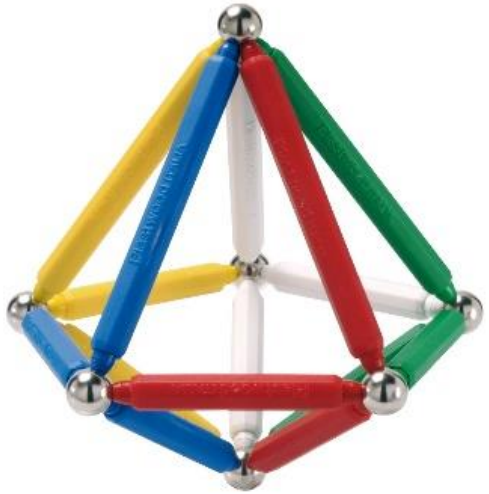
Building a sustainable supply chain for magnetic rare earth materials: the REEsilience project

Prof. Dr. Carlo Burkhardt
Pforzheim University
Jožef Stefan International Postgraduate School

Co-funded by the European Union

Rare Earth as High Performance Materials

Magnets…



Co-funded by
the European Union

REEsilience

Rare Earth as High Performance Materials

Microstructure…

Microstructure of sintered NdFeB magnets

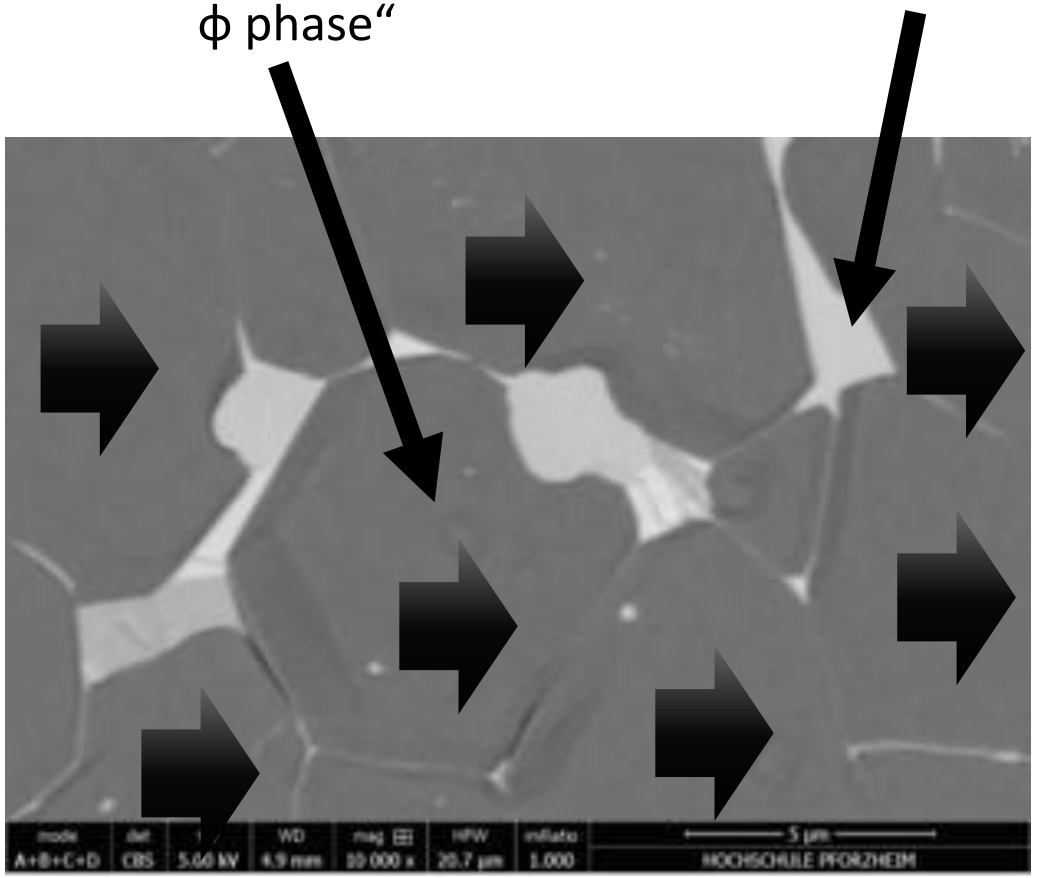
(Hard-)magnetic grains ($Nd_2Fe_{14}B$)

- magnetically coupled

Neodymium-rich intergranular Phase for insulation

- magnetically decoupled

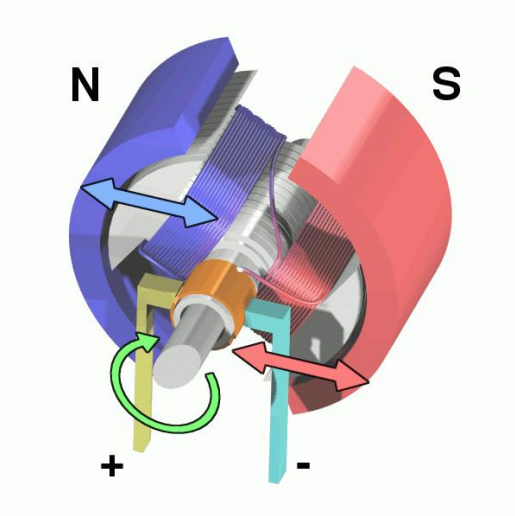
Typical base alloy : $Nd_{15-x}Fe_{77}B_8$
(x= alloying additions e.g. Dy, Tb, Zr, Ga …)

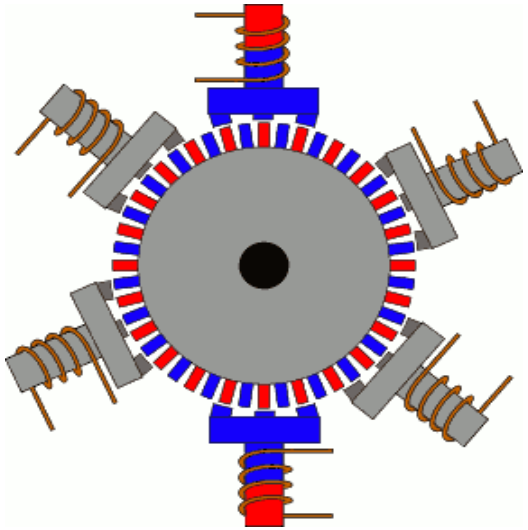


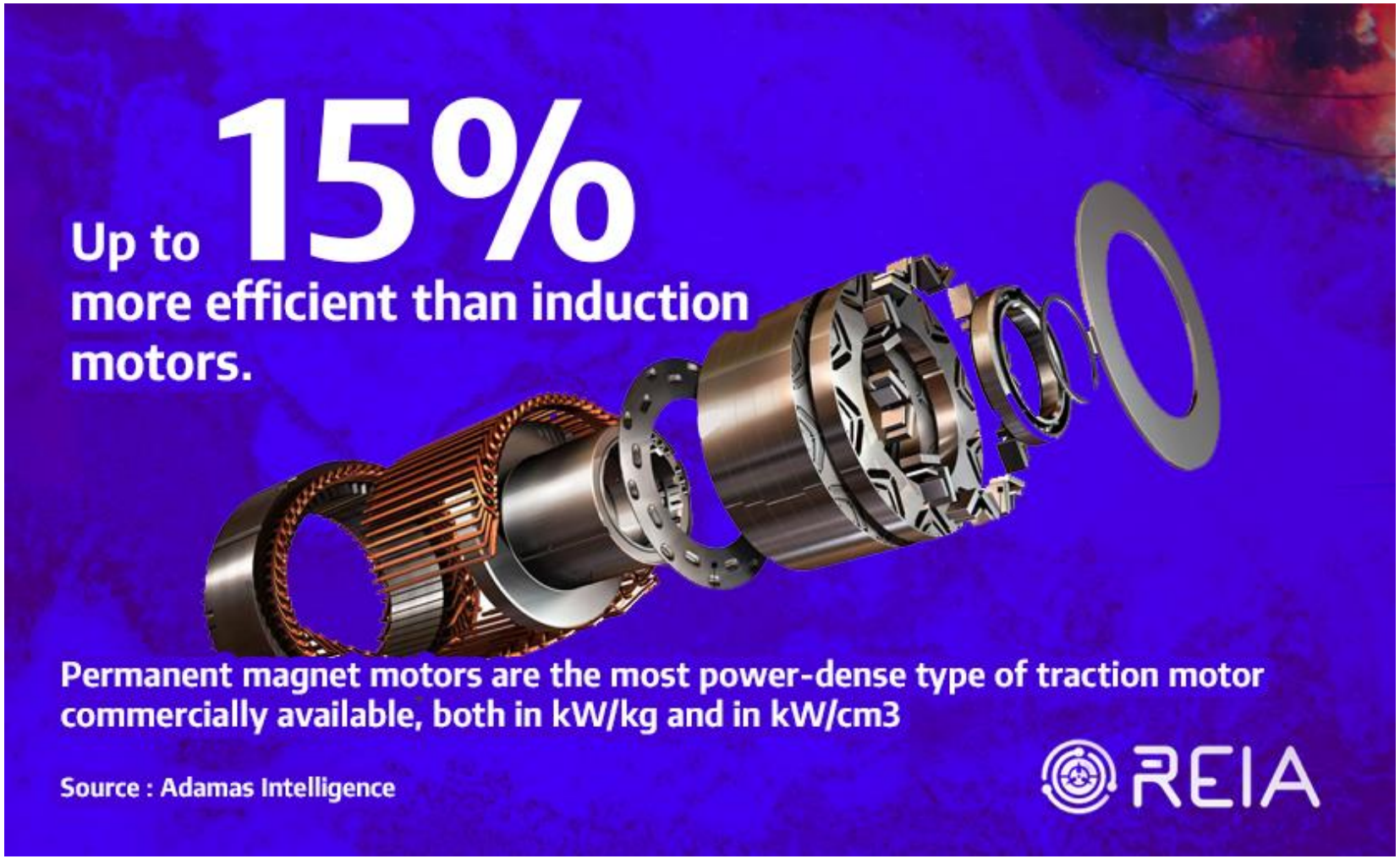
Co-funded by the European Union

REEsilience

Rare Earth Magnets empower the devices of our future







Co-funded by the European Union

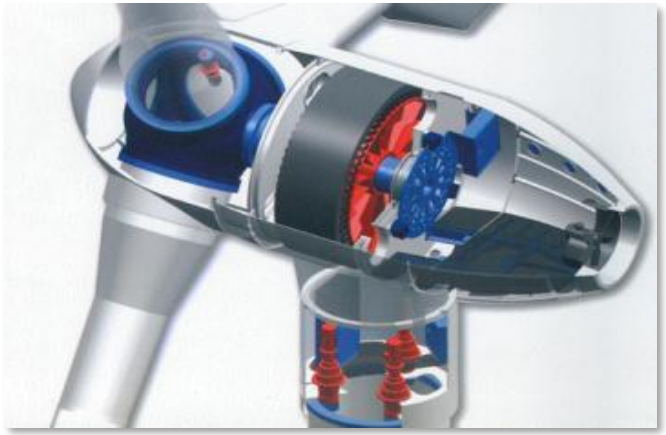
REEsilience

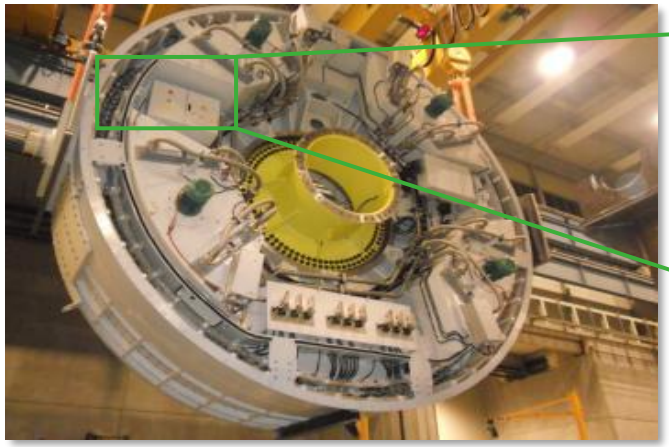
Rare Earth Magnets empower the devices of our future

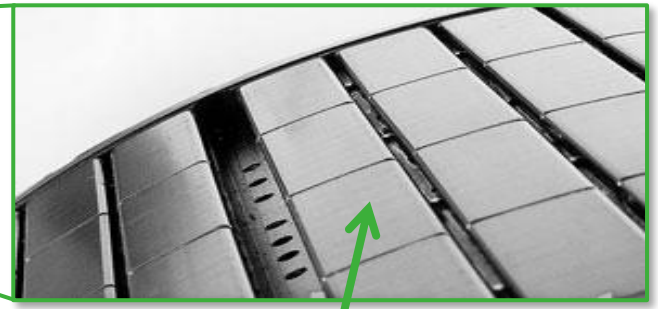
Co-funded by
the European Union

REEsilience

Rare Earth Magnets empower the devices of our future







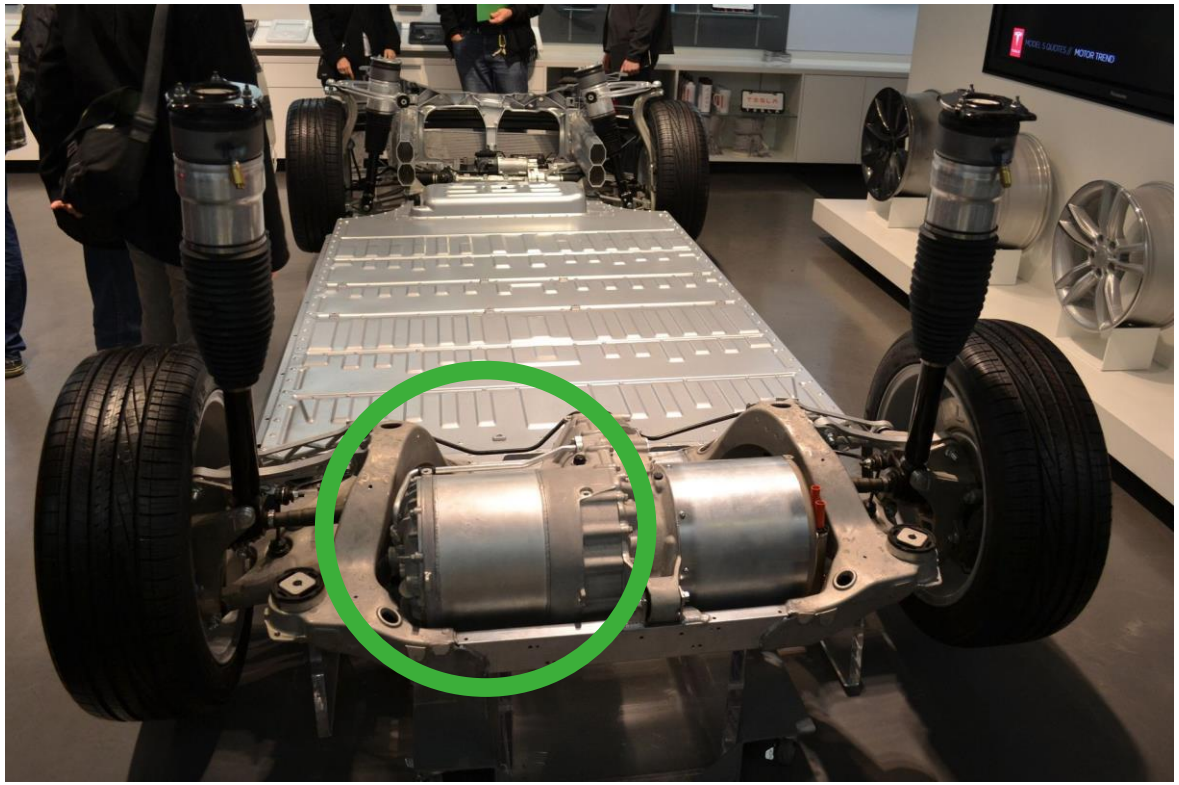
Permanent Magnets (NdFeB-type)

Co-funded by
the European Union

REEsilience

Rare Earth Magnets empower the devices of our future

Mercedes AMG, 320 kW



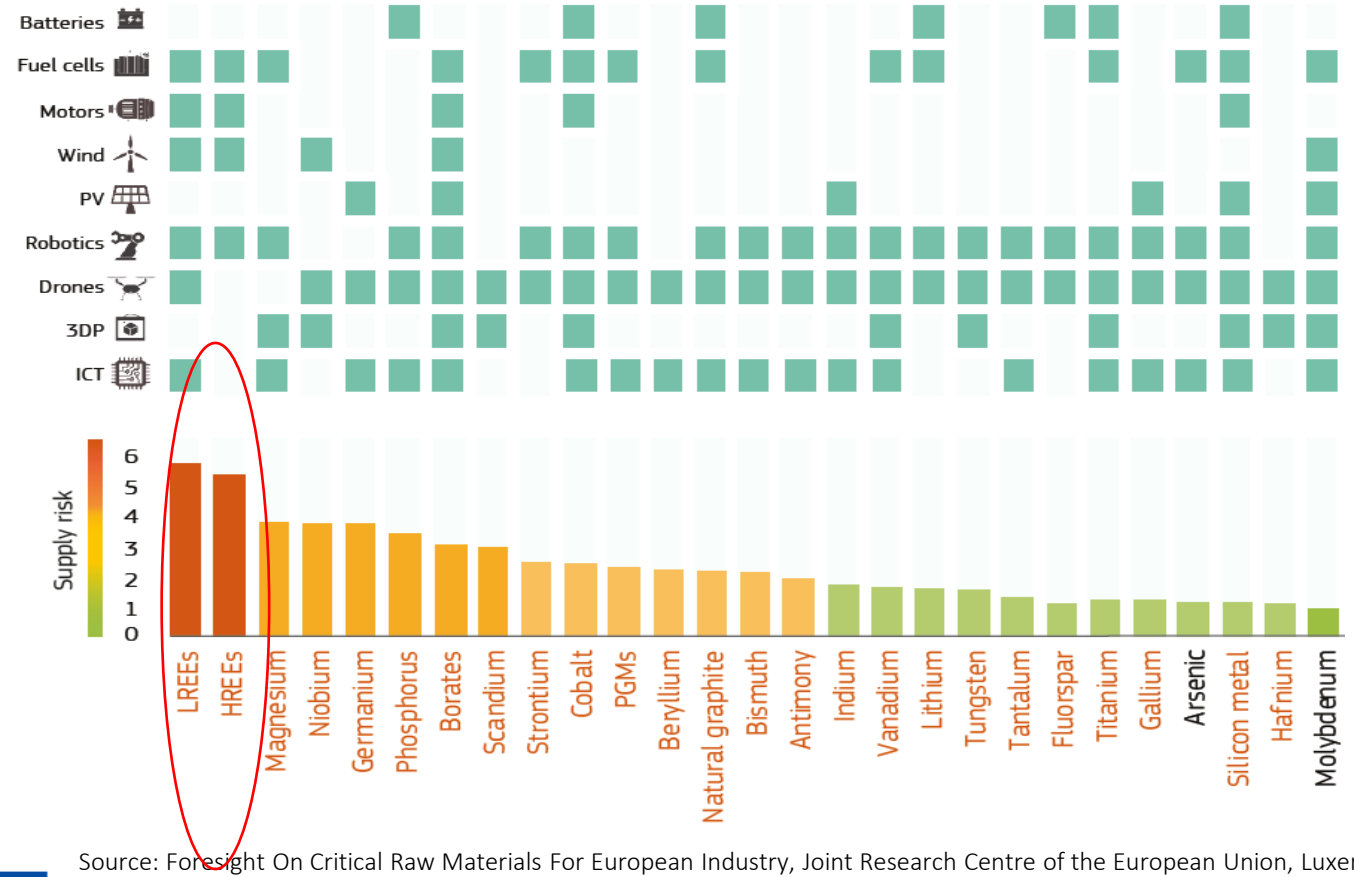
Tesla Model 3, 320 kW

95% of electric cars use permanent magnet motors

Co-funded by
the European Union

REEsilience

Rare Earth: Critical Raw Materials



Source: Foresight On Critical Raw Materials For European Industry, Joint Research Centre of the European Union, Luxembourg, 2024

Source: Jaguar.com

Electric SUVs can contain up to 5kg of NdFeB

Source: WikiCommons

Offshore wind turbines can contain up to 10-12 tonnes of NdFeB

Co-funded by the European Union

REEsilience

Rare Earth: European Strategy

- Supporting mining project in Europe and in „reliable partner countries“

  → Canada, Australia, Indonesia, Namibia […]

- Supporting strategic investments over the whole value chain

  → mining, refinery, metal making, magnets making, recycling

- Critical raw materials act (14.11.2023)

  domestic capacities along the strategic raw material supply chain to be reached by 2030:

  → **10%** of the EU's annual needs for extraction

  → **40%** of the EU's annual needs for processing

  → **25%** of the EU's annual needs for recycling

Co-funded by the European Union

REEsilience

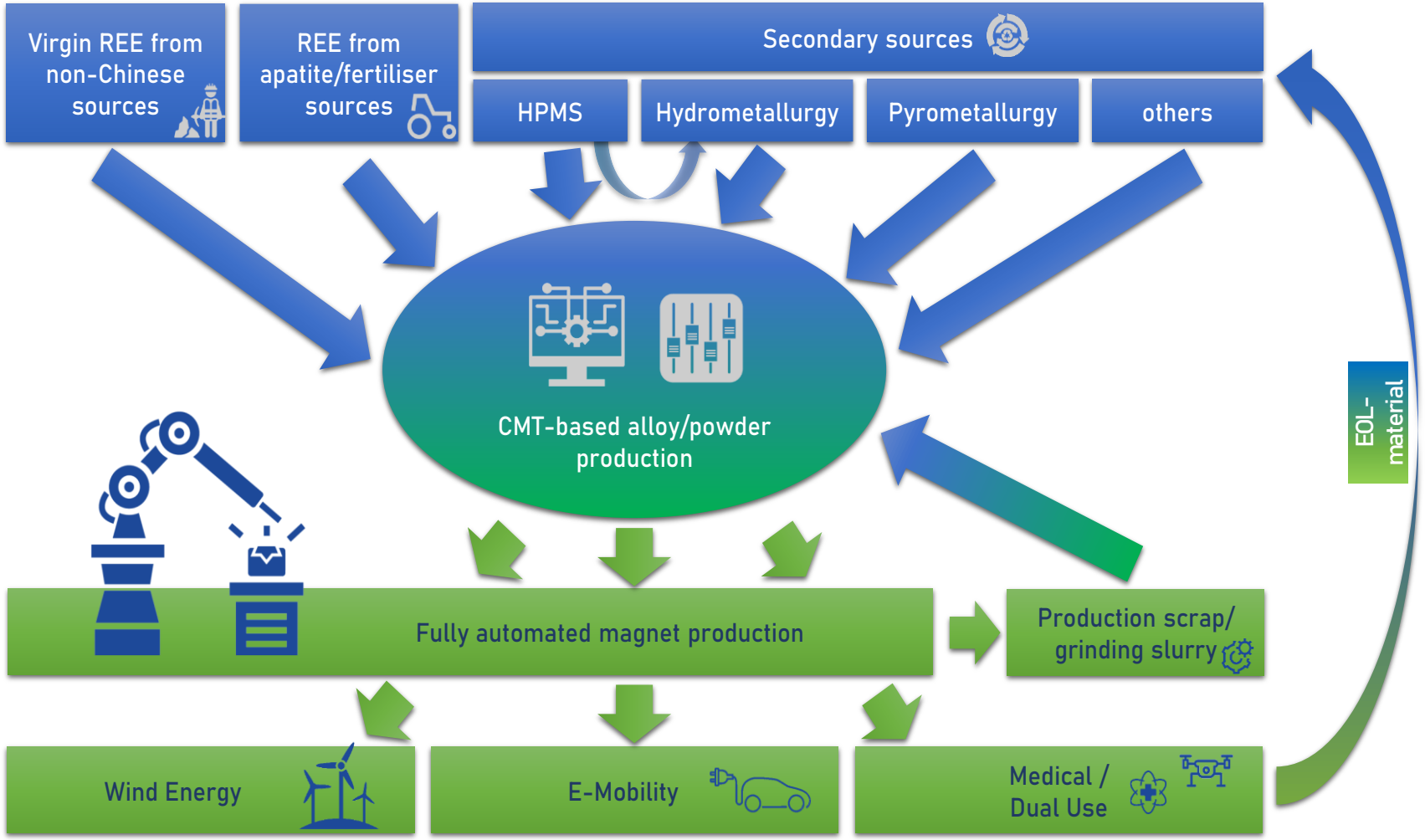
The REEsilience project: Main activities and expected results

- Meeting rising demand
  - Securing a resilient and sustainable REE supply
  - Establishing a circular economy for RE magnets through consistent increase of recycling rates
  - Bringing transparency into the material flow
  - Increasing EU production figures
- Developing magnets with enhanced functionalities
- Creating jobs over the whole supply chain
- Developing a concept to educate magnets experts
- Dissemination, Exploitation and Communication

Co-funded by
the European Union

REEsilience

The REEsilience project: Main activities and expected results



Co-funded by the European Union

REEsilience

REEsilience: Brief introduction to the consortium

Nu.	Acronym	Organisation	Type	Country
1	HSPF	Pforzheim University	Academia	Germany
2	SEZ	Steinbeis Europa Zentrum	Tech Transfer	Germany
3	JSI	Jožef Stefan Institute	RTO	Slovenia
4	ULEI	University of Leiden	Academia	Netherlands
5	VLO	VALEO	Industry	France
6	RISE	Research Institutes of Sweden	RTO	Sweden
7	INS	Inserma Anoia	SME	Spain
8	MKP	Mkango Polska	Industry	Poland
9	KOL	Kolektor Group	Industry	Slovenia
11	TUBAF	Bergakademie Freiberg	Academia	Germany
12	HMG	Hypromag GmbH	SME	Germany
13	DUK	Danube University Krems	Academia	Austria
14	TUD	Delft University	Academia	Netherlands
15	CAR	Carester	SME	France
16	REIA	Rare Earths Industry Association	Association	Belgium
17	UoB	University of Birmingham	Academia	UK
18	HML	HyProMag Ltd	SME	UK

Co-funded by the European Union

REEsilience

RE Magnets Recycling

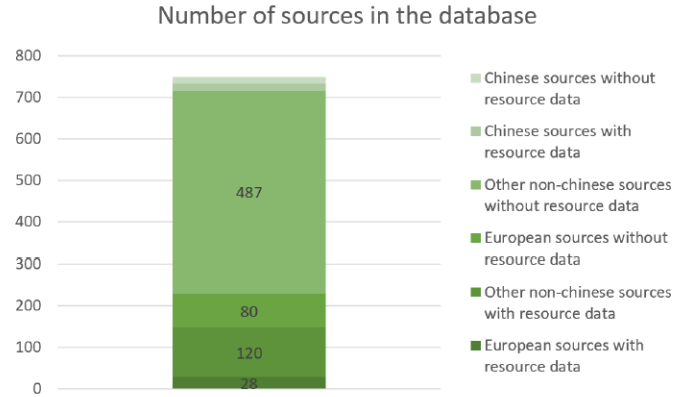
Mapping of sources

Primary sources

e.g., monazite, bastnasite, loparite, xenotime, ion-absorption clays, etc.

Primary sources

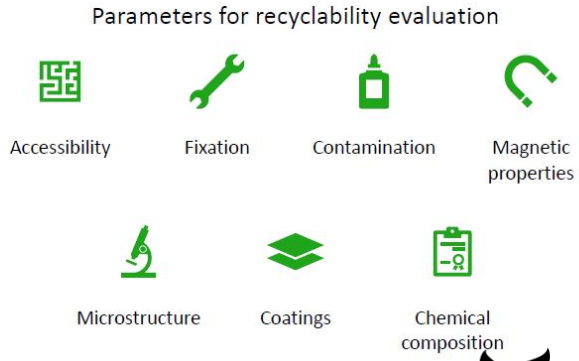
- **Current database**
  - 715 total non-Chinese sources (749 when including Chinese)
  - 148 non-Chinese sources with resource data (28 European)
  - 567 non-Chinese sources without resource data (80 European)
  - 14 non-Chinese processing facilities (19 when including Chinese)



Secondary sources

- **Current database**

So far over 180 magnet containing applications, ranging from audiomodules in smartphones to wind turbine magnets have been dismantled and analysed for recyclability

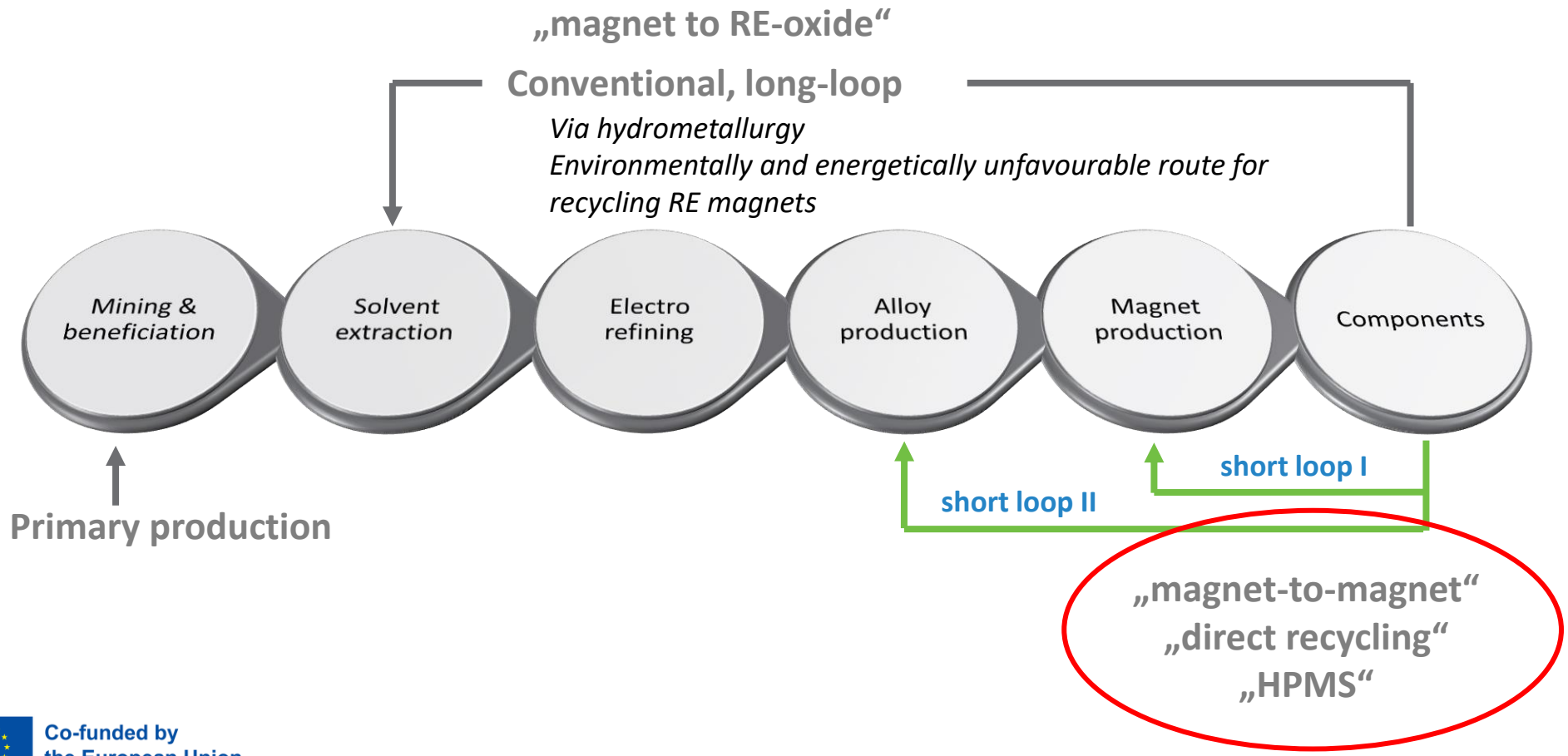


Co-funded by the European Union

REEsilience

Rare Earth Recycling

Long loop vs. short loop

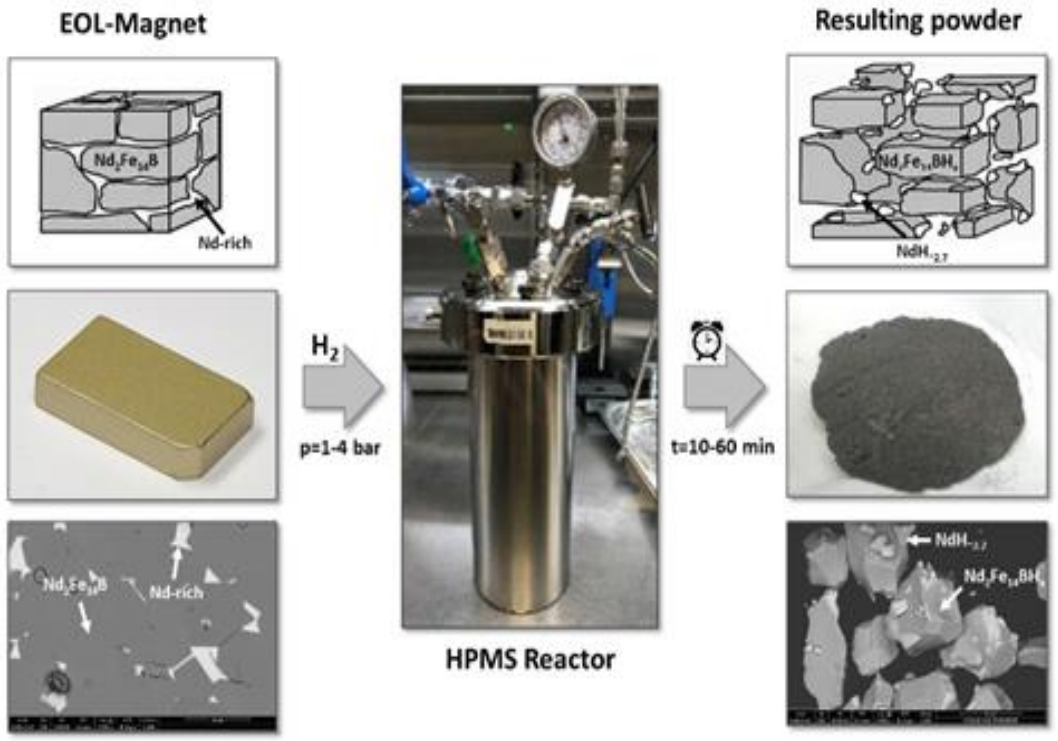


Co-funded by the European Union

REEsilience

Rare Earth Recycling

Short loop/Direct/HPMS recycling



Route A: Sintering

Route B: HDDR/poly-mer bonding

Route C: Metal Injection Moulding

Route D: Recasting

Co-funded by the European Union

REEsilience

RE Magnets Recycling

Technical issues

Other technology metals (Ag, Pt, Pd) have recycling rates of ~30%

- Recycling rate of Nd is **<1%**

→ Large diversity of End-of-Life Magnets:

- SmCo, Ferrite, NdFeB....
- no design for recycling

→ Underdeveloped recycling schemes

Co-funded by
the European Union

REEsilience

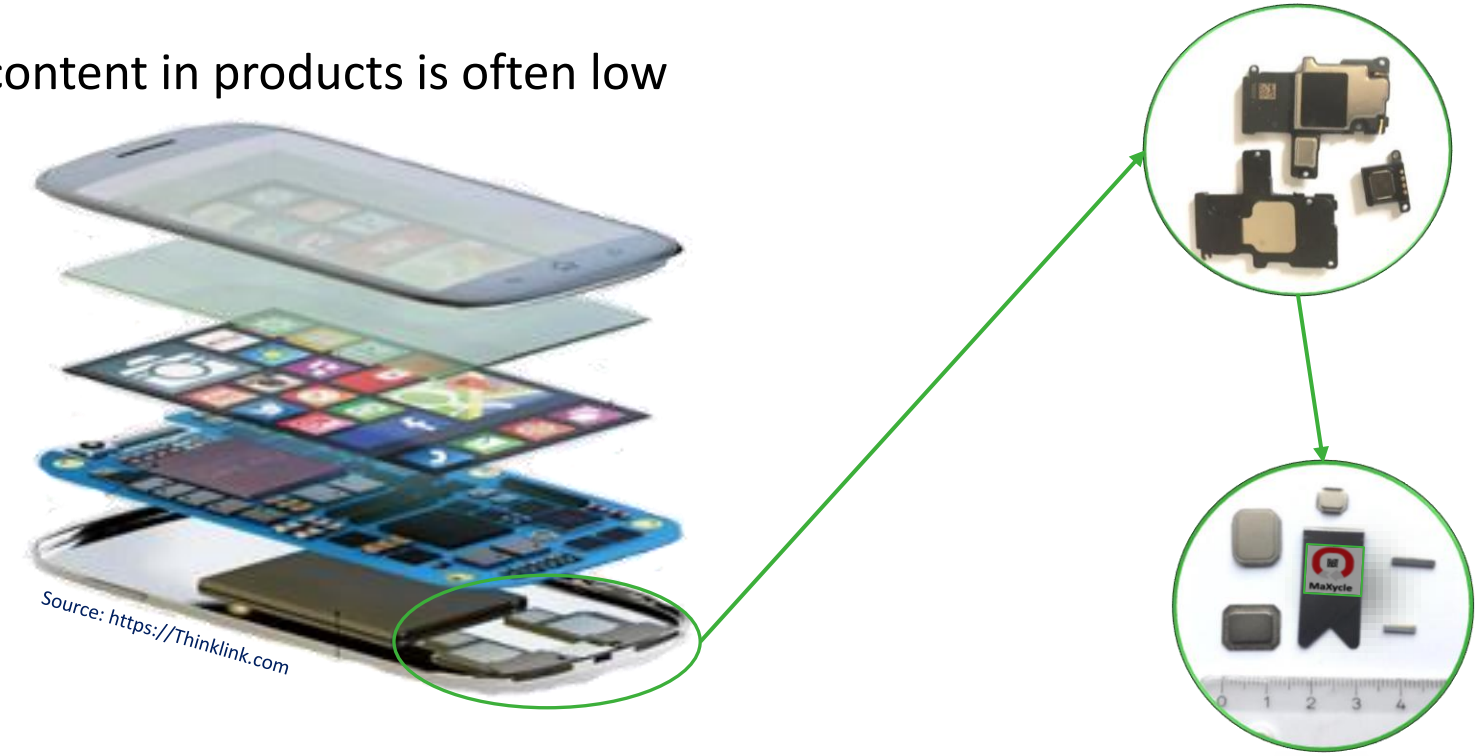
RE Magnets Recycling

Technical issues

Other technology metals (Ag, Pt, Pd) have recycling rates of ~30%

- Recycling rate of Nd is **<1%**

→ Magnet content in products is often low



Co-funded by the European Union

REEsilience

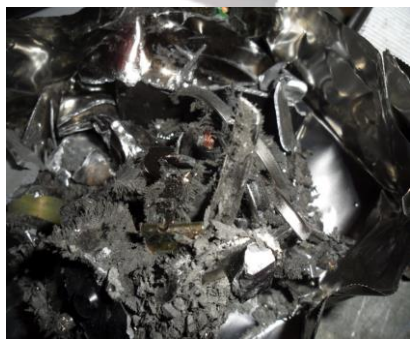
RE Magnets Recycling

Technical issues

Other technology metals (Ag, Pt, Pd) have recycling rates of ~30%

- Recycling rate of Nd is **<1%**

→ Current shredder processes are not suitable for recycling NdFeB



Source: University of Leiden

shredding

Source: Axion

Magnetic material

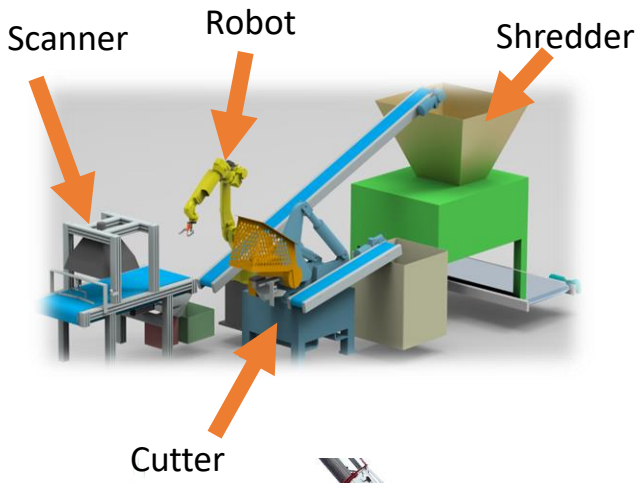
Source: EMR, Birmingham

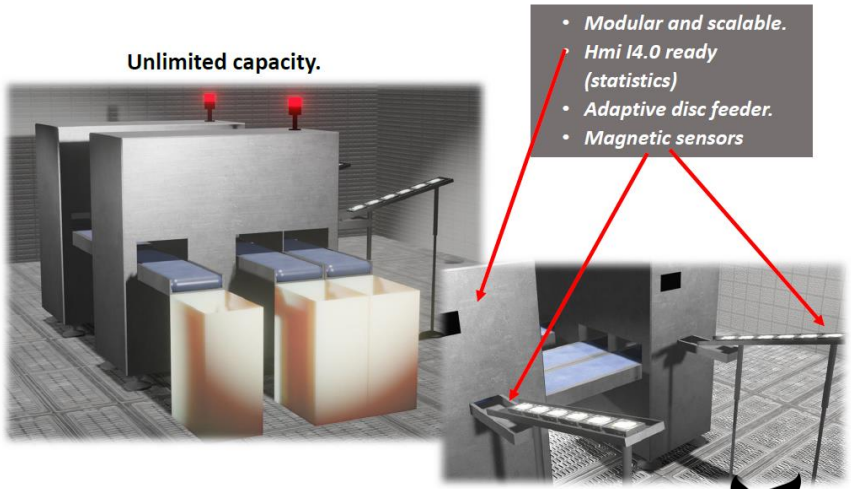
Co-funded by the European Union

REEsilience

RE Magnets Recycling

Automated disassembly



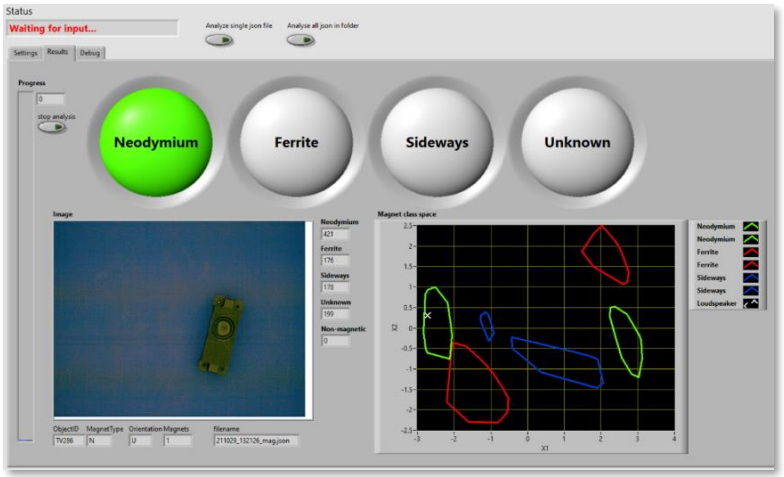


Co-funded by
the European Union

REEsilience

RE Magnets Recycling

Automated disassembly

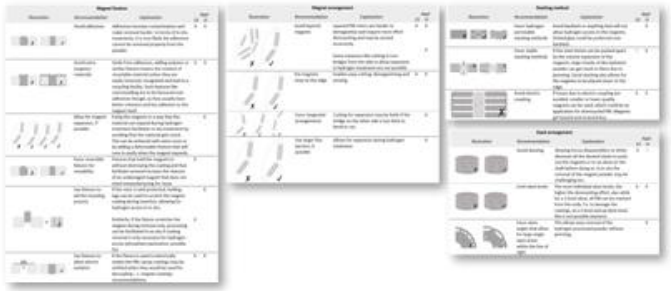


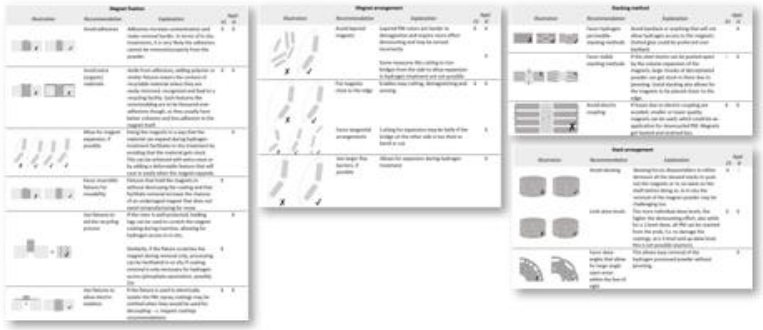
Co-funded by
the European Union

REEsilience

RE Magnets Recycling

Design for Recycling Guide





[…]

- Creation of a D4R guide; evaluation of different design solutions for performance vs. cost vs. recyclability

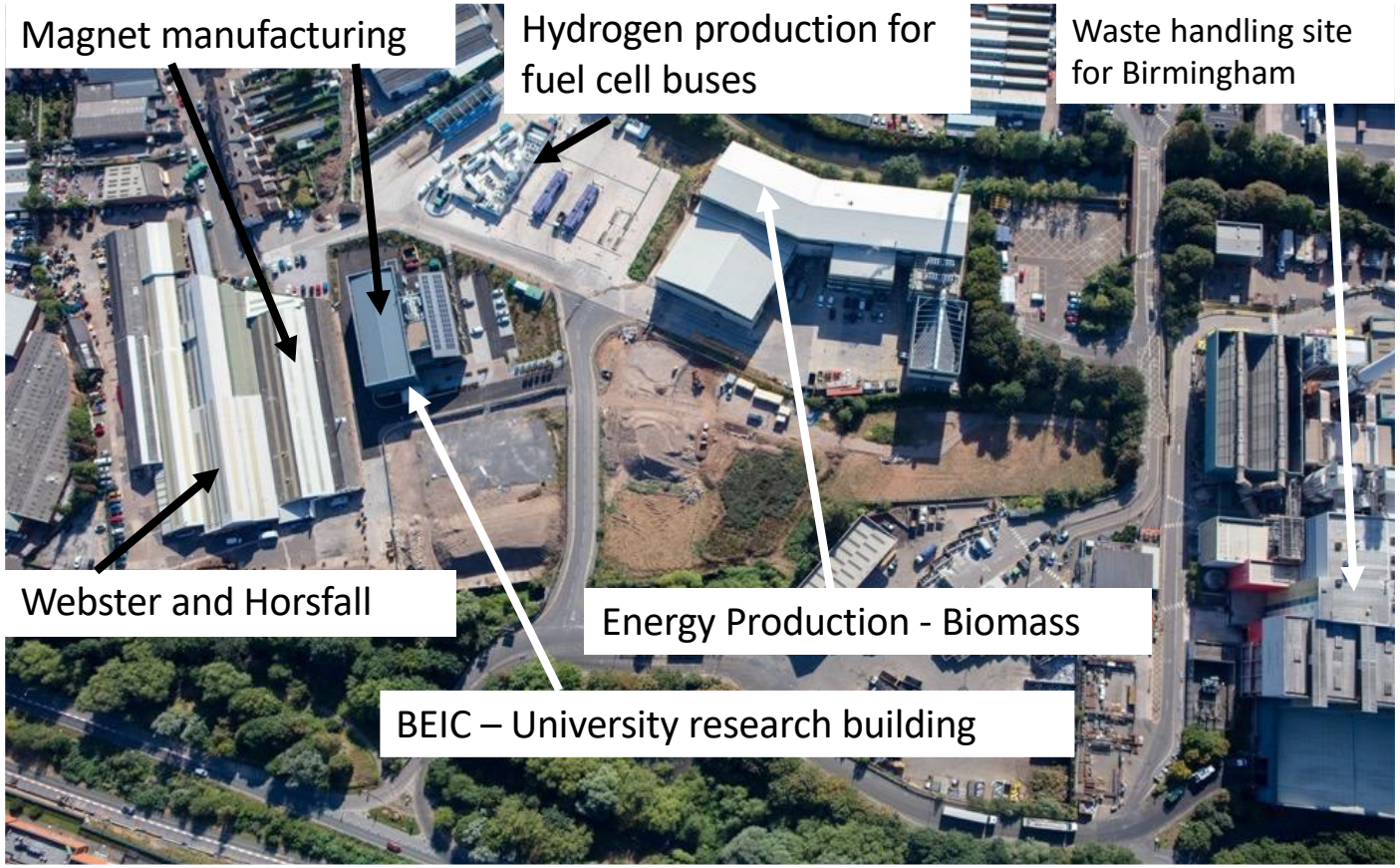
  → Carried out in close-cooperation with Tier1 and OEM

Co-funded by the European Union

REEsilience

Production Scale Up

Tyseley Energy Park (UK)



Co-funded by the European Union

Production Scale Up

Tyseley Energy Park (UK)

Delivery and commissioning of Alignment Presses

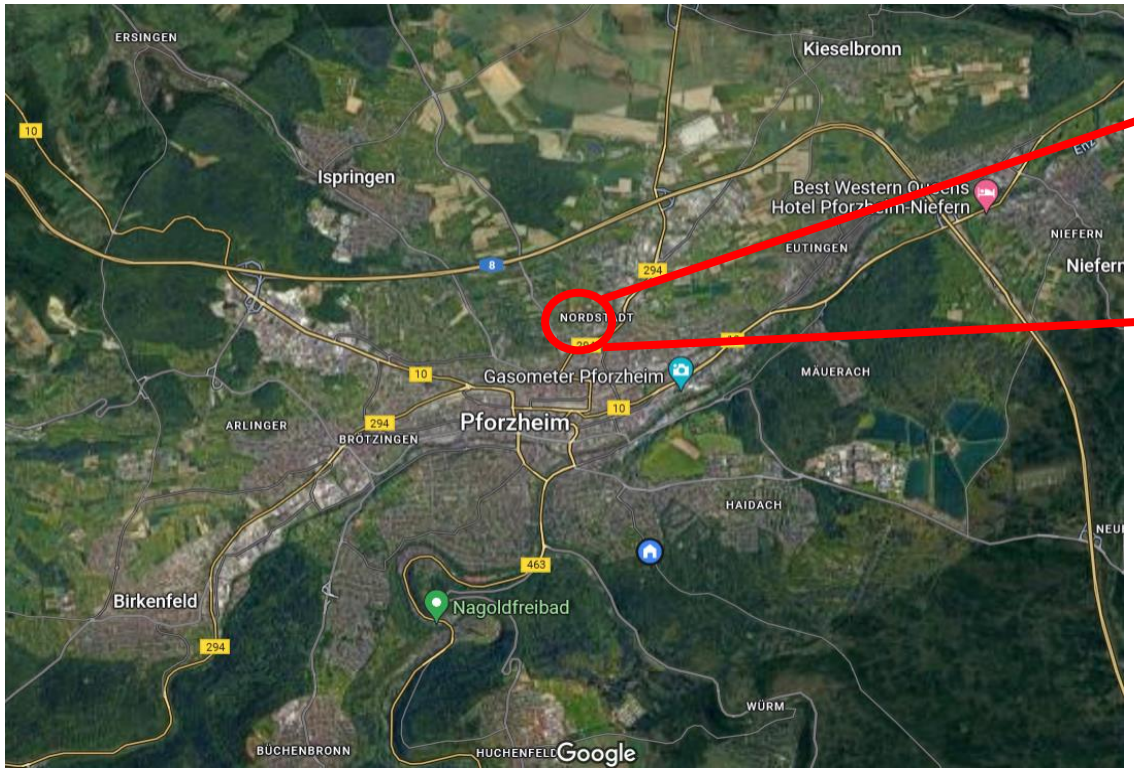
Delivery of Sintering Furnace

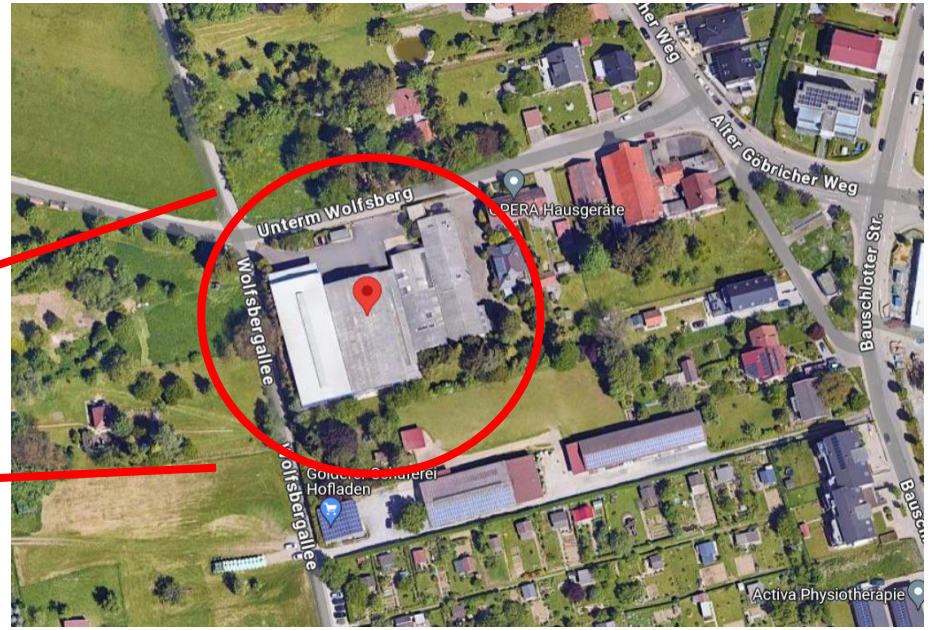
Co-funded by
the European Union

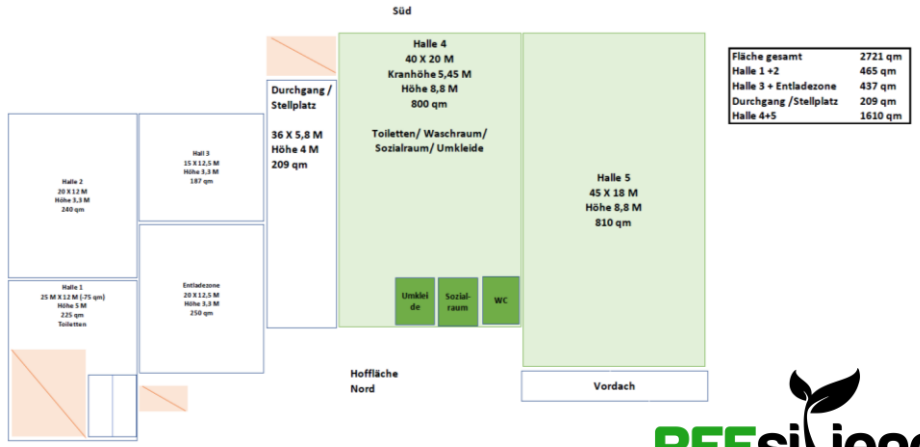
REEsilience

Production Scale Up

Pforzheim (GER)







Co-funded by the European Union

REEsilience

Production Scale Up

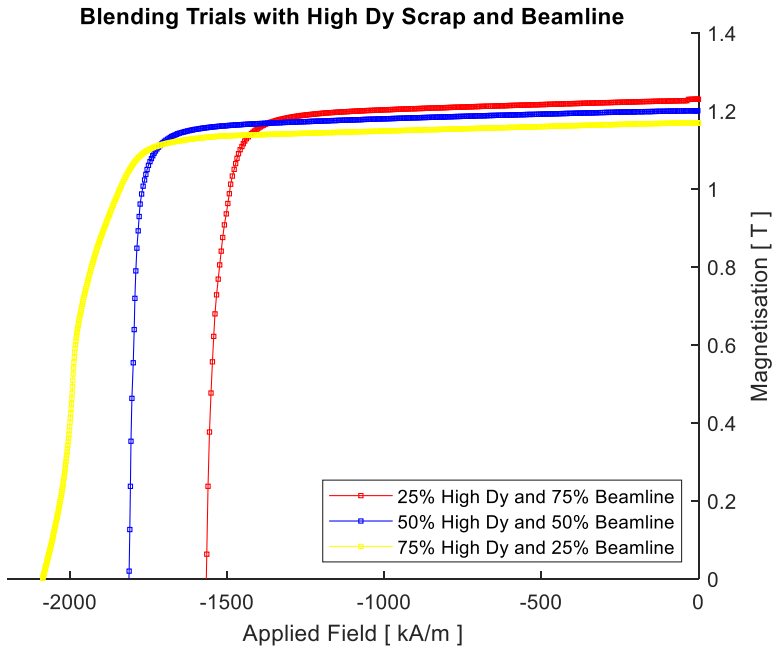
Pforzheim (GER)

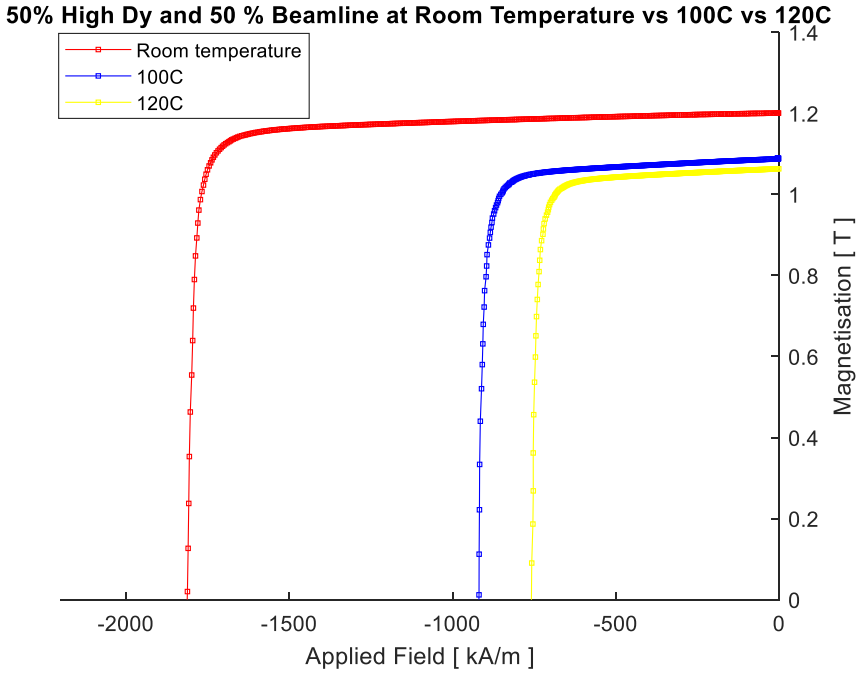
Co-funded by
the European Union

Production Scale Up

Blending of Materials (Pre-Trials)

- Blending of different feedstock, understanding of minor additions (e.g. grain boundary wetting agents)
- Sintering Temperature and Profile Trials





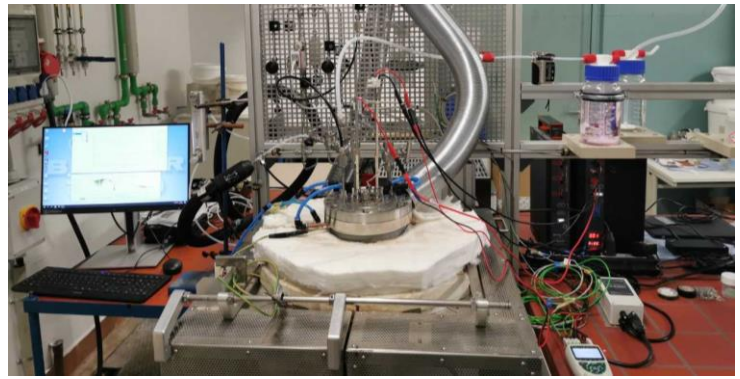
Co-funded by the European Union

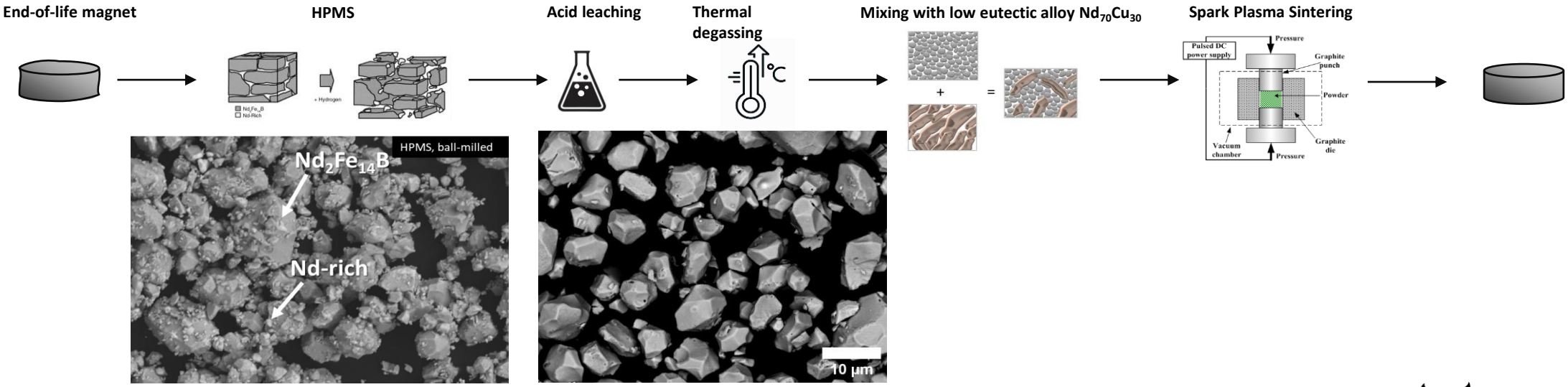
Development of more sustainable magnet production routes

- Development and testing of non-consumables inert anodes for sustainable electrowinning of RE-metals

- Redesign of the grain boundary phase, using low-eutectic alloys

Molten salt electrowinning reactor





Co-funded by the European Union

REEsilience

RE Magnets Recycling

Curriculum „Magnet‘s expert“

Credit Framework (ECTS)

Total number of ECTS for the second-cycle study programme	120 ECTS
Required Courses	55 ECTS
Elective Courses	20 ECTS
Individual Research/Project Work	15 ECTS
Master Thesis	30 ECTS

1st YEAR (50 ECTS)

Required Courses (30 ECTS)

- Introduction to Magnets (5 ECTS)
- Fundamentals of Raw Materials, refining and alloys (10 ECTS)
- Fundamentals of Magnets production (10 ECTS)
- Seminar I (5 ECTS)

Elective Courses (20 ECTS)

- *Magnet simulations and applications (10 ECTS)*
- *Reuse, recycling and circular economy (10 ECTS)*
- *Life Cycle Assessment and Techno-Economic Assessments (10 ECTS)*

2nd YEAR (70 ECTS)

Required Courses (25 ECTS)

- Innovation, Creativity and Intercultural competences
- Leadership skills, entrepreneurship
- Seminar II (5 ECTS)

Project: Individual Research/Project Work (15 ECTS)

Master Thesis (30 ECTS)

- Forming a consortium to roll out the curriculum

Co-funded by the European Union

REEsilience

Thank you very much for your kind attention!

Prof. Dr. Carlo Burkhardt
Pforzheim University
Jožef Stefan International Postgraduate School

www.reesilience.eu

REEsilience

@REEsilience1

carlo.burkhardt@hs-pforzheim.de

Co-funded by the European Union

REEsilience