

Horizon Europe BEETHOVEN and GREENE projects: substitution of Rare-Earth for the development of novel magnets and applications

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CNR-IMEM, Parco Area delle Scienze 37/A, 43124 Parma, Italy

Le sostanze abilitanti: materie rare e critiche e il ruolo della ricerca chimica

Milan, 6th October 2026

Funded by the European Union

BEETHOVEN and GREENE have received funding from the European Union's Horizon Europe programme under the agreements 101129912 and 101129888, respectively. Views and opinions expressed are however those of the authors(s) Only and are not necessary reflect those of the European Union or of the European Health Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.

IMEM-CNR for magnets

MATERIALI MAGNETICI E MULTIFERROICI

imem



www.imem.cnr.it

IMEM-CNR for magnets

New Materials

Processing

Recycling

Permanent Magnet Expertise

RE-intermetallic materials (2:14:1, 2:17)
Nano and micron hexaferrites
Novel RE free magnets
Hybrid nanomaterials

Characterization techniques
Reversal process
Nano to Bulk
Recycling

Projects

Funded by the European Union

nanoJUMP AMPHIBIAN INSPIRES BEETHOVEN greene MOST CENTRO NAZIONALE PER LA MOBILITÀ SOSTENIBILE hyperMag MADELEN

BEETHOVEN and GREENE projects

Magnets in life

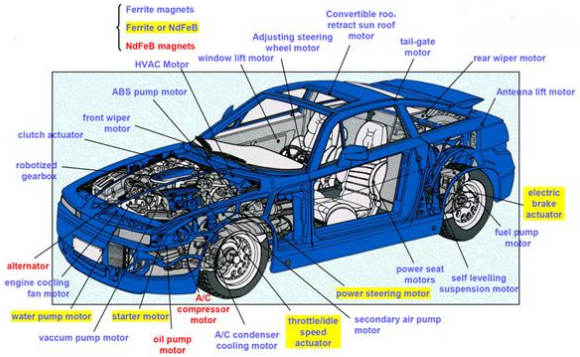




Fridge magnets



Motors
generators



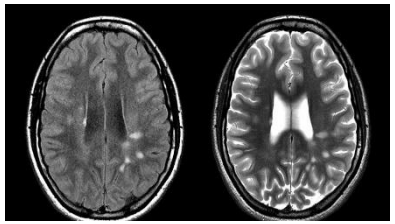
Vehicles



Wind turbine



Magnetic levitation



Magnetic resonance devices



Magnetic fridges



Buzzels

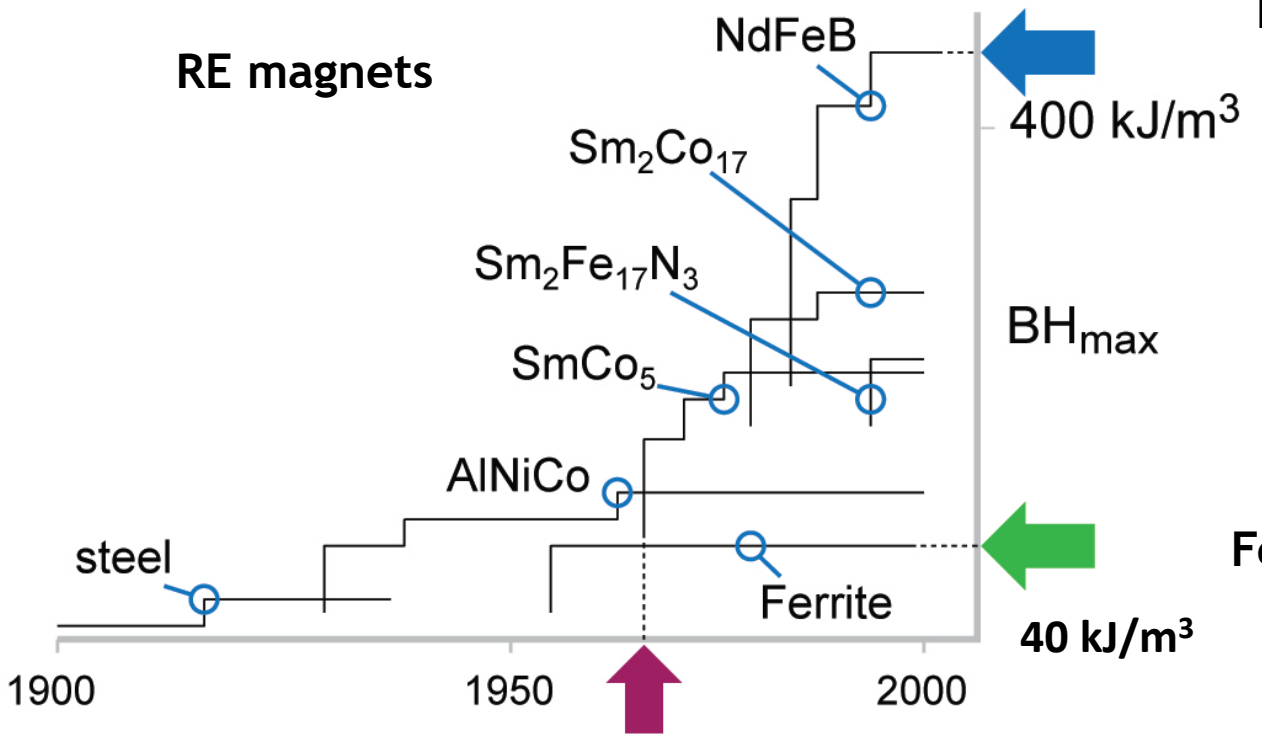


Speakers



Magnetic
recording

Hard magnetic materials



Improving magnetic properties in the past 100 years.

NdFeB magnets

M_s=1.6 T, H_A=8T

Complex metallurgy

40-100 €/kg

Ferrite magnets

M_s=0.4 T, H_A=1,8T

Insulator

High temperature behaviour

6 €/kg

Rare-Earth Magnets in the Green Transition

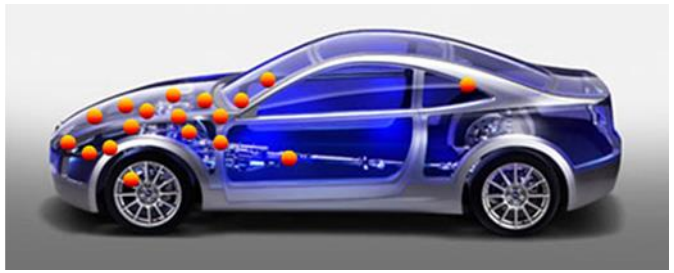


Magnets constitute key elements of many Green Transition technologies

Wind turbines



Electric mobility

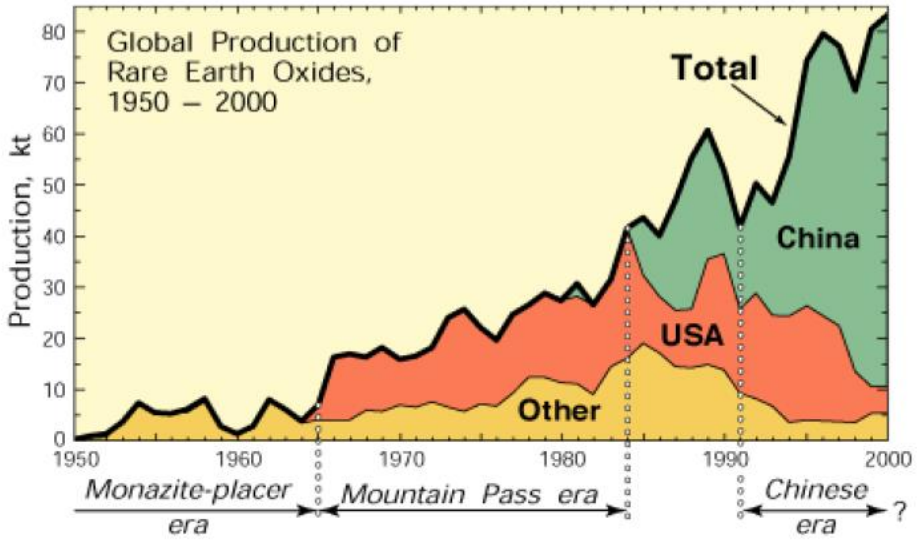


Reduction of CO2 emissions
Green Energy
Low Carbon technologies

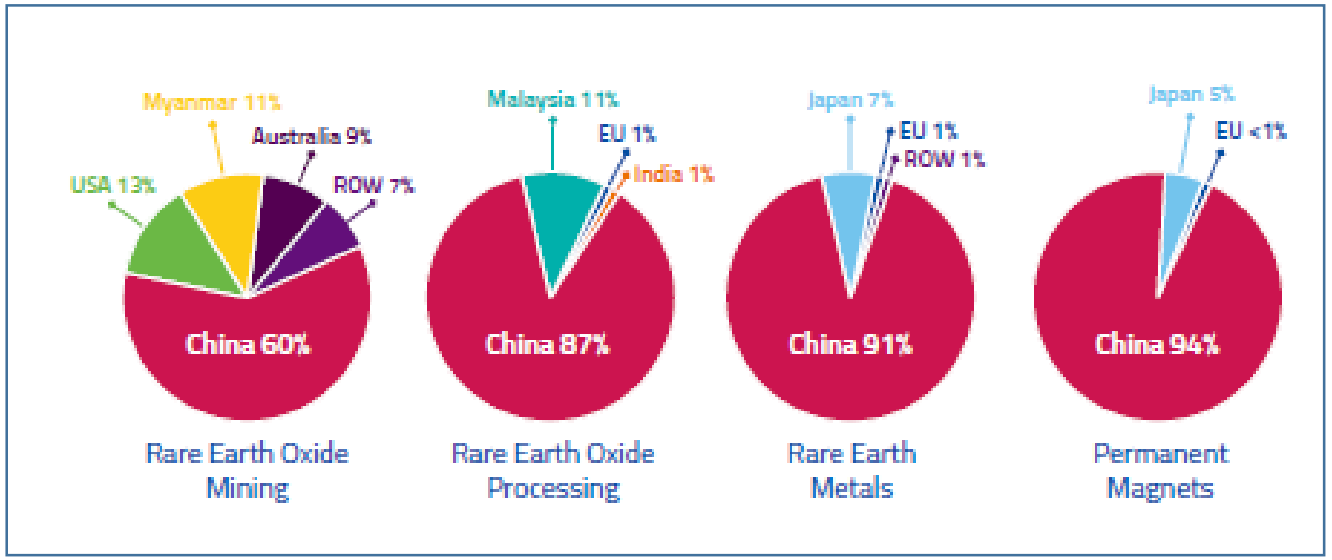
BEETHOVEN and GREENE projects

Permanent magnets production

RE production



Today (2021)

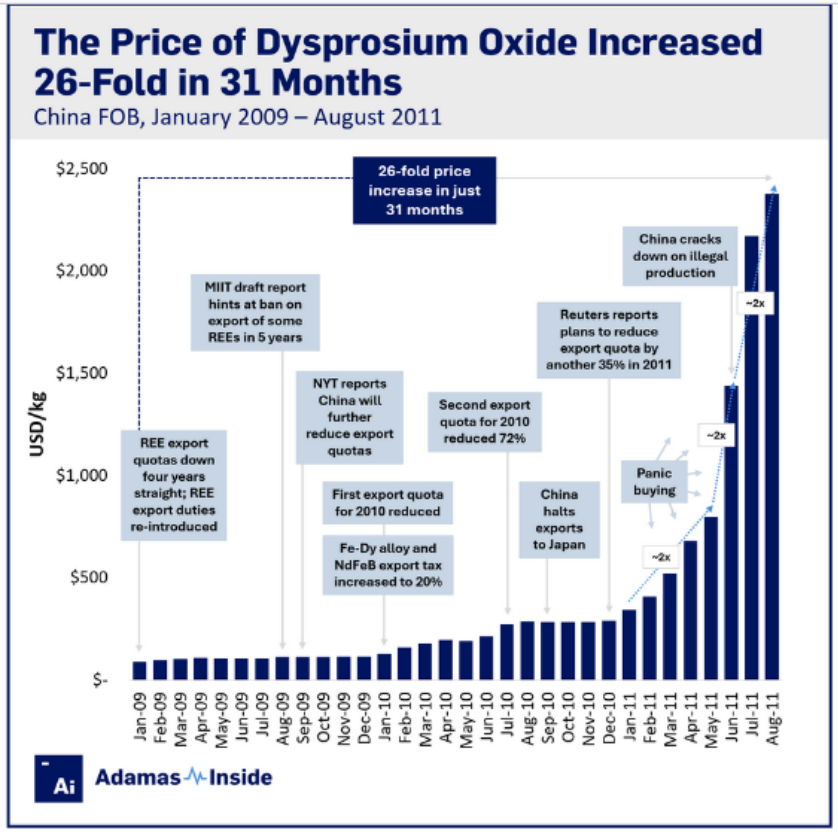


Monopoly of the magnet's supply
Almost NO EU producer

Gauß et al. Rare Earth Magnets and Motors: A European Call for Action. A report by the Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance. Berlin 2021

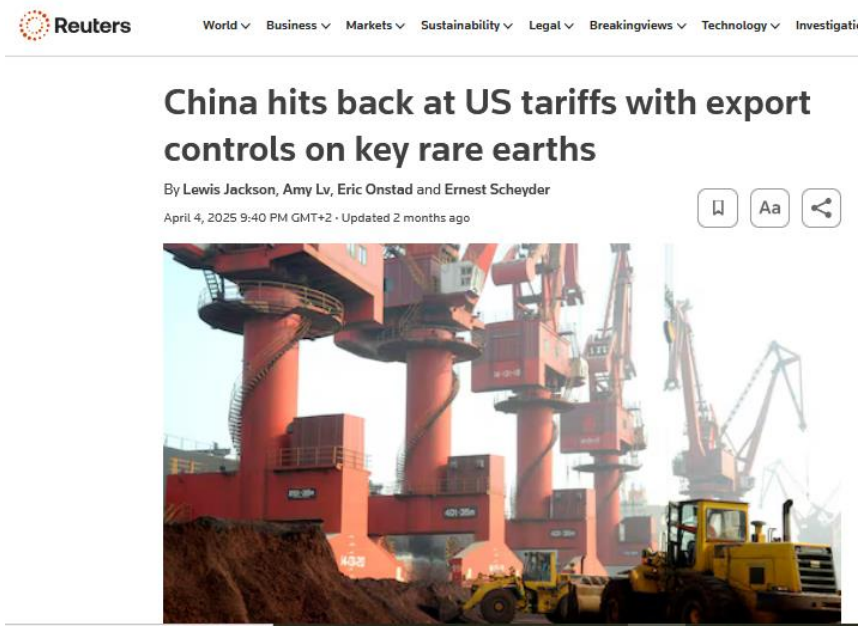
Geopolitical crisis

2012



January 2009: $91/kg

2025



The EU answer

CRM Lists

European Commission, Study on the EU's list of Critical and Strategic Raw Materials 2011- 2025

Political actions

EUROPEAN CRITICAL RAW MATERIALS ACT

SETTING 2030 BENCHMARKS FOR STRATEGIC RAW MATERIALS

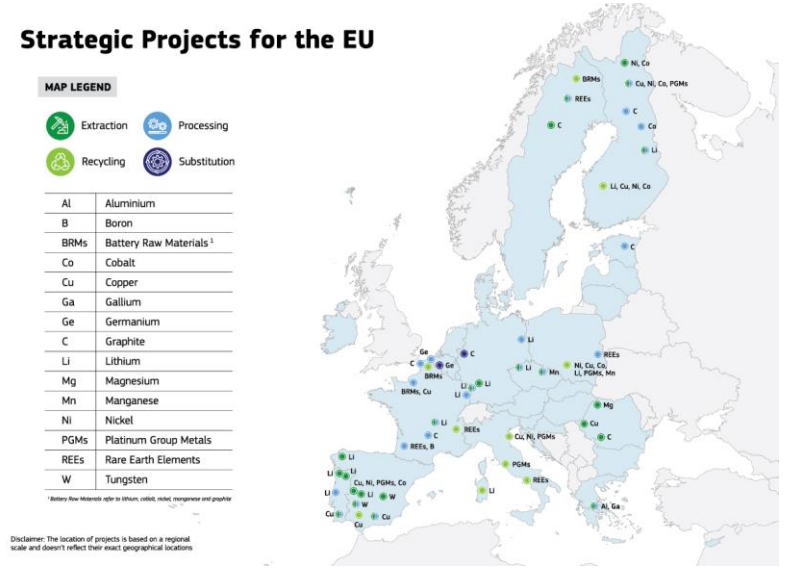
EU EXTRACTION
At least **10%** of the EU's annual consumption for extraction

EU PROCESSING
At least **40%** of the EU's annual consumption for processing

EU RECYCLING
At least **15%** of the EU's annual consumption for recycling

EXTERNAL SOURCES
Not more than **65%** of the EU's annual consumption of **each strategic raw material at any relevant stage of processing** from a single third country

Economical actions



Pulawy Rare Earths Separation Plant Mkango Resources Ltd.

MagFactory MagREEsource

LIFE-22-ENV- IT- INSPIREE Itelyum Regeneration SpA |

ReeMAP Project: Malmberget, Lulea Industrial Park

CAREMAG CAREMAG SAS

Cross-institutions projects

eit RawMaterials Connecting matters

EUROPEAN RAW MATERIALS ALLIANCE | ERMA

BEETHOVEN and GREENE projects

MATERIALI MAGNETICI E MULTIFERROICI imem

The EU answer

Scientific projects

SUSMAGPRO
SUSTAINABLE RECOVERY, REPROCESSING AND REUSE OF RARE-EARTH MAGNETS IN THE CIRCULAR ECONOMY

NEOHIRE

DEMETER
EU MSCA-ETN

VALOMAG

nanoMyne

REMANENCE

PERMANET

MAGELLAN
MAGnets in rEsiLient supply chAiNs

PASSENGER
FOR SUSTAINABLE AND EFFICIENT RE-FREE MAGNETS

REM Hub

AMPHIBIAN

SICAPERMA

CIRCUIT4EU

CoCoMag

SUPREEMO

NEW-RE

INSPIRES

LOW REE MOTORS

eit RawMaterials
Connecting matters

HORIZON-CL4-2023-RESILIENCE-01-37
Advanced materials for magnets in applications for the New Energies Market (RIA)

greene

BEETHOVEN

MagNEO

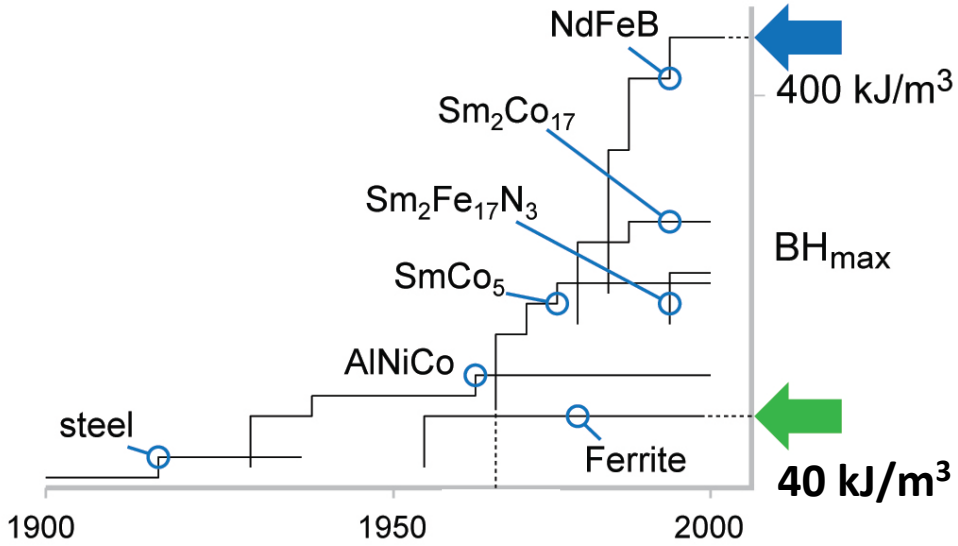
BEETHOVEN and GREENE projects

HORIZON-CL4-2023-RESILIENCE-01-37 - Advanced materials for magnets in applications for the New Energies Market

Production of RE-free or RE lean magnets

Independent, resilient and scalable supply of key materials, magnets and components within Europe

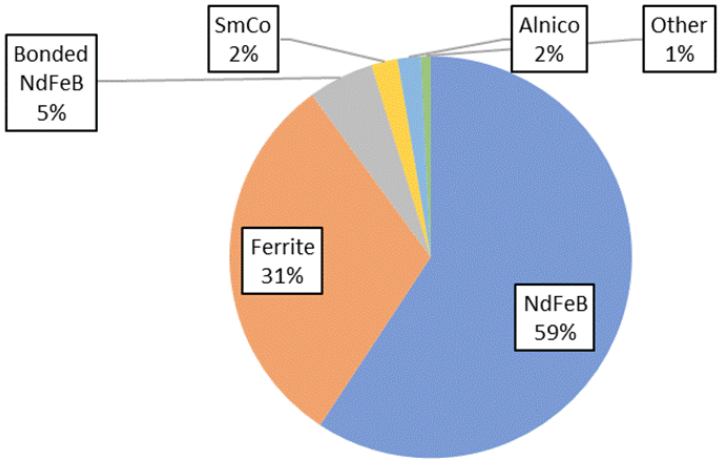
Society and stakeholders better equipped for a sustainable green transition in Europe



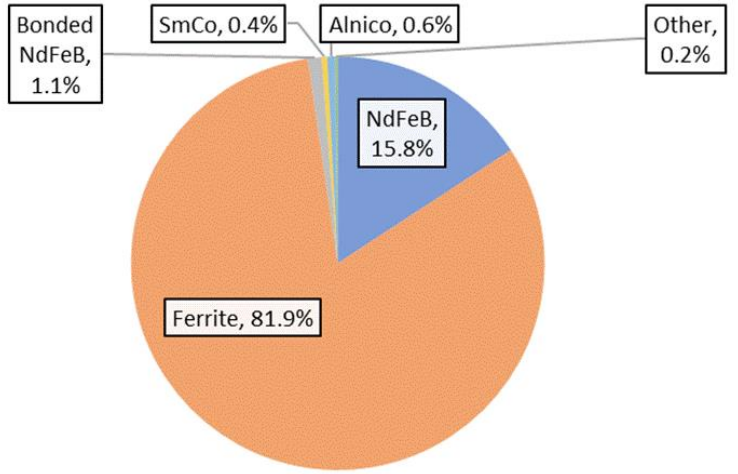
BEETHOVEN and GREENE projects

Market of the Magnets

Market ($) Is Dominated By NdFeB And Ferrite



Production (Tons) Is Dominated By Ferrite



The BEETHOVEN Project

SUBSTITUTION OF RARE-EARTHS FOR ADVANCED NOVEL MAGNETS IN ENERGY AND TRANSPORT APPLICATIONS



Project Leader:
Dr. Adrian Quesada
Institute of Ceramics and Glasses
Spanish Research Council
E-mail: e-mail: a.quesada@icv.csic.es
https://projectbeethoven.eu/

7.7 M€

4 years

BEETHOVEN has received funding from the European Union's Horizon Europe programme under the agreement 101129912. Views and opinions expressed are however those of the authors(s) Only and are not necessary reflect those of the European Union or of the European Health Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.

The BEETHOVEN Project

SUBSTITUTION OF RARE-EARTHS FOR ADVANCED NOVEL MAGNETS IN ENERGY AND TRANSPORT APPLICATIONS

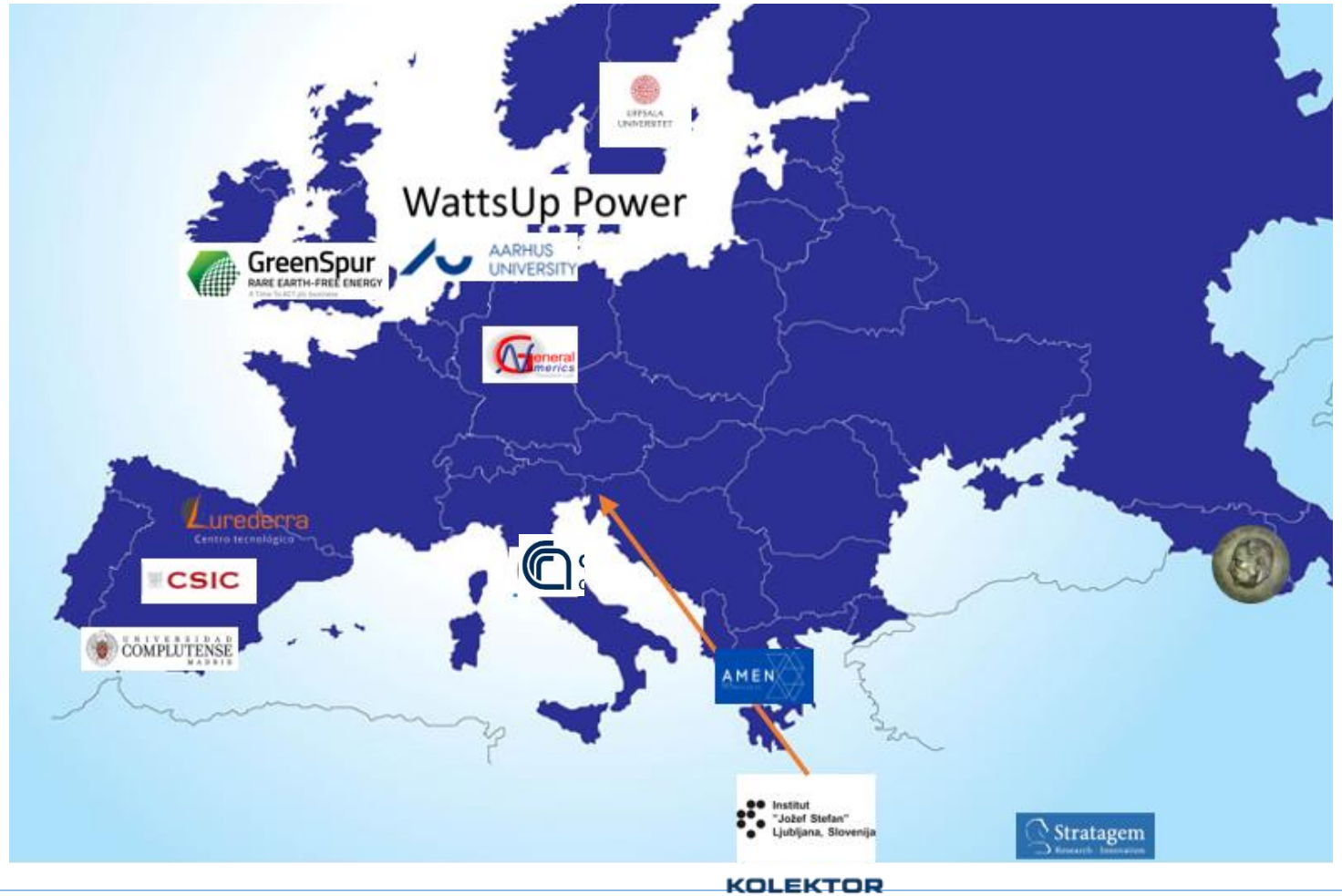
14 partners

10 countries

Consiglio Nazionale delle Ricerche

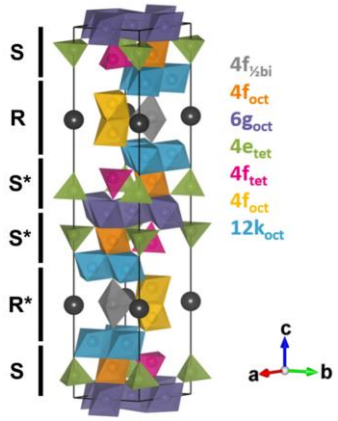
imem
Parma

iCCOM Istituto di Chimica dei Composti Organometallici
Consiglio Nazionale delle Ricerche
Sesto Fiorentino



Materials

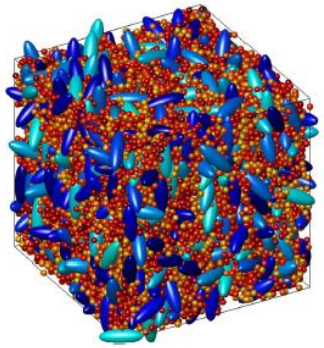
New (old) Oxides



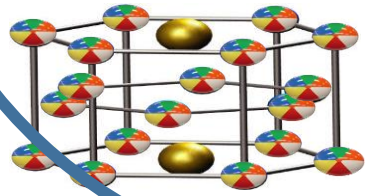
Composites



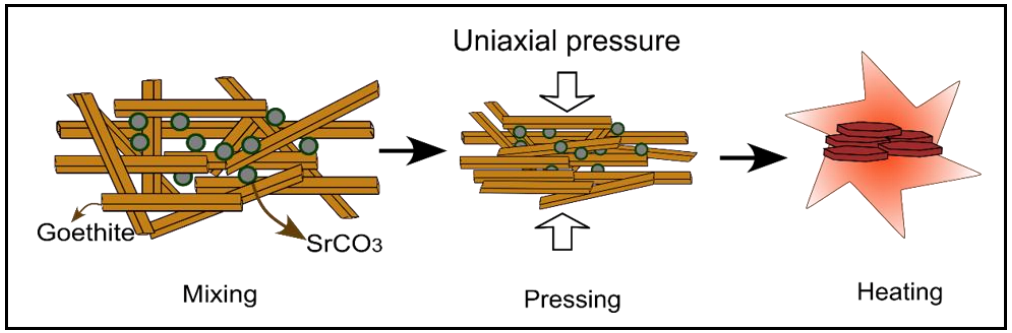
Simulations



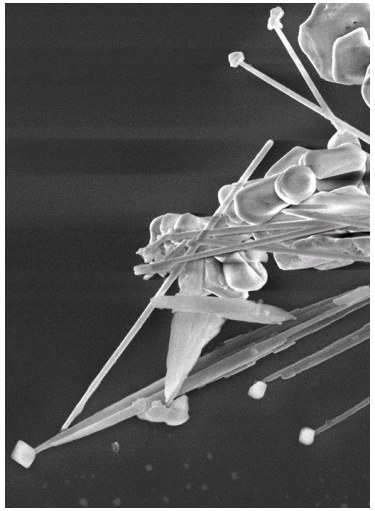
Lean-RE alloys



W- ferrite phase



Strontium ferrite-Fe Nanowires



Up-scaling

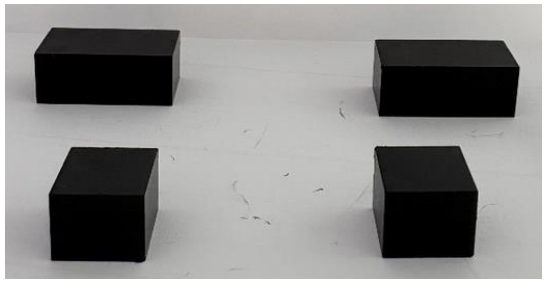
Materials production



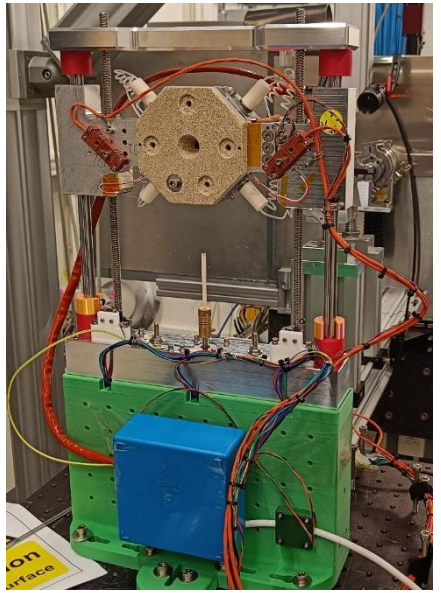
Pilot plants

Use of commercial
(nano) precursors

Magnets production



Conventional production



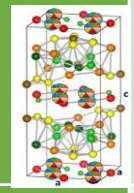
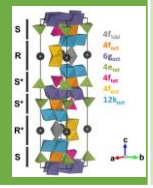
Ultra-fast treatments



HP densification

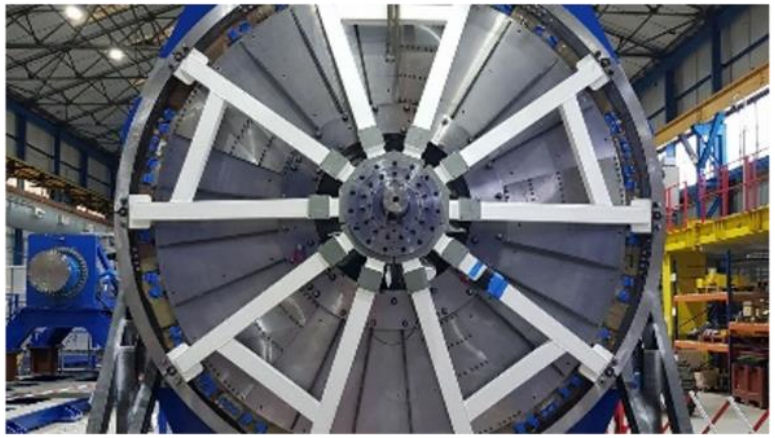
Green precursors – recycling criteria- Sustainability

BEETHOVEN magnets

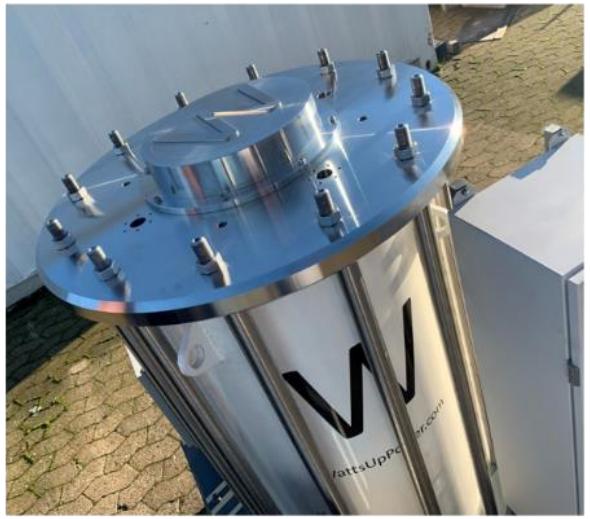
Material	Ms(Am^2/kg)	Tc (K)	Hc (expected) (T)	$(BH)^{theor}_{max}$ (kJ/m^3)	Substitution potential	Estim. cost (€/kg)	Advantages	Drawbacks
$(RE\text{-}HEAs)_2$ $-Fe_{14}B$ 	125-145	550-600	>1	55-220	20-40% of NdPr-Dy	50-60 €/kg	High BH	Lower subtitution potential
$SrFe_{12}O_{19}$ -FeCo NWs composites 	65-100	723 K	>0.3	55-65	100% of NdPr-Dy	40 €/kg	High subtitution potential. High Tc	Lower BH, challenging scalability
W-type Ferrites 	80-91	700 K	>0.4	55-70	100% of NdPr-Dy	50 €/kg	High subtitution potential, Scalability	Lower BH, low coercivity

Novel materials for gap magnets → **Performances > 30% ferrites** **RE-free/lean magnets** **Low costs**

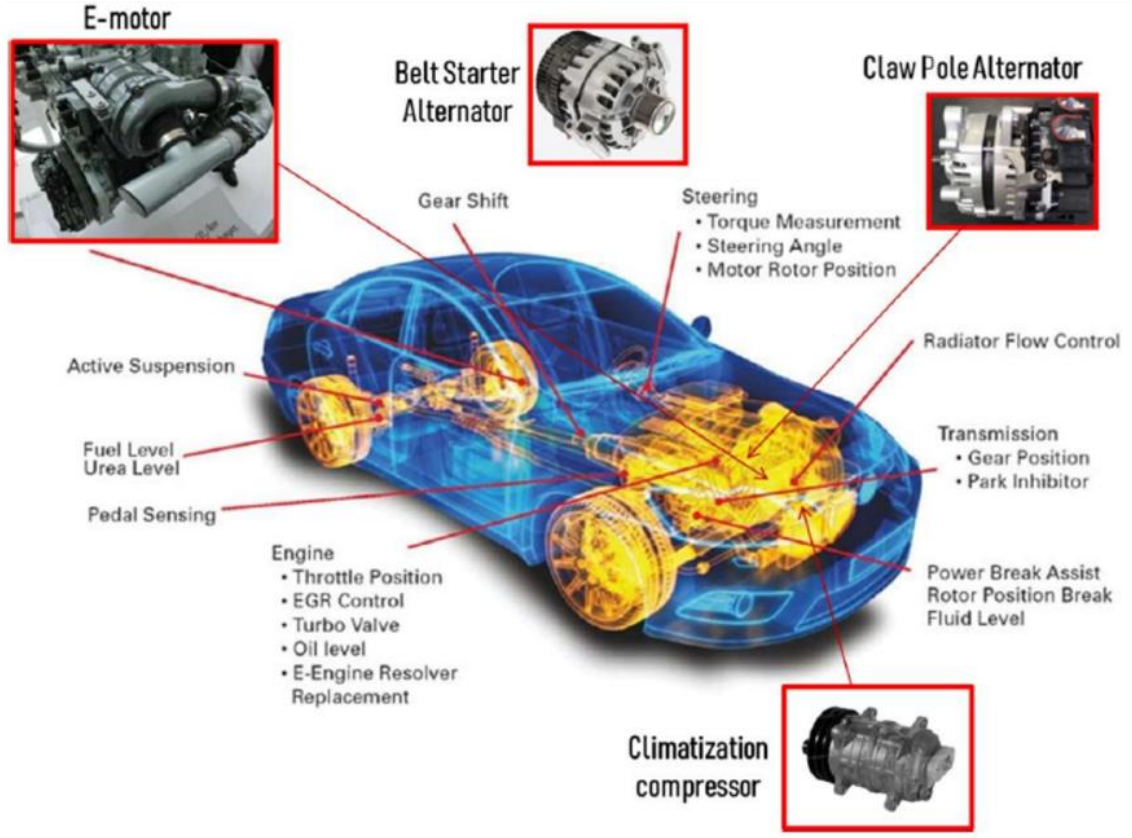
Beethoven Applications



REE-lean wind 5 kW wind turbines



Ferrite based flywheels



REE free Motors and pumps in electric vehicles

Funded by
the European Union

Single-grain Re-engineered Nd-Fe-B Permanent Magnets

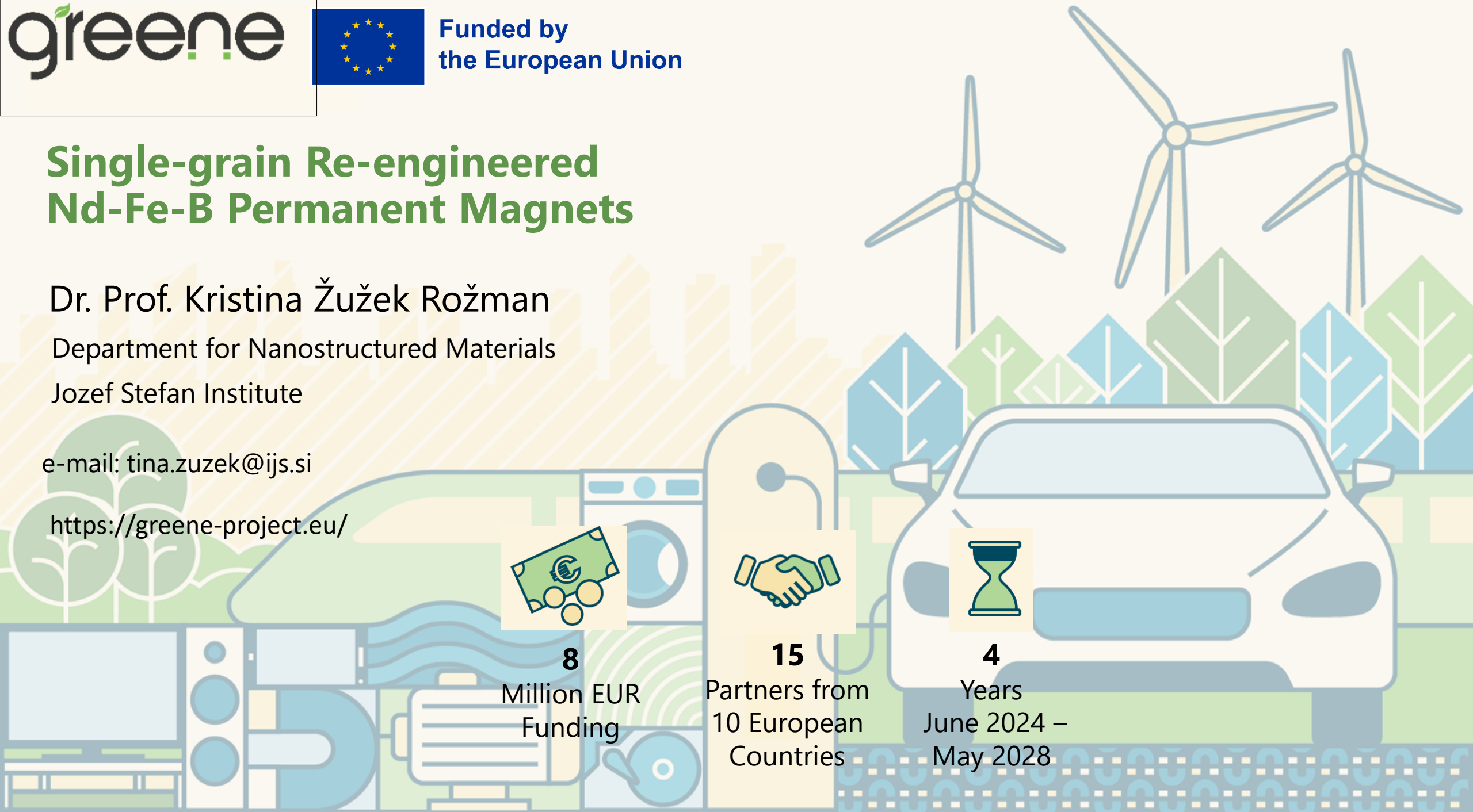
Dr. Prof. Kristina Žužek Rožman

Department for Nanostructured Materials

Jozef Stefan Institute

e-mail: tina.zuzek@ijs.si

https://greene-project.eu/

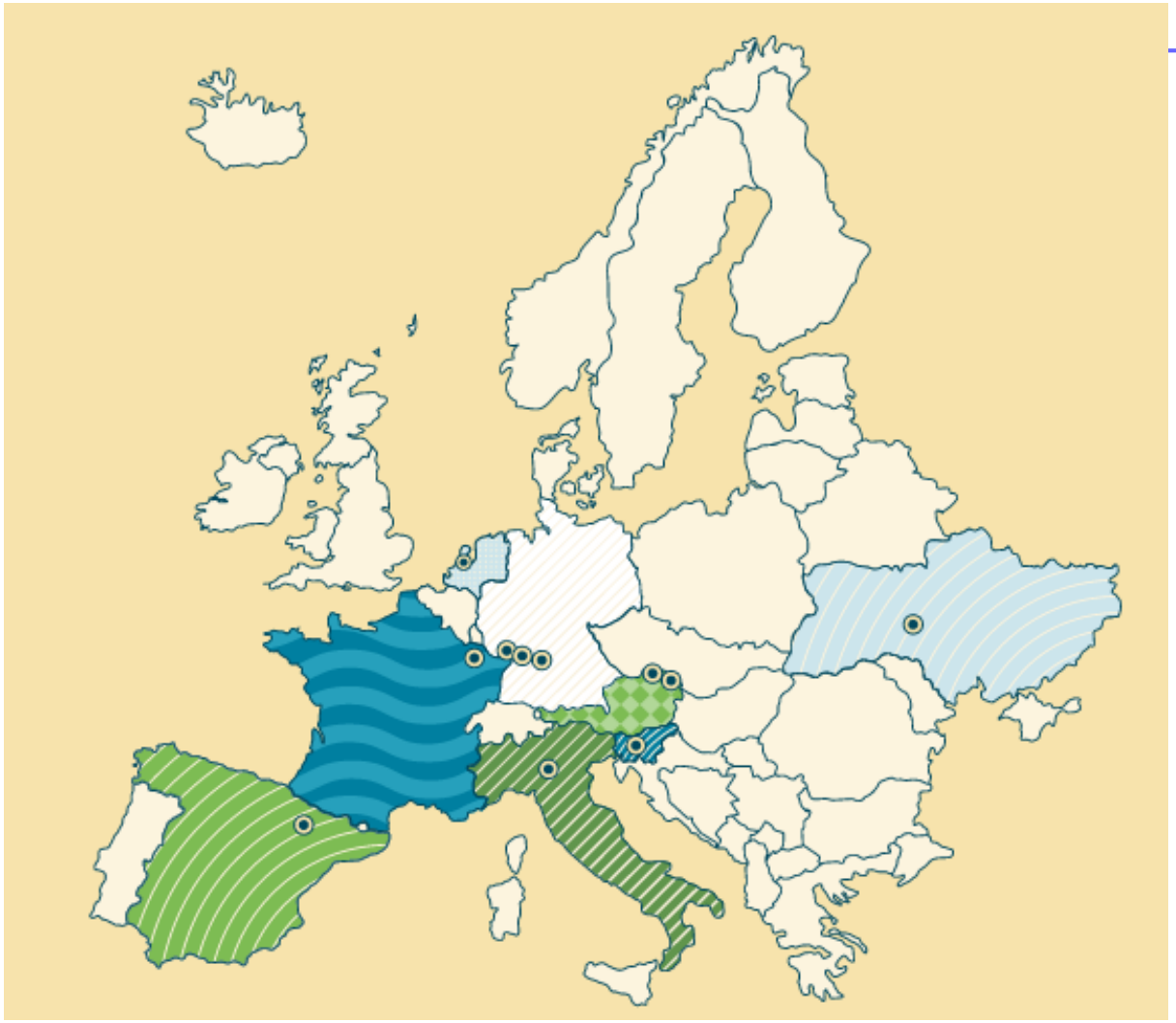


8
Million EUR
Funding

15
Partners from
10 European
Countries

4
Years
June 2024 –
May 2028

GREENE CONSORTIUM



Jožef Stefan Institute

HS PF

DONAU UNIVERSITÄT KREMS

CSIC
Consejo Superior de Investigaciones Científicas

Universidad Zaragoza
1542

Hochschule Aalen

VNTU

cnrs

MAGNETI LJUBLJANA, d.d.

Steinbeis Europa Zentrum

Universiteit Leiden
The Netherlands

Consiglio Nazionale delle Ricerche

TU WIEN
TECHNISCHE UNIVERSITÄT WIEN

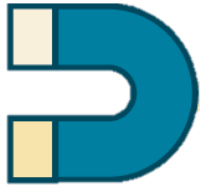
HYPROMAG
Magnet Recycling

BOSCH

PROJECT GOALS



Resource efficient, high-performance Nd-Fe-B magnets with -20% RE content, +20% coercivity, and maximum energy product +20%

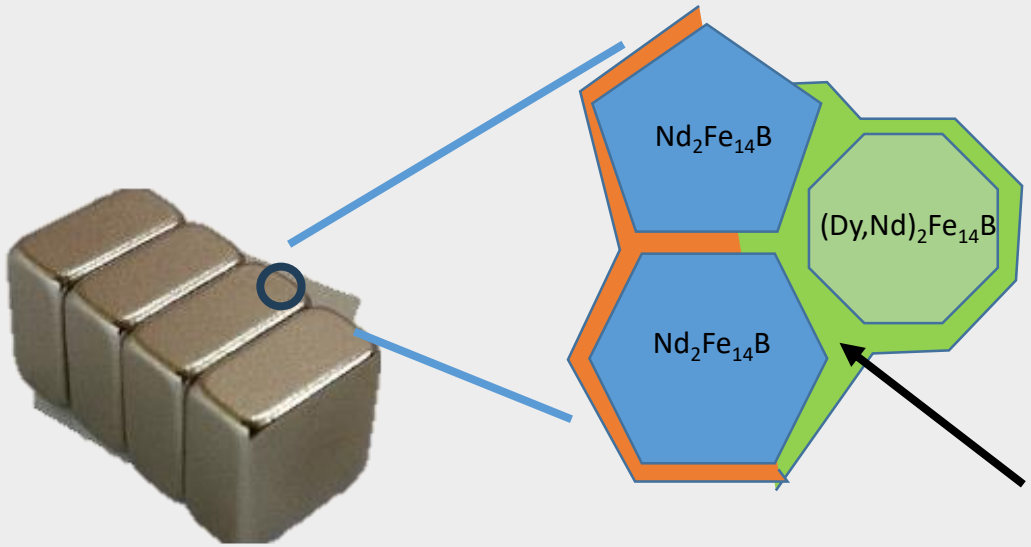


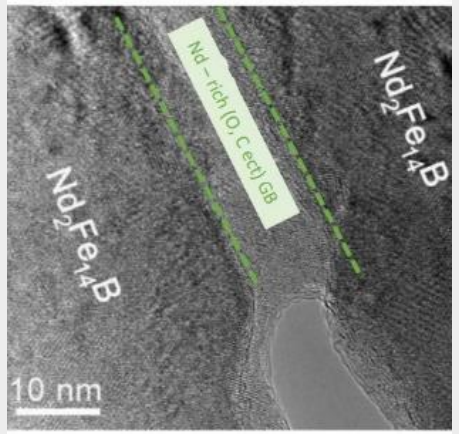
Increased sustainability of magnet production with -5% scrap rates, -15% energy consumed and -30% toxicity

GREENE CONCEPT

Redesigned rare-earth magnets

Key role of intergranular region





A. Mazilkin Mater. Desig. 199 (2021)

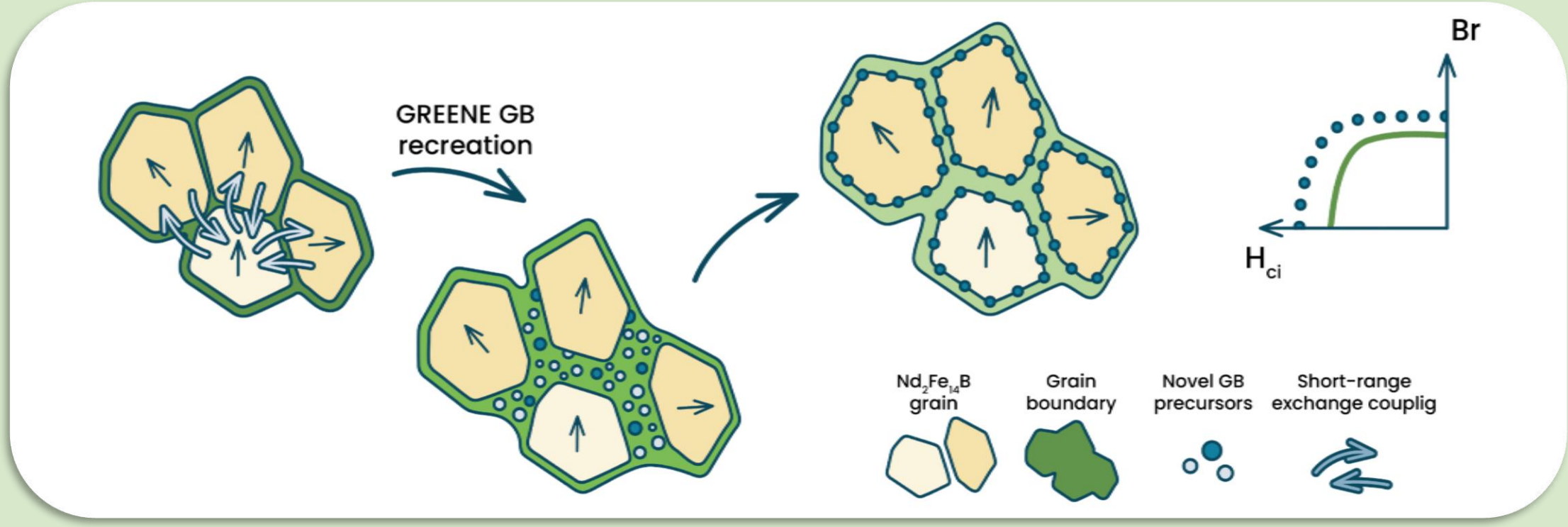
Optimized magnets require

- Excess of REEs in PMs
- Dy and Tb REE

Funded by
the European Union

GREENE CONCEPT

Redesigned rare-earth magnets



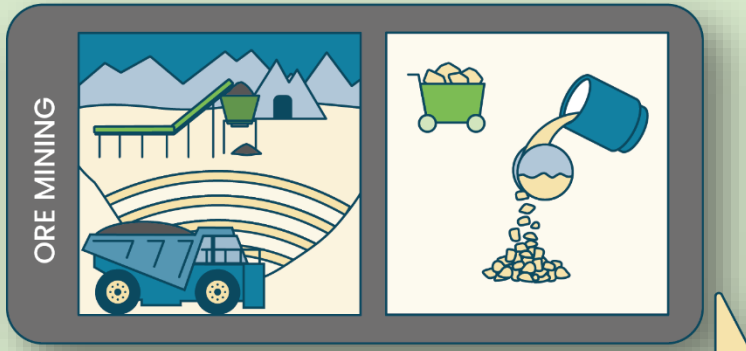
Models & Simulation

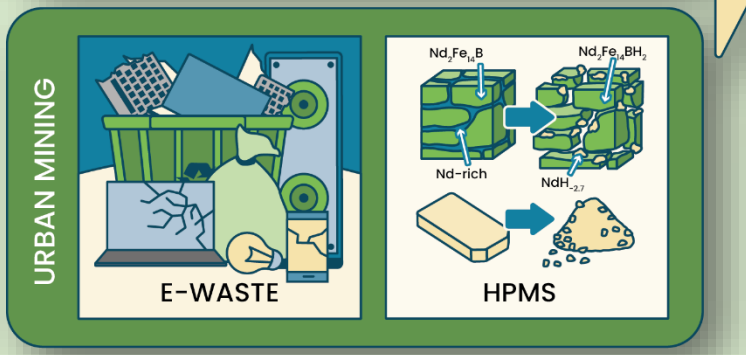
Optimisation of the grain boundary & Production of magnets **with enhanced properties and less critical materials**

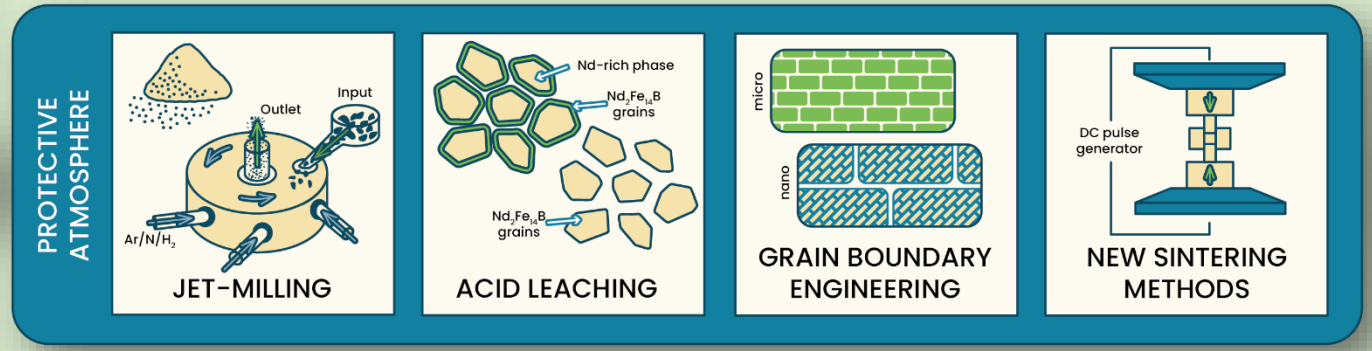
Funded by the European Union

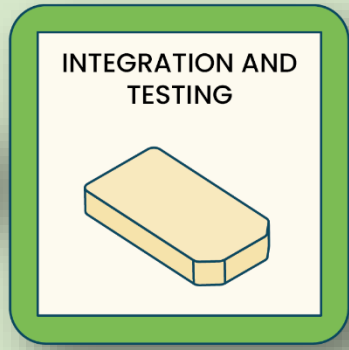
GREENE CONCEPT

A complete value chain









Applications



Magnets

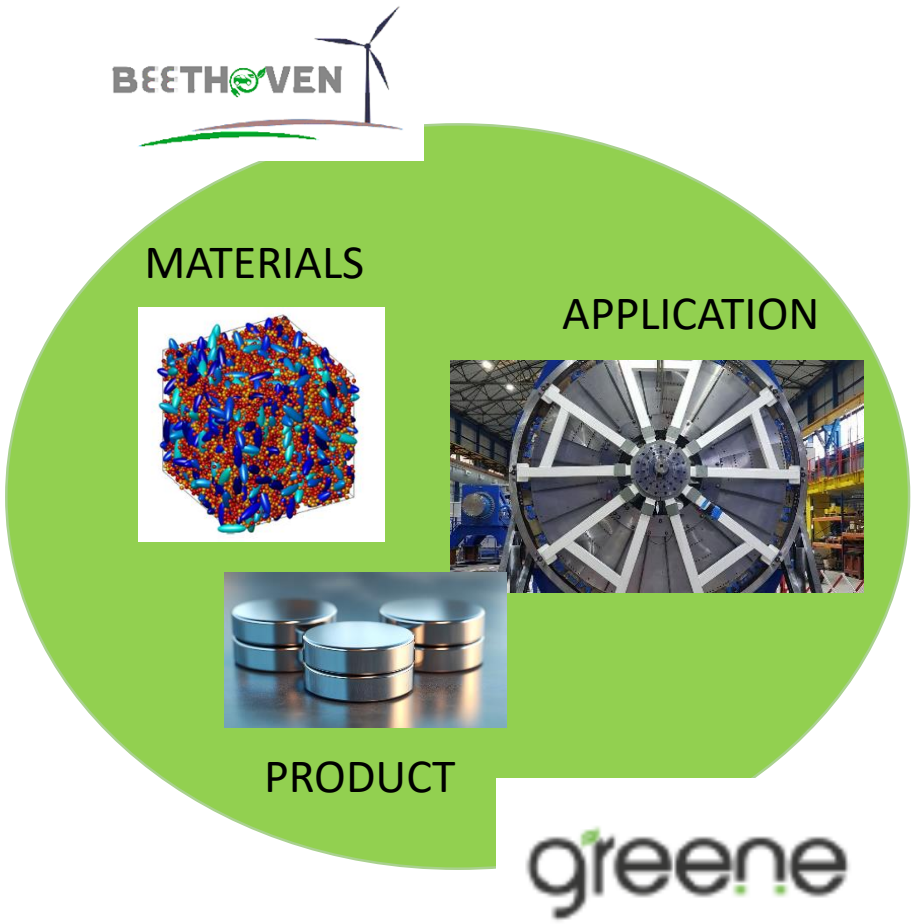


Motors

greene

Funded by the European Union

Beethoven and Greene



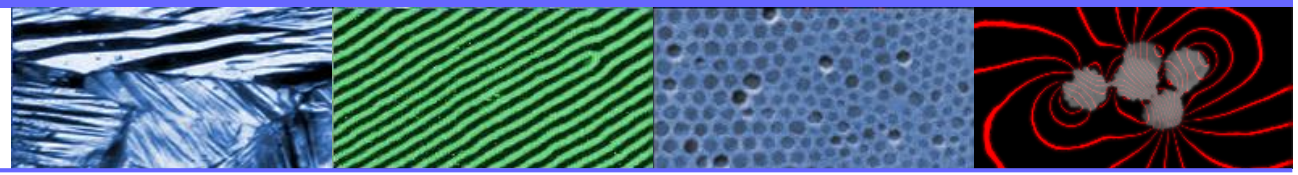
Sustainability

- Green precursors
- Cold production
- Final recycling

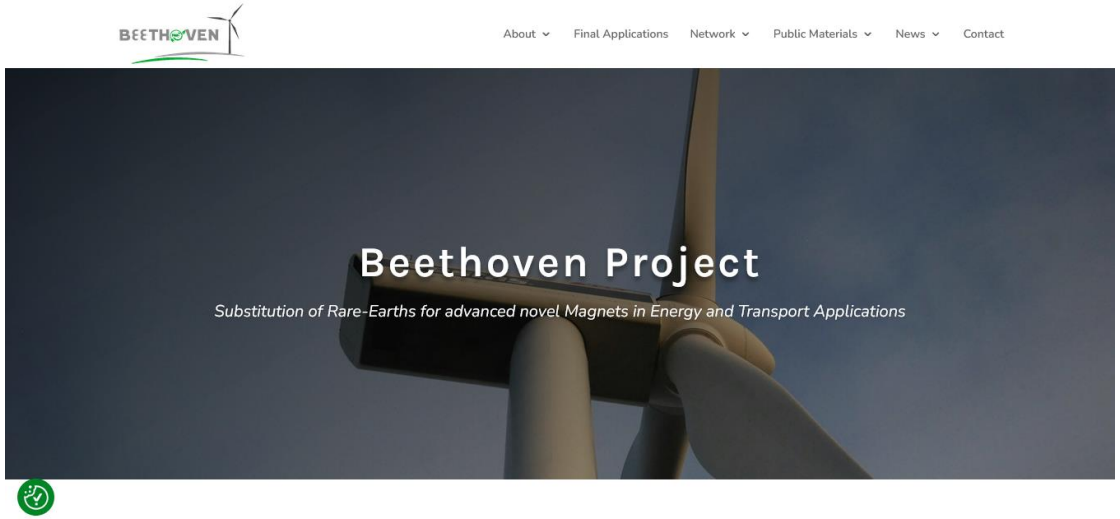
- Life and social cycle assessments

Techno-Economic Assessment including Cost-Benefit Analysis

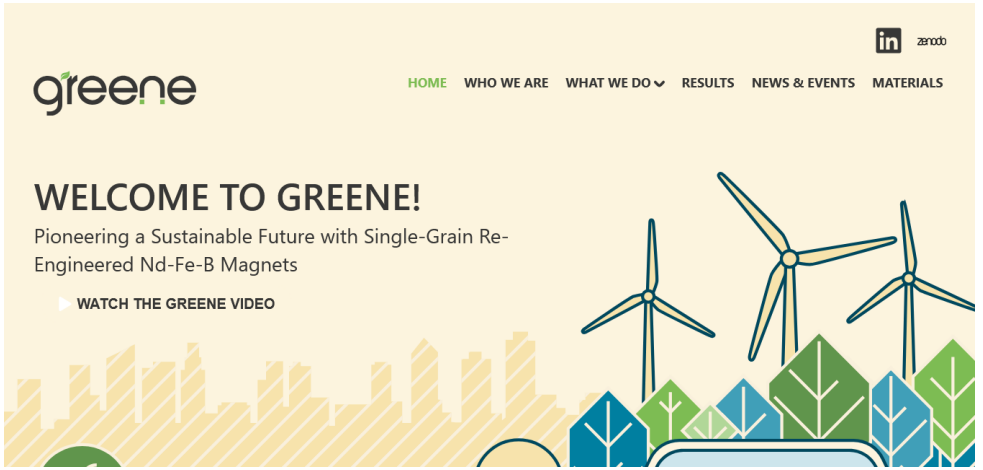
Istituto dei Materiali per l'Elettronica e il Magnetismo
Consiglio Nazionale delle Ricerche



https://projectbeethoven.eu/



https://greene-project.eu/



Talking Magnets Summer School 2027

From Fundamentals to Sustainable Permanent Magnets

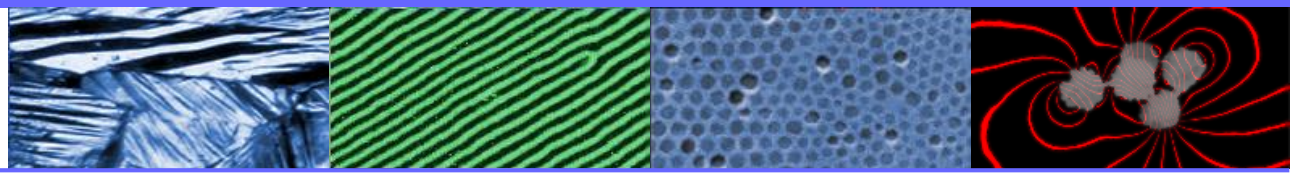
La Cristalera, Miraflores de la Sierra (Madrid) · 25–27 May 2027

Jointly organised by the Horizon Europe projects BEETHOVEN, GREENE and MagNEO

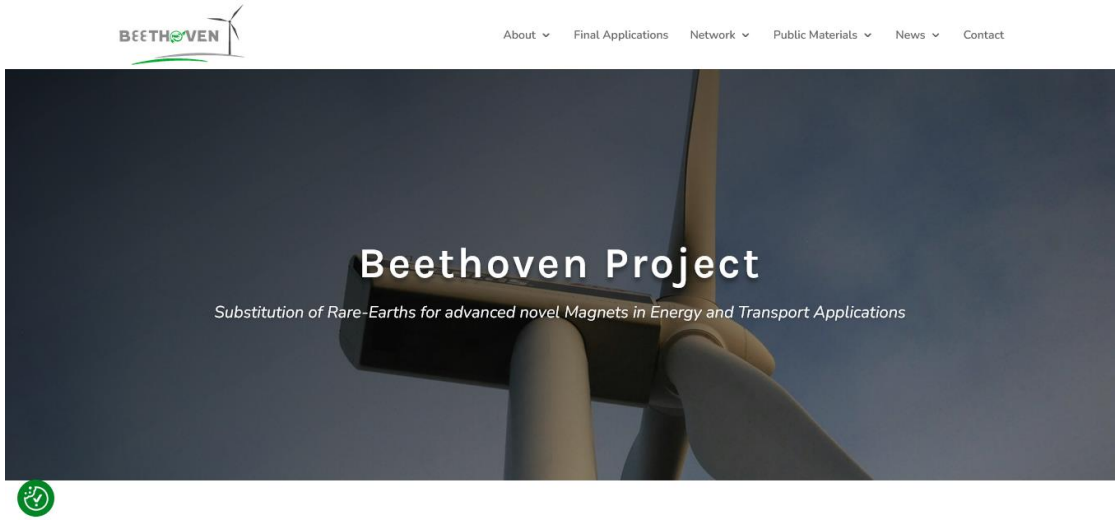
Funded by the European Union

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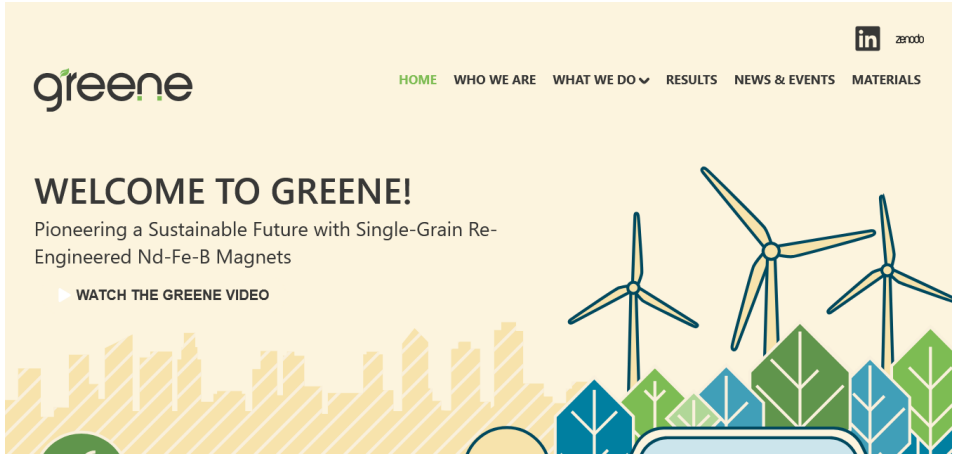
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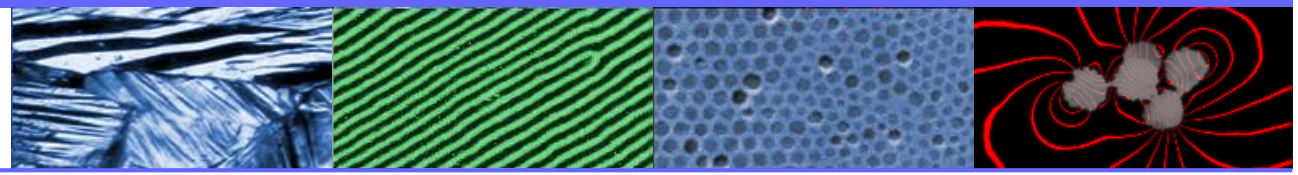
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Thanks for your attention

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