ERA-MIN 2
RESEARCH & INNOVATION PROGRAMME ON RAW MATERIALS TO FOSTER CIRCULAR ECONOMY

MaXycle

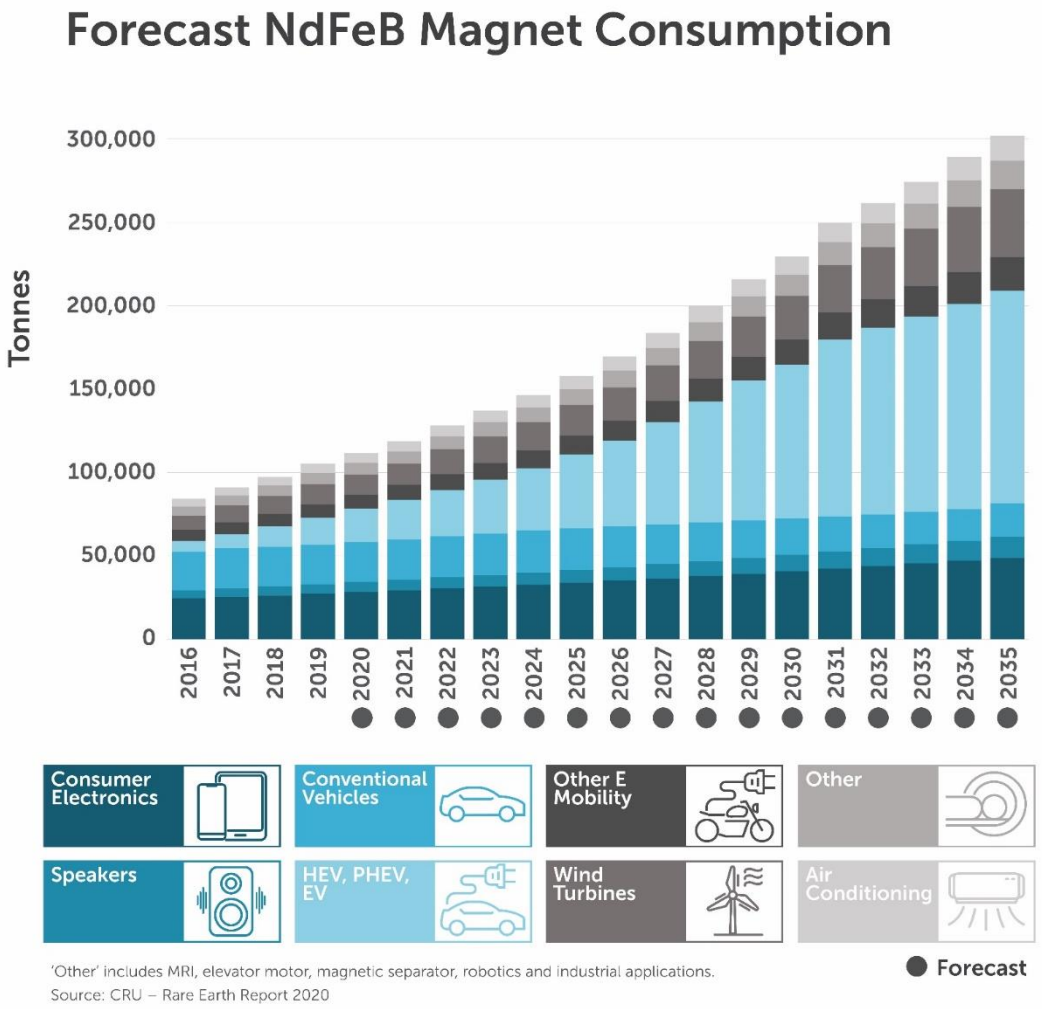
MaXycle

A novel circular economy for sustainable RE-based magnets

Coordinator: Spomenka Kobe, Jožef Stefan Institute

ERA-MIN 2 Final Conference,
virtual, 18th-19th November, 2021

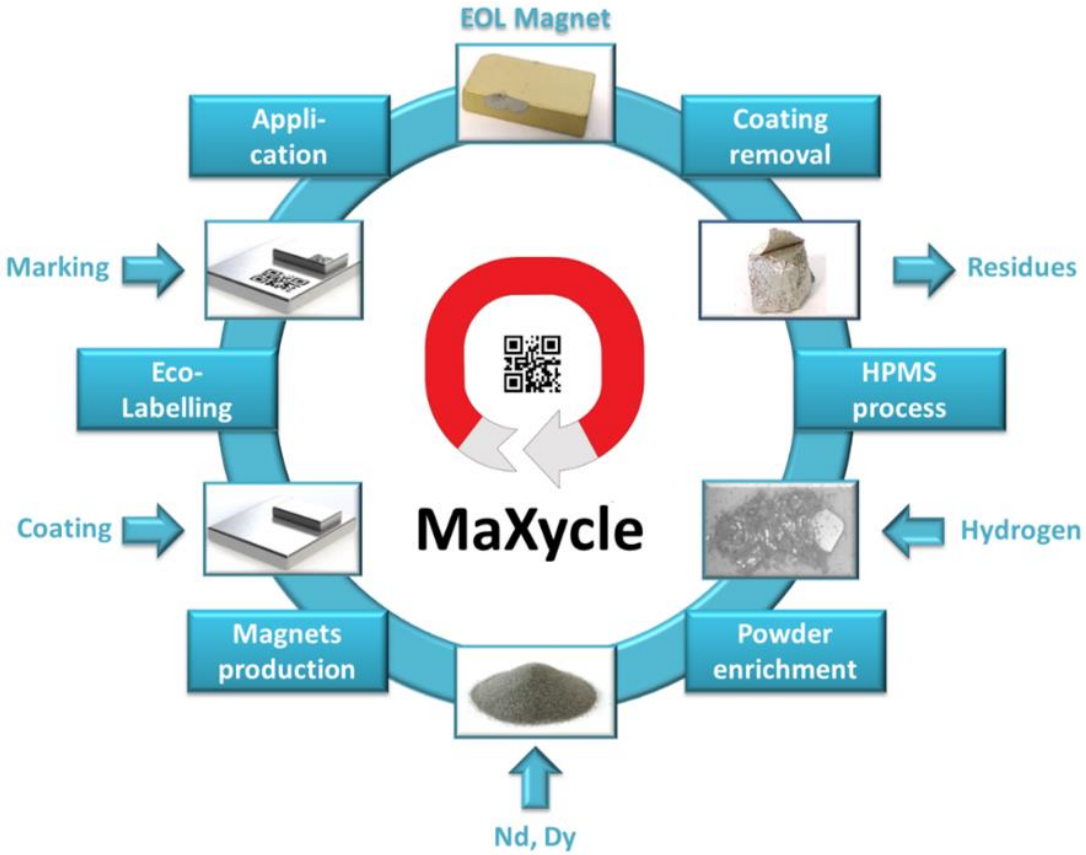
Recycling of EOL magnets – a rout to strategic raw materials



- For the **independence** of Europe and the rest of the world from China which controls 97% of raw materials,
- Is **recycling** of EOL Nd-Fe-B magnets **mandatory**.

MaXycle - A novel circular economy for sustainable RE-based magnets

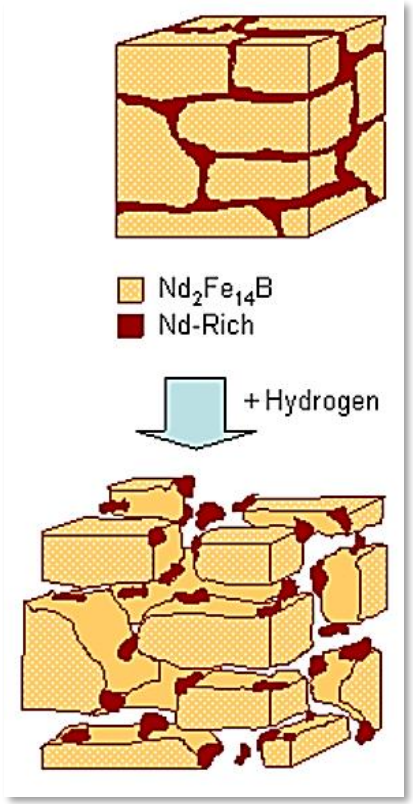
- **Definition of standardised quality criteria** for EOLM and a classification system for contamination levels to categorise products by pre-processing requirements.
- Development of a **labelling system** for newly produced RE magnets to identify different magnet types and qualities, including provision of reliable and durable marking methods.



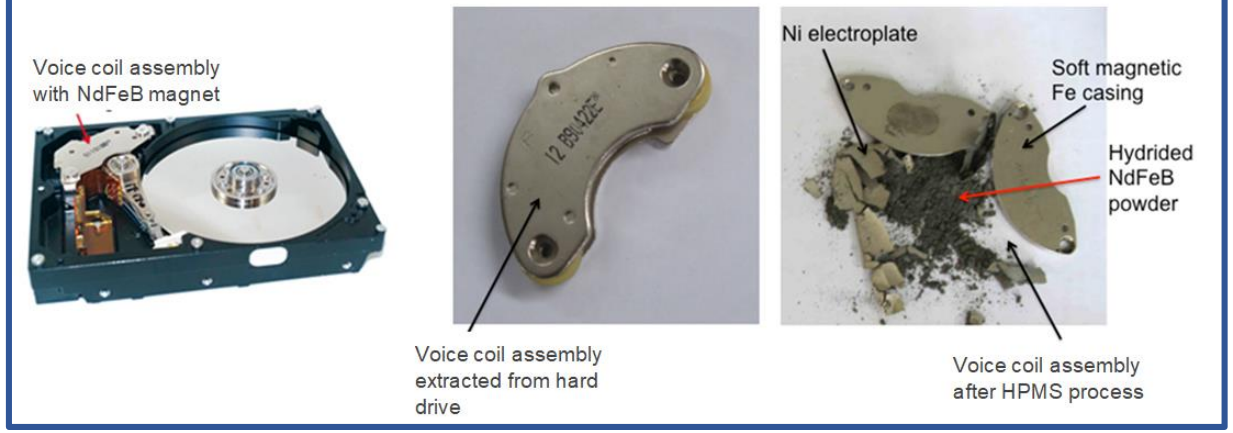
Partners:

IJS Ljubljana Slovenia
HS PF
ivl
AMIM plus
MAGNETI LJUBLJANA d.d.
UNIVERSITY OF BIRMINGHAM
RockLink Rare Metals Recycling

MaXycle – Approach: Not based on conventional recycling by chemical or pyrometallurgical processes



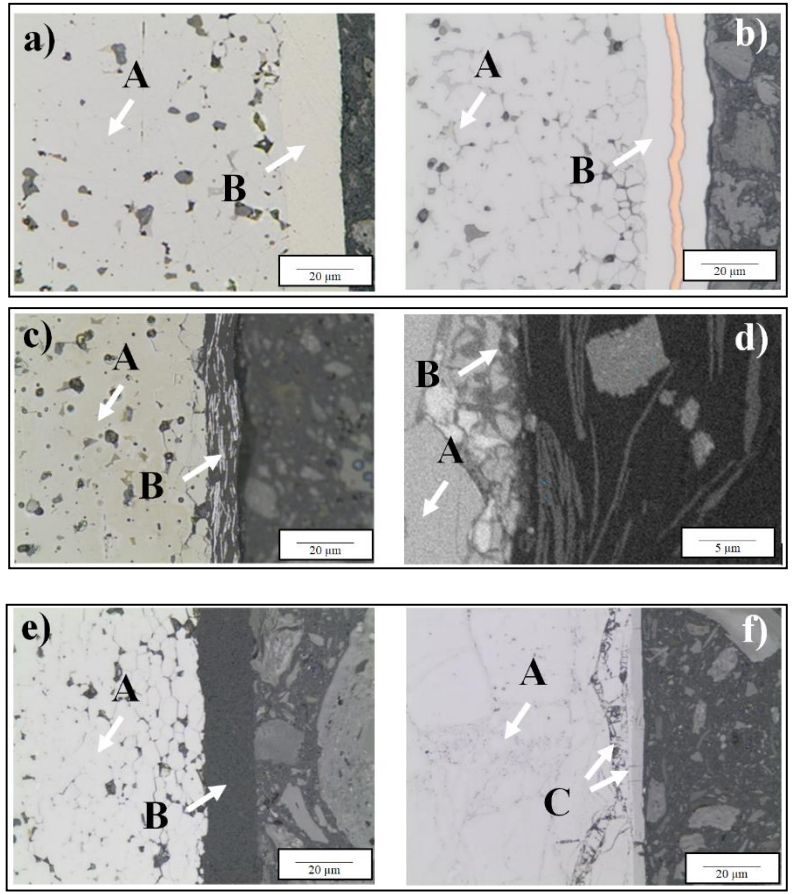
Recycling of EOL Nd-Fe-B magnets is based on the highly effective HPMS process (Hydrogen Processing of Magnetic Scrap)



Using hydrogen for recycling of EOL magnets enables 88% energy efficiency and is 98% less toxic as the standard hydrometallurgical process

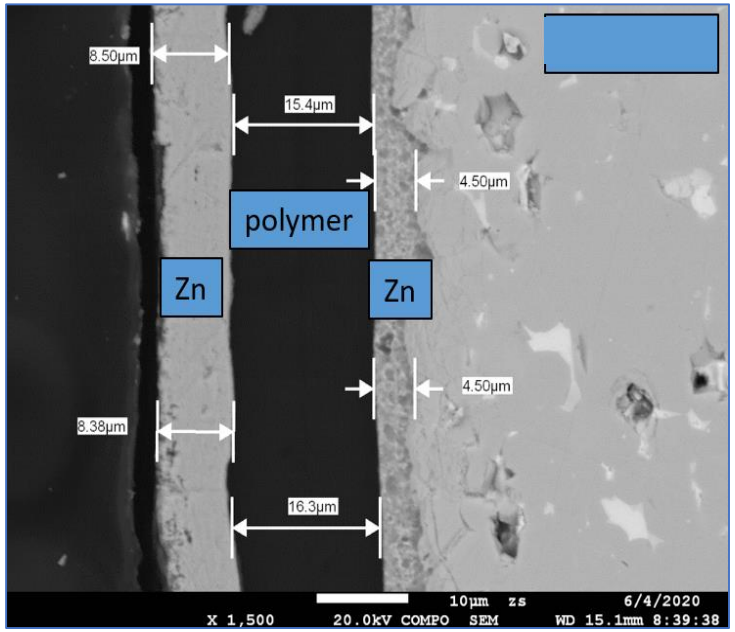
- Walton, A., Williams, A.J., Speight, J.D. and Harris, I.R.; US Patent No. US 13/169,839. "Magnet recycling" (Priority 2010, Application 2012, granted 2014)
- Walton, A., et al..; The Use of Hydrogen to Separate and Recycle Neodymium-Iron-Boron-type Magnets from Electronic Waste, Journal of Cleaner Production 104 (2015) p236-241. DOI: 10.1016/j.jclepro.2015.05.033

MaXycle – RESULTS: Coating of Nd-Fe-B magnets: analyses – few examples

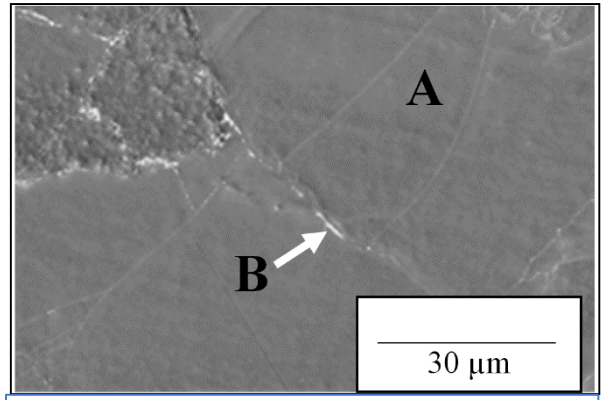


A-matrix phase; B- Nd-rich phase; C-Dy grain boundary diffusion

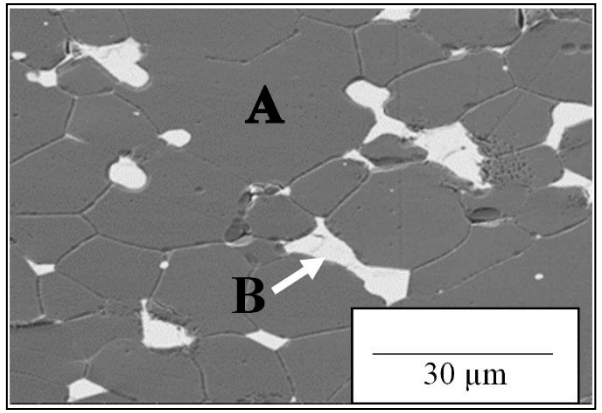
a): Ni (electroplated)
b): multilayer Ni-Cu-Ni (electroplated)
c) and d): polymer with fibers (different magnifications)
e): single layer polymer,
f): uncoated



Example of multilayered coating



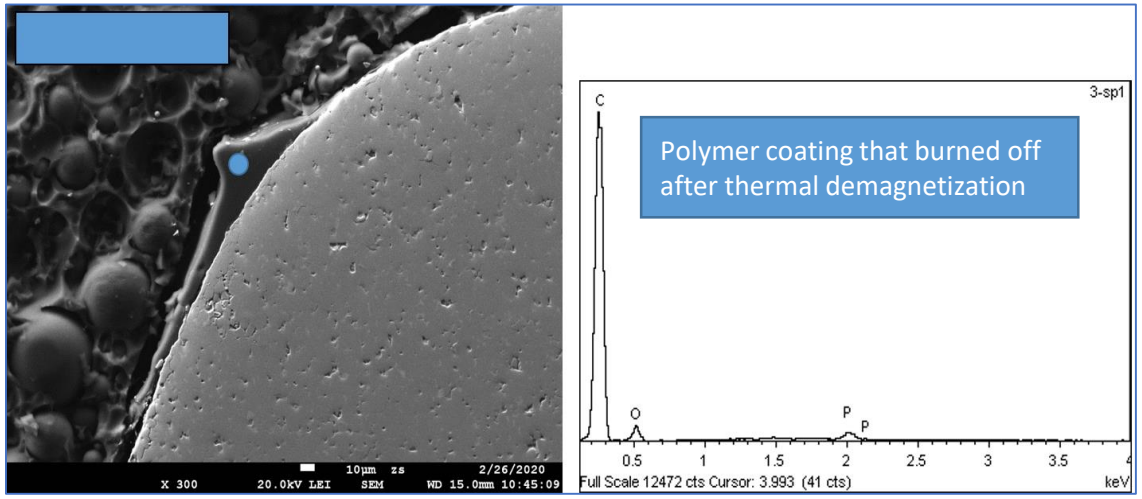
Typical microstructure of EOL magnet from electric motor of DIY drilling machine (A-matrix phase, B-Nd-rich phase)

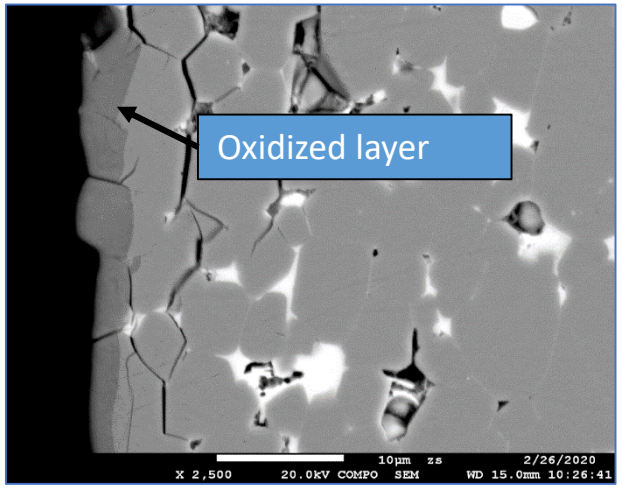


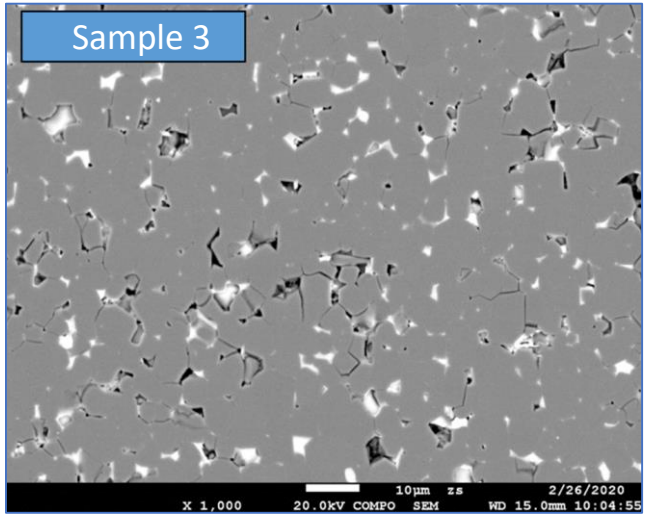
Typical microstructure of EOL magnet from wind turbine generator (A-matrix phase, B- Nd-rich phase)

❑ C. Burkhardt, A. Lehmann, B. Podmiljšak, S. Kobe, A systematic classification and labelling approach to support a circular economy ecosystem for NdFeB-type magnet. *Journal of materials science and engineering. B.*, ISSN 2161-6221, **2020**, vol. 10, no. 7/8, str. 125-133

MaXycle – RESULTS: Coating of Nd-Fe-B magnets: removal



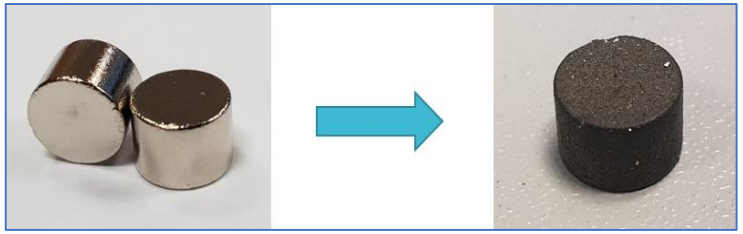


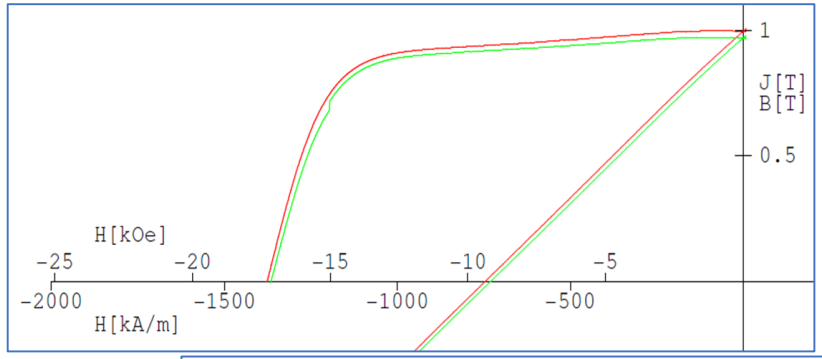


Microstructure of the Sample3 magnet

Table: EDX of the matrix phase in three samples

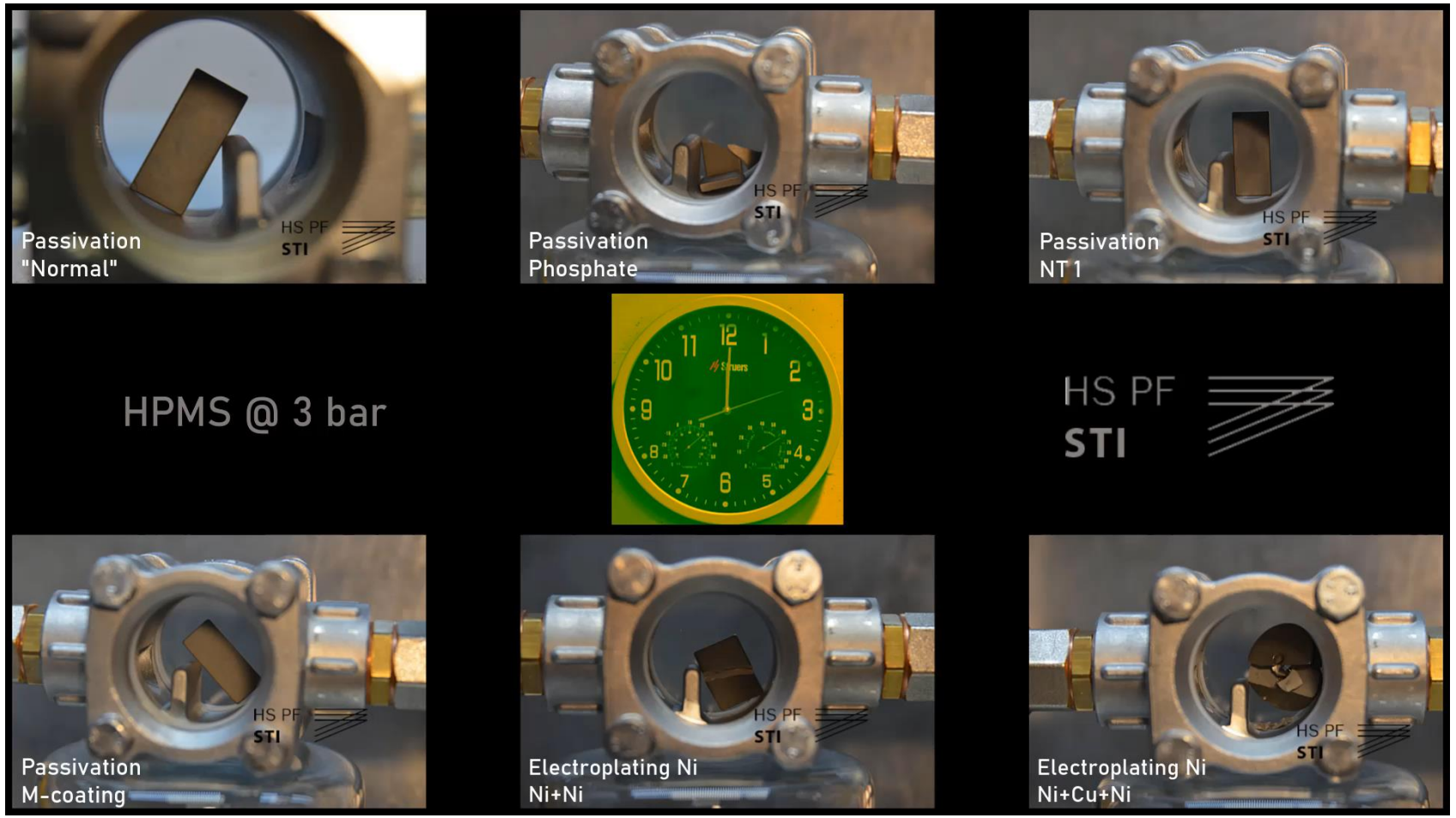
At%	Fe K	Co K	Pr L	Nd L	Dy L
Sam. 3	86,07	1,23	2,39	8,19	2,13
Sam. 5	85,75	1,44	2,50	8,100	2,20
Sam. 6	86,69	-	2,63	8,52	2,16



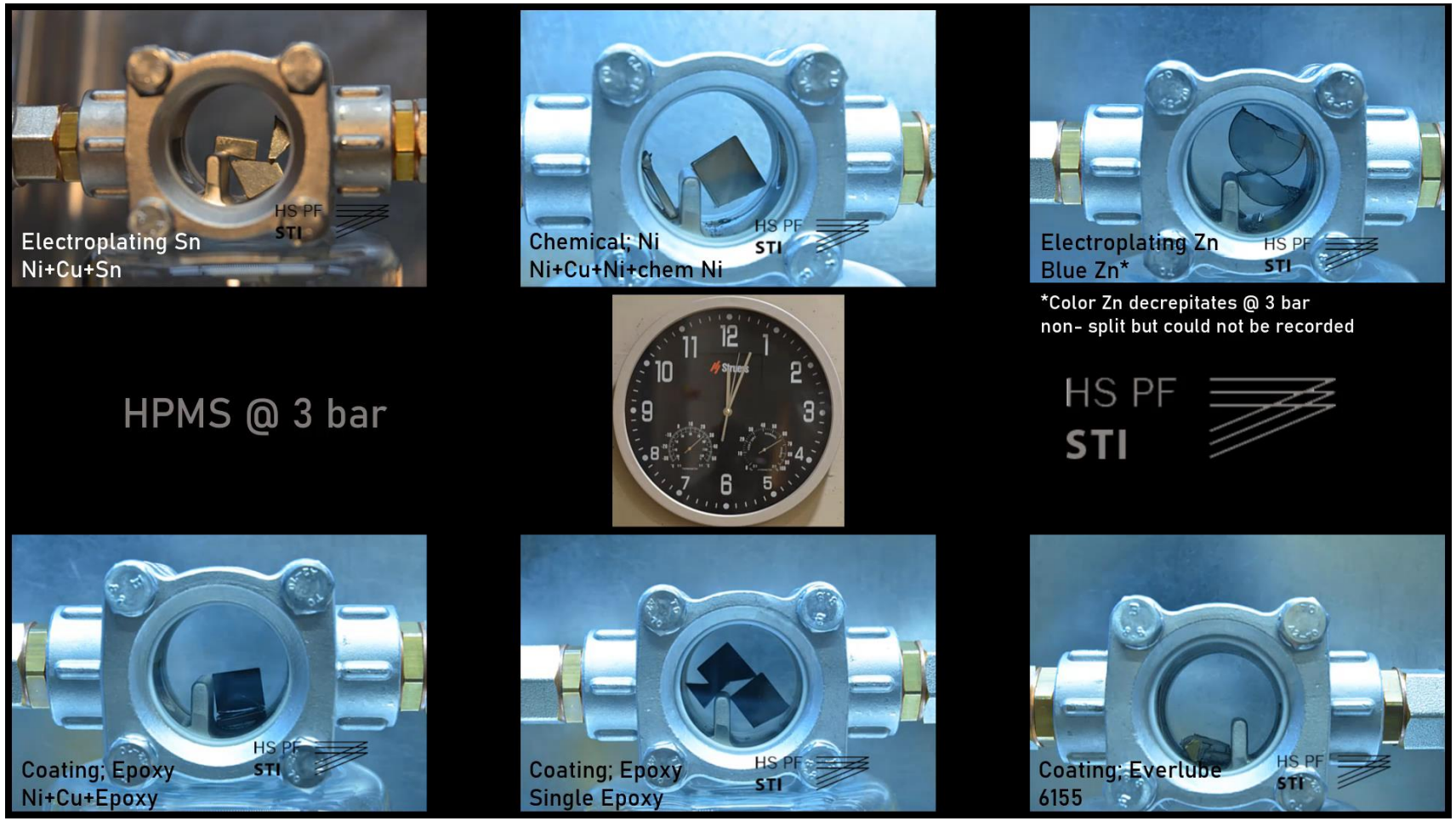


The magnetic properties before (red) and after (green) the coating was removed. Ni-Cu-Ni coating removed after 2 hours in a 5% Br_2 solution

MaXycle – RESULTS: HPMS processing



MaXycle – RESULTS: HPMS processing



MaXycle – RESULTS: HPMS processing followed by sieving

S1: Passivated "Normal"	S5: Electroplated Ni+Ni	S9: Electroplating blue Zn	S13: Everlube
Magnet: Large chunks	Magnet: Small chunks	Magnet: small chunks	Magnet: medium chunks
Coating: Small flakes	Coating: Nt disintegrated	Coating: Mixed size	Coating: Oblong flakes
Sieving likely not helpful	Sieving likely helpful	Sieving possibly helpful	Sieving likely helpful
S2: Passivated Phosphate	**S6 Electroplated Ni+Cu+Ni**	**S10: Electroplating color Zn**	
Magnet: Large chunks	Magnet: Small chunks	Magnet: Medium chunks	
Coating: Small flakes	Coating: Not disintegrated	Coating: Medium flakes	
Sieving likely not helpful	Sieving likely helpful	Sieving possibly helpful	
S3: Passivated NT1	**S7: Electroplated Ni+Cu+Sn**	**S11: Ni+Cu+Epoxy**	
Magnet: Large chunks	Magnet: Medium chunks	Magnet: Small chunks	
Coating: Small flakes	Coating: Oblong flakes	Coating: Not disintegrated	
Sieving likely not helpful	Sieving possibly helpful	Sieving likely helpful	
S4: Passivated M-coating	**S8: Chemical Ni**	**S12: Single Epoxy**	
Magnet: Mixed size	Magnet: Medium chunks	Magnet: Small chunks	
Coating: Mixed size	Coating: Not disintegrated	Coating: Not disintegrated	
Unclear	Sieving likely helpful	Sieving likely helpful	

H2-permeable

Assumption, if sieving may separate magnetic- and coating material. Colours indicate if the observed properties are recycling friendly or not.

MaXycle – RESULTS: Labelling of Nd-Fe-B magnets

Example Magnet 1

1	production method	sintered		x
		polymer bonded		
2	content of heavy RE	Dy	<1%	
			1-3%	
			3-5%	
			>5%	x
3	coating	nickel		x
		zinc		
		polymer		
		multi-layer		
4	fixation	mechanical		x
		glued (one side)		
		glued (2+ sides)		
		buried		
5	access-ability	magnet only		x
		easy to dismantle		
		moderate to dismantle		
		complicated to dismantle		
6	oxygen content	<500 ppm		x
		500- 1.000 ppm		
		1.000- 3.000 ppm		
		3.000- 5.000 ppm		
		5.000- 8.000 ppm		
		>8.000 ppm		
7	availability p.a.	<1 t		
		1-5 t		
		5-10 t		
		10-50 t		
		>50 t		x
10800				

Example Magnet 2

1	production method	sintered		x
		polymer bonded		
2	content of heavy RE	Dy	<1%	
			1-3%	
			3-5%	
			>5%	x
3	coating	nickel		x
		zinc		
		polymer		
		multi-layer		
4	fixation	mechanical		
		glued (one side)		
		glued (2+ sides)		x
		buried		
	access-ability	magnet only		
		easy to dismantle		x
		moderate to dismantle		
		complicated to dismantle		
5	oxygen content	<500 ppm		
		500- 1.000 ppm		
		1.000- 3.000 ppm		
		3.000- 5.000 ppm		x
		5.000- 8.000 ppm		
		>8.000 ppm		
6	availability p.a.	<1 t		
		1-5 t		x
		5-10 t		
		10-50 t		
		>50 t		
240				

Example Magnet 3

1	production method	sintered		x
		polymer bonded		
2	content of heavy RE	Dy	<1%	
			1-3%	x
			3-5%	
			>5%	
3	coating	nickel		
		zinc		x
		polymer		
		multi-layer		
4	fixation	mechanical		
		glued (one side)		
		glued (2+ sides)		x
		buried		
	access-ability	magnet only		
		easy to dismantle		
		moderate to dismantle		x
		complicated to dismantle		
5	oxygen content	<500 ppm		
		500- 1.000 ppm		
		1.000- 3.000 ppm		
		3.000- 5.000 ppm		
		5.000- 8.000 ppm		
		>8.000 ppm		x
6	availability p.a.	<1 t		
		1-5 t		x
		5-10 t		
		10-50 t		
		>50 t		
0				

HPMS recycling factors for different lots of sintered NdFeB-type magnets

- C. Burkhardt, A. Lehmann, B. Podmiljšak, S. Kobe, A systematic classification and labelling approach to support a circular economy ecosystem for NdFeB-type magnet. *Journal of materials science and engineering. B.*, ISSN 2161-6221, **2020**, vol. 10, no. 7/8, str. 125-133

MaXycle – RESULTS: Labelling od Nd-Fe-B magnets

Type of Magnet select from drop down list	Type of Coating select from drop down list	Heavy RE-Content [%] enter value in mass%	Magnet Grade select from drop down list	Certified Producer Code select from drop down list
NdFeB_sintered	Zn	0,30	N27 EH	Magneti

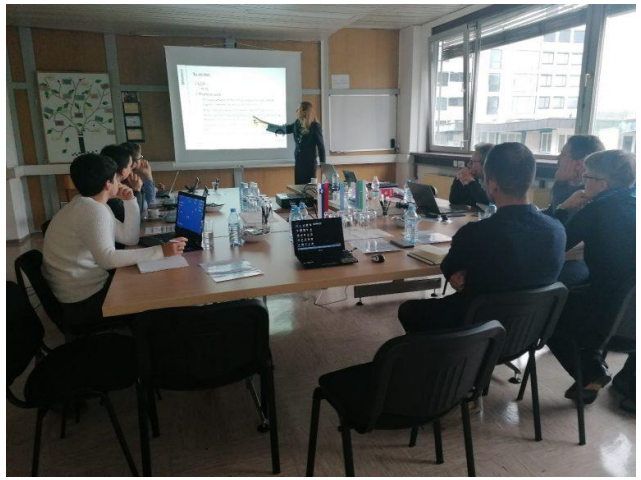
MAXYCLE MAGNET CODE: **A 2 003 N27 EH P123M**

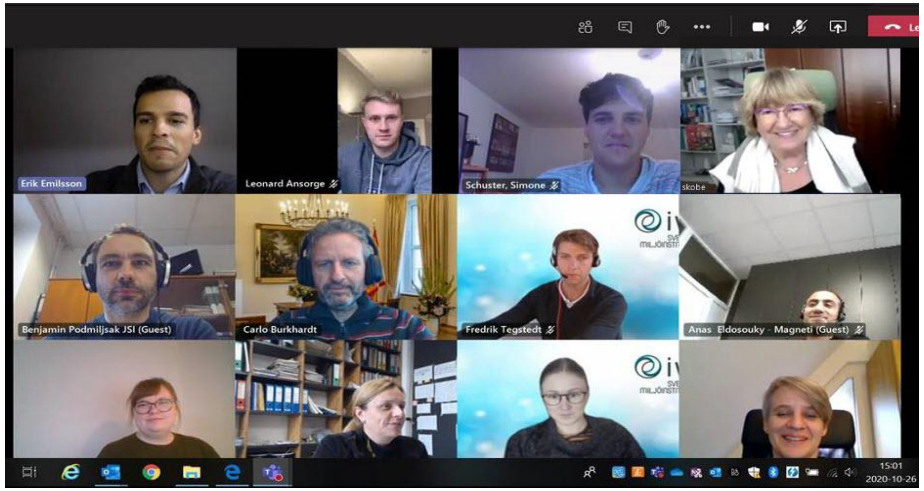
MaXycle code-generator (left) and resulting DMC-code (right)

Various labeling after corrosion testing

- C. Burkhardt, A. Lehmann, B. Podmiljšak, S. Kobe, A systematic classification and labelling approach to support a circular economy ecosystem for NdFeB-type magnet. *Journal of materials science and engineering. B.*, ISSN 2161-6221, **2020**, vol. 10, no. 7/8, str. 125-133

MaXycle - TEAM





FEBRUARY 16, 2021

Testimonial of the MaXycle project

CONCLUSIONS

It is envisaged to enable a **circular economy ecosystem** for NdFeB magnets in **renewable energy** and **e-mobility sectors**:

- By using a **highly effective HPMS** process **for recycling.**

This work was financed by ERA-MIN2 ID:142.

Project website: www.maxycle.eu

Thank you for your attention!