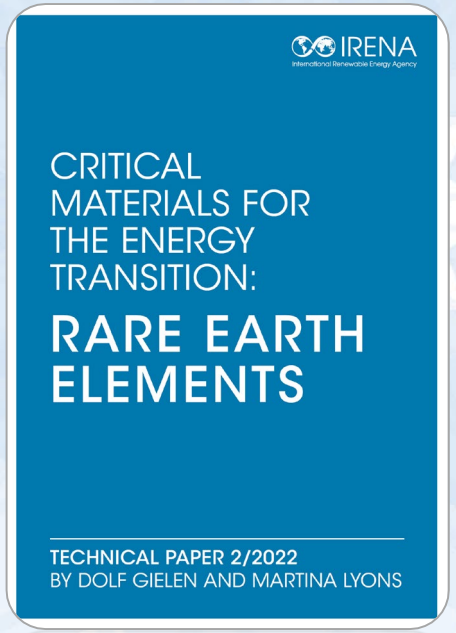

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International Renewable Energy Agency

Rare Earth Elements
Critical Materials for the Energy Transition

18 May 2022

Agenda

PART I: Key takeaways from the Rare Earth Elements paper

PART II: Commentary from several reviewers

PART III: Q&A

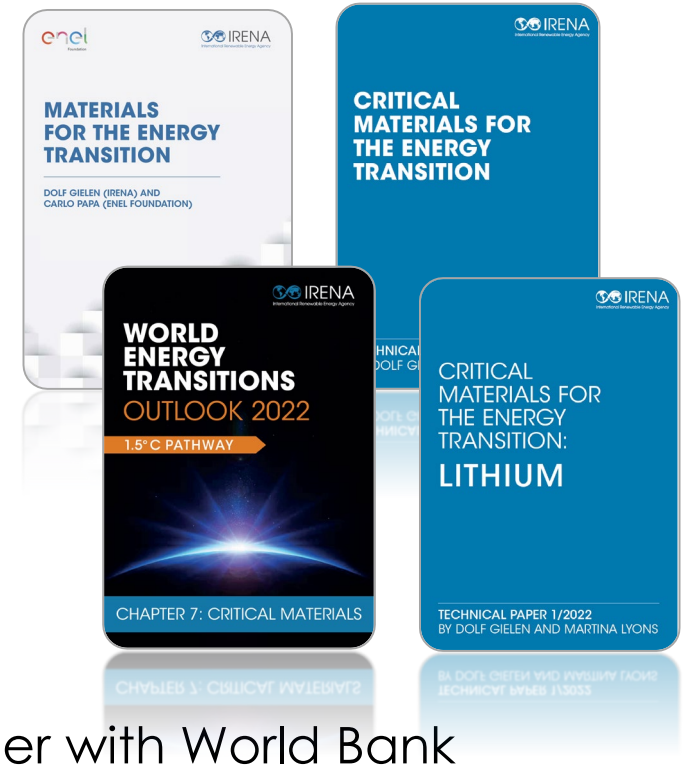
Part I:
Key takeaways from the Rare Earth Elements' paper

Key takeaways from the Rare Earth Elements paper

Dolf Gielen
Director Innovation and Technology Centre
IRENA

IRENA work to date

- IRENA Assembly January 2022 provided a mandate for Agency work on critical materials
- To date:
  - Scoping paper – together with ENEL Foundation – October 2021
  - Technical paper critical materials – November 2021
  - Deep dive lithium – February 2022
  - Chapter World Energy Transitions Outlook 2022 – March 2022
  - Nickel editorial
  - Editorials on critical materials in energy-post and smart-energy



- In preparation:
  - Deep dive sustainable critical materials supply in Africa – together with World Bank
- This webinar:
  - Deep dive rare earth elements
- **Goal**: **Enhance Members understanding of critical materials**

Collaborative Framework & working groups

Aim: develop a set of activities to:

- support a better **understanding** of the role and market dynamics of critical materials to sustain the energy transition,
- facilitate **discussion** among the different groups,
- Establish a **list of experts** across Members and stakeholders, and
- assist in systematizing and disseminating **knowledge**.

Observatory

Collect data that help **understand scarcity and potential supply shortages** that may affect the energy transition in the coming decade

De-risking supply

Develop and apply **strategies to de-risk supply**

ESG & mining

Develop strategies to **raise acceptance for new mining projects**

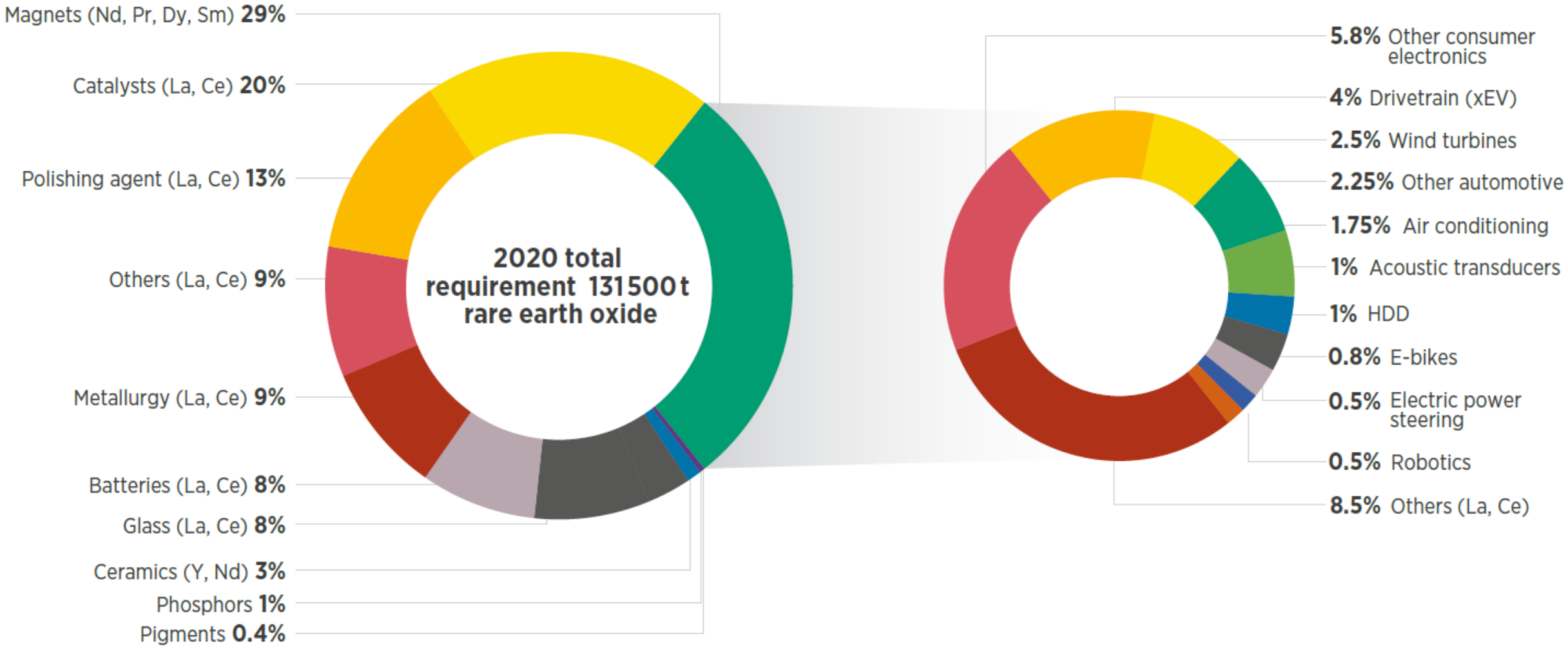
What are we talking about today?

- **REE constitute a group of 17 elements**
- **That are not rare, but they are hard to separate**
  - The 40 largest ore exploration projects contain over 3 000 megatonnes (Mt) of inferred resources at various grades in over 15 countries
  - Only 11 mines in operation and 0.24 Mt production in 2020
- **Therefore they were discovered late**
- **They have funny names**
  - Light elements are lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium and gadolinium.
  - The heavy elements are terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium
  - Additionally scandium and yttrium
- **About 40 years ago it was discovered they make great permanent magnets**
  - Only 4 elements have relevance for todays permanent magnets
- **These magnets are needed for generators (wind turbines) and motors (EV)**

Permanent magnets

- Largely **neodymium-dysprosium** based, with some praseodymium and terbium
- About a **third of magnet weight** is REE
- **Dysprosium** is added for **thermal stability**
- Dysprosium is **more scarce than neodymium**, therefore more likely a bottleneck
- **Innovation** is aimed at more efficient use or even elimination of dysprosium
- REE free magnets are in an **R&D stage**
- **Permanent free motors & generators** exist but they have **lower performance**

Rare Earth Demand (2020) – 29% magnets of which around a third energy transition related – quantities are still small



REE price trends – rising prices for permanent magnet materials

PRODUCT (OXIDE)	(% PURITY)	USD/KG		
		2017	2018	24 DECEMBER 2021
Scandium	99.990	4 600	4 600	836
Yttrium	99.999	3	3	11.9
Lanthanum	99.500	2	2	2
Cerium	99.500	2	2	1.5
Praseodymium	99.500	65	63	140
Neodymium	99.500	50	50	143
Samarium	99.500	2	2	4.5
Europium	99.990	77	53	32
Gadolinium	99.999	37	44	76.2
Terbium	99.990	501	455	1720
Dysprosium	99.500	187	179	452

REE reserves are plenty and widely distributed

COUNTRY	MINE PRODUCTION, 2020 [TONNES/YEAR]	RESERVES [TONNES]	% OF TOTAL WORLD RESERVES
China	140 000	44 000 000	38.0
Viet Nam	1 000	22 000 000	19.0
Brazil	1 000	21 000 000	18.1
Russia	2 700	12 000 000	10.4
India	3 000	6 900 000	6.0
Australia	17 000	4 100 000	3.5
United States	38 000	1 500 000	1.3
Greenland	-	1 500 000	1.3
Tanzania	-	890 000	0.8
Canada	-	830 000	0.7
South Africa	-	790 000	0.7
Other countries	100	310 000	0.3
Myanmar	30 000	NA	NA
Madagascar	8 000	NA	NA
Thailand	2 000	NA	NA
Burundi	500	NA	NA
World Total	**243 300**	**115 820 000**	**100**

Todays REE mining is concentrated in China, USA and Australia

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COUNTRY OR LOCALITY	2016		2017		2018		2019		2020
Australia[est]	15 000		19 000		21 000		20 000		17 000
Brazil	2 700	rev, est	1 700	est	1 200		710		1 000
Burundi[est]	-		40		620		200		500
China[a]	105 000		105 000		120 000		132 000		140 000
India[est, b]	1 500		1 800		2 900		2 900		3 000
Madagascar	-		-		2 000		4 000		8 000
Malaysia[est]	1 100		180		990		pm		pm
Myanmmar[est]	3 500		15 000		23 000		pm		pm
Russia	2 700	rev	2 700	rev	2 700		2 700		2 700
Thailand[est,c]	1 600		1 300		1 000		1 900		2 000
United States[est]	-		-		14 000		28 000		38 000
Viet Nam[est, c]	240	rev	220	rev	920		1 300		1 000
Total	133 000	rev	147 000	rev	190 000		220 000		240 000

Rare Earth Ores – mostly bastnaesite and monazite
Neodymium and dysprosium come from different deposits

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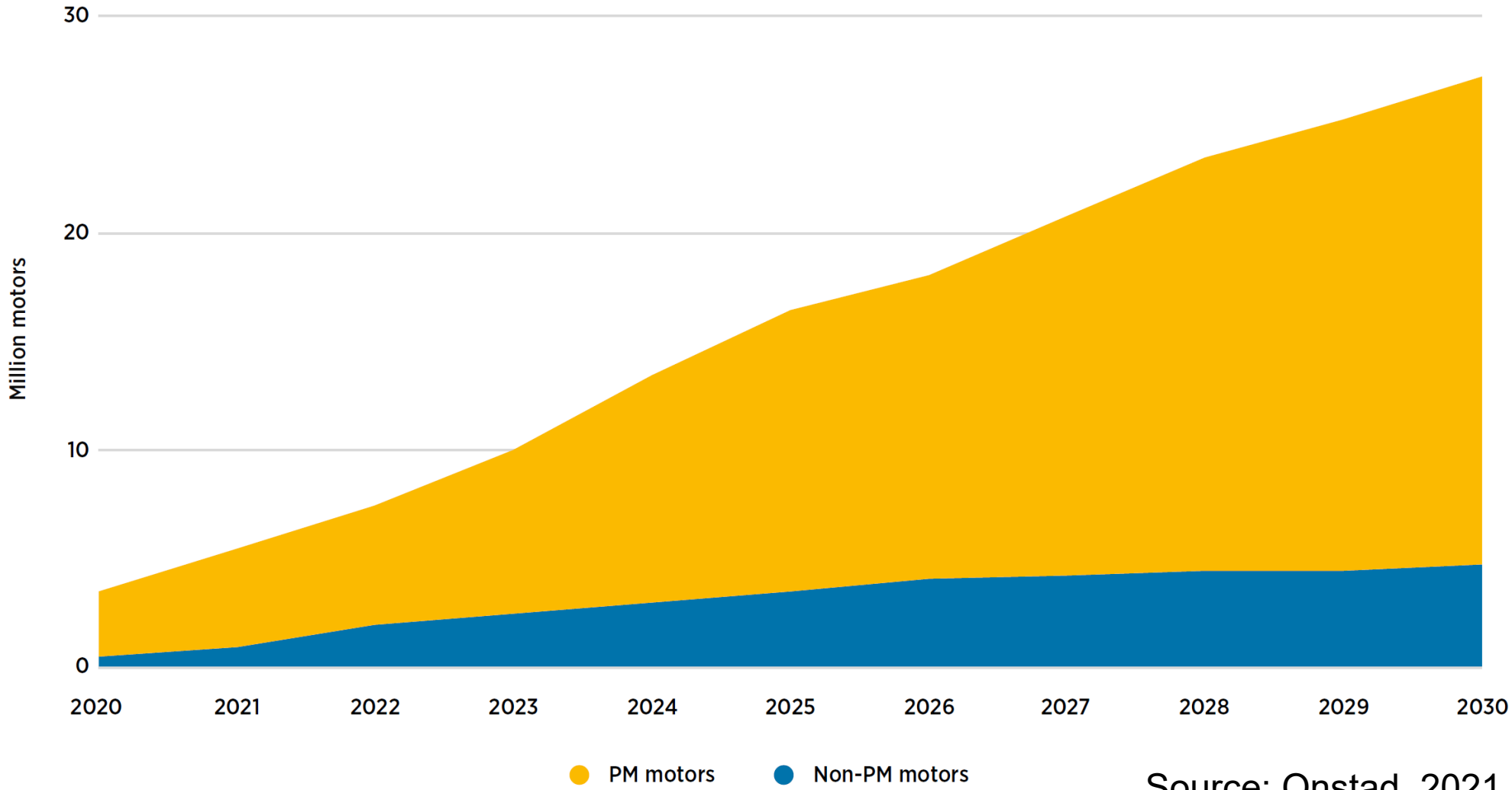
Radioactivity is a problem with some ore types

PRIMARY SOURCE	COUNTRY	LOCATION	LANTHANUM (LA)	CERIUM (CE)	PRASEODYMIUM (PR)	NEODYMIUM (ND)	SAMARIUM (SM)	EUROPIUM (EU)	GADOLINIUM (GD)	TERBIUM (TB)	DYSPROSIUM (DY)	HOLMIUM (HO)	ERBIUM (ER)	THULIUM (TM)	YTTERBIUM (YB)	LUTETIUM (LU)	YTTRIUM (Y)
Bastnaesite	China	Bayan Obo, Nei Mongol Autonomous Region[a]	23.00	50.00	6.20	18.50	0.80	0.20	0.70	0.10	0.10	NA	NA	NA	NA	NA	NA
		Dechang, Sichuan Province[b]	35.60	43.80	4.73	13.10	1.22	0.23	0.52	0.06	0.09	0.05	0.04	0.01	0.06	NA	0.40
		Maoniuping, Sichuan Province[b]	29.50	47.60	4.42	15.20	1.24	0.23	0.65	0.12	0.21	0.05	0.06	0.04	0.05	0.01	0.70
		Weishan, Shandong Province[b]	35.50	47.80	3.95	10.90	0.79	0.13	0.53	0.14	NA	NA	NA	NA	0.03	NA	0.76
	United States	Mountain Pass, CA[c]	34.00	48.80	4.20	11.70	0.79	0.13	0.21	NA	NA	NA	NA	NA	NA	NA	0.12
Loparite	Russia	Revda, Murmansk Oblast[d]	25.00	50.50	5.00	15.00	0.70	0.09	0.60	NA	0.06	0.70	0.80	0.10	0.20	0.15	1.30
Monazite	Australia	Mount Weld Central Lanthanide, Western Australia[e]	23.90	47.60	5.16	18.10	2.44	0.53	1.09	0.09	0.25	0.03	0.06	0.01	0.03	NA	0.76
	China	Nangang, Guangdong Province[b]	23.00	42.70	4.10	17.00	3.00	0.10	2.00	0.70	0.80	0.12	0.30	NA	2.40	0.14	2.40
	India	Manavalakurichi, Tamil Nadu[f]	22.00	46.00	5.50	20.00	2.50	0.02	1.20	0.06	0.18	0.02	0.01	0	0	0	0.45
Rare-earth laterite	China	Xunwu, Jiangxi Province[b]	38.00	3.50	7.41	30.20	5.32	0.51	4.21	0.46	1.77	0.27	0.88	0.13	0.62	0.13	10.10
		Xinfeng, Jiangxi Province[b]	27.30	3.23	5.62	17.60	4.54	0.93	5.96	0.68	3.71	0.74	2.48	0.27	1.13	0.21	24.30
		Longnan, Jiangxi Province[b]	2.18	<1.09	1.08	3.47	2.34	<0.37	5.96	1.13	7.48	1.60	4.26	0.06	3.34	0.47	64.90
Xenotime	China	Southeast Guangdong Province[g]	1.20	3.00	0.60	3.50	2.20	0.20	5.00	1.20	9.10	2.60	5.60	1.30	6.00	1.80	59.30

EV motor needs – a 6-fold growth is foreseen in reference scenario, permanent magnets supply must grow accordingly



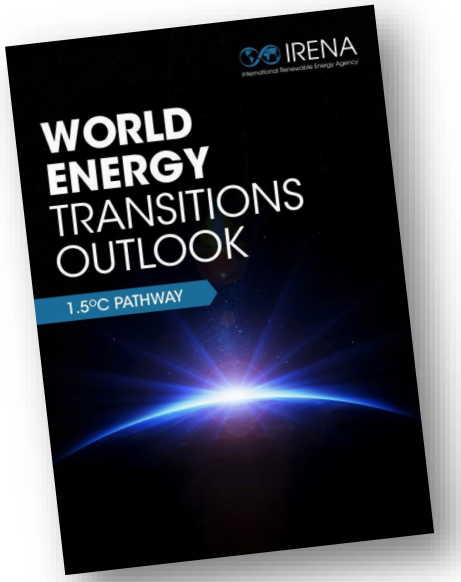
Source: Onstad, 2021

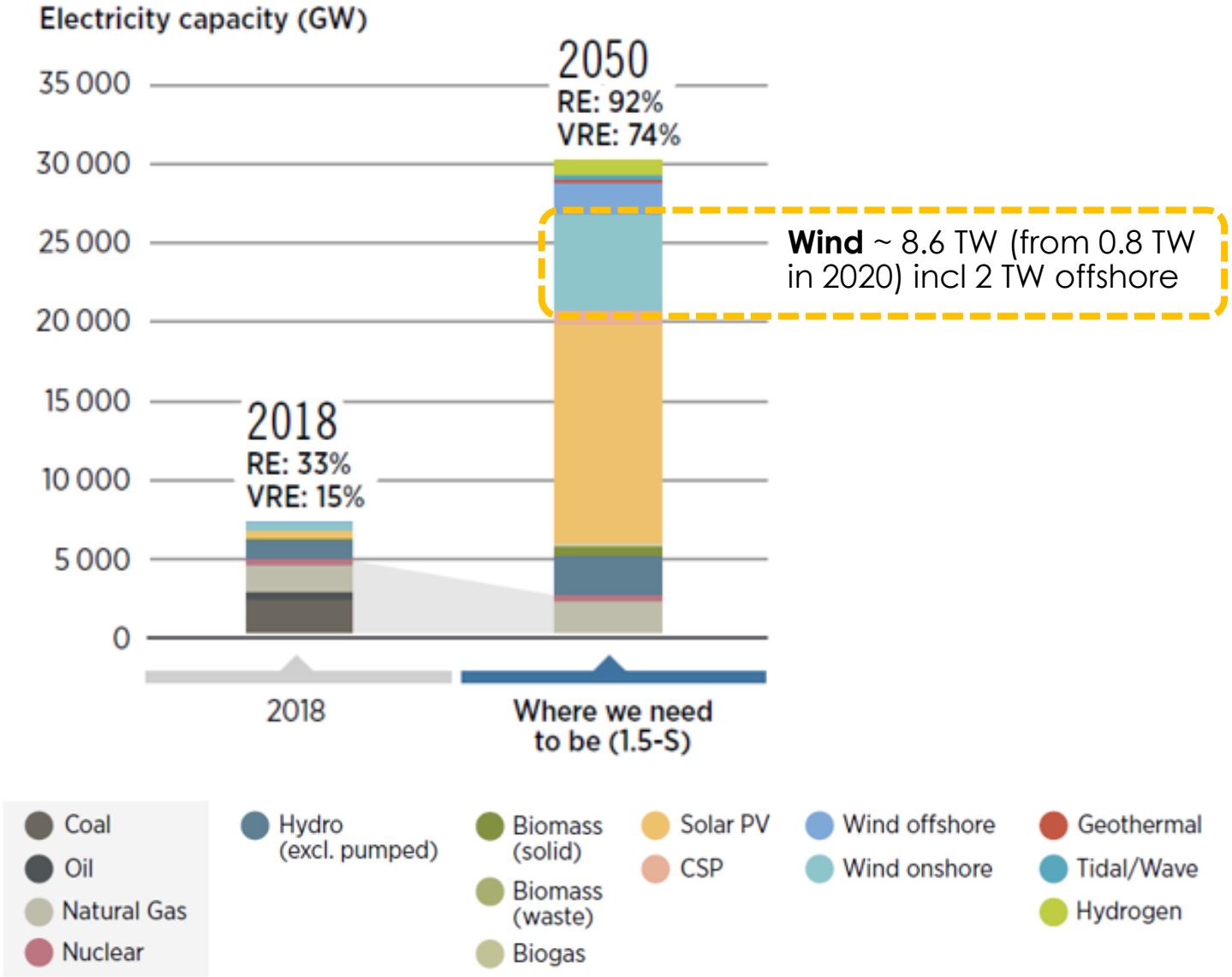
Role of wind in the electricity sector in a 1.5°C scenario

PV sector in the next three decades

- Annual additions ~ 200 GW (doubling)
- Offshore grows faster than onshore
- Today REE based generators concentrated in offshore + China

Consensus among different actors on the direction





Source: https://www.irena.org/publications/2022/Mar/World-Energy-Transitions-Outlook-2022

Wind power and REE

Expansion of wind power

→ impact on **supply and demand for some REEs** (neodymium, praseodymium and dysprosium)

→ REE to raise 11-26 times by 2050, after 2050 recycled metals growing role

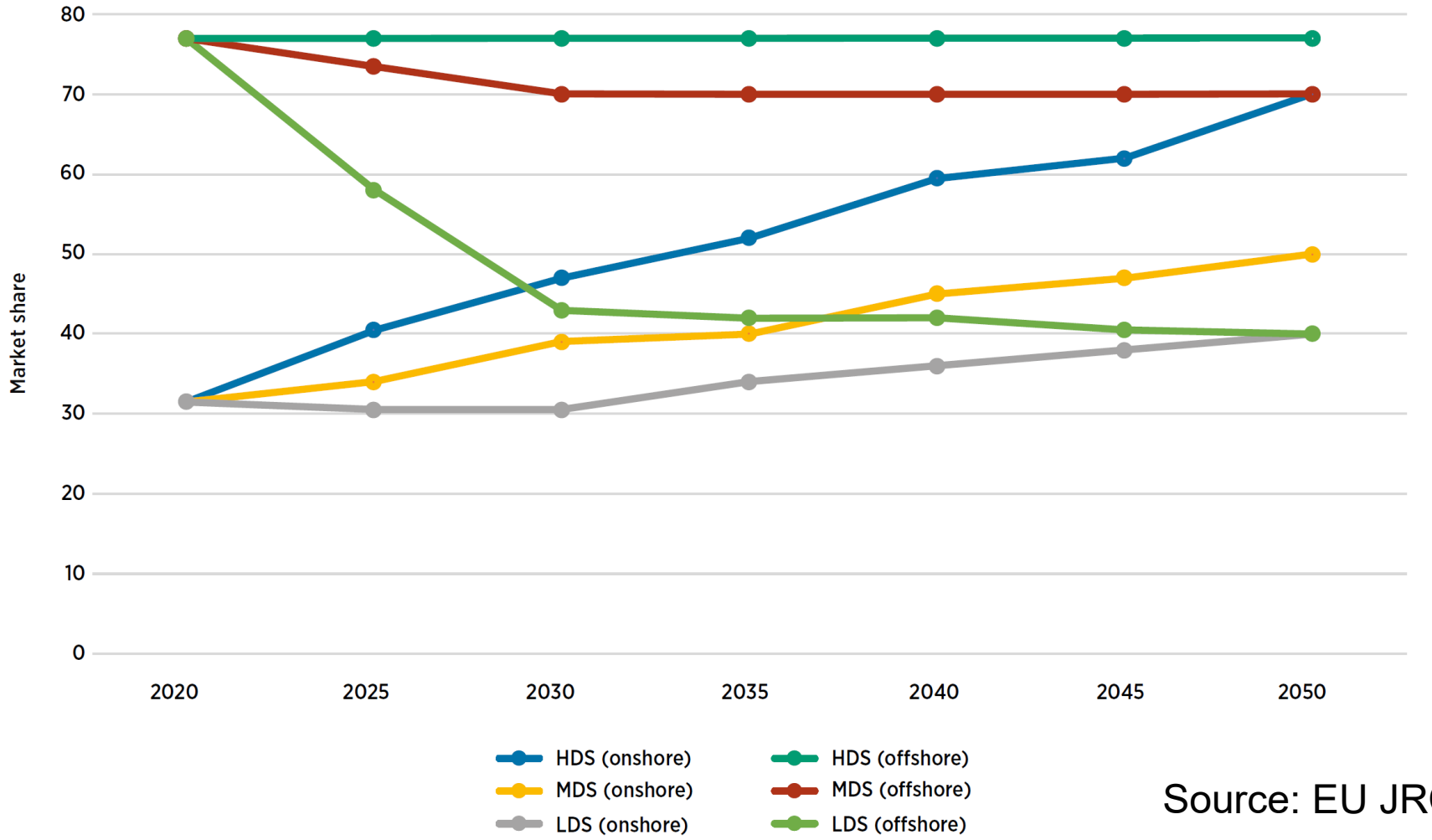
Generators → major difference in their REE content (also speed and mass)

- **Direct-drive**: most use PM, are smaller and use less REE; but high-temperature superconductors (in offshore) can reduce REE content resulting in better performance – but more R&D and further cost reduction needed
- **Gearbox**: some assisted by PM → medium-speed gearbox – popular in onshore and offshore farms, but design less competitive in large plants due to weight and periodic maintenance
- **Hybrid-drives:** smaller PM → less REE than direct drive

➢ PM – 75% of offshore wind

➢ PM - 52% of onshore wind

Scenarios for wind turbines with PM based generators



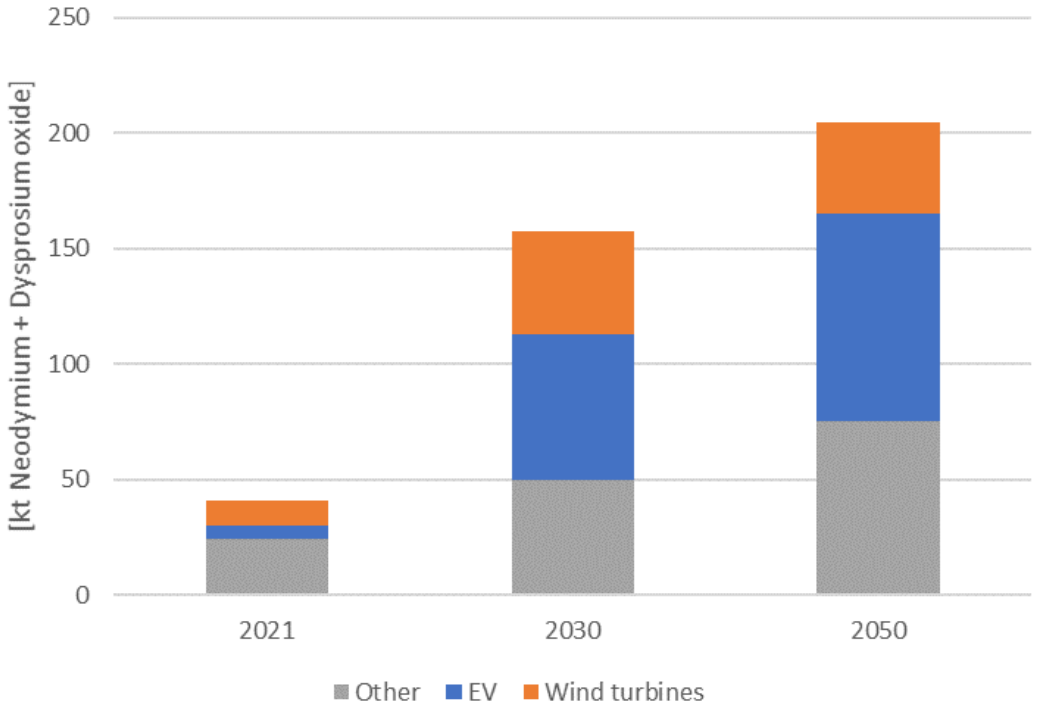
Offshore 75% share today, 40-80% in future

Onshore 30% share today, 40-70% share in future

Source: EU JRC

Demand projections for rare earths

- Simple model for permanent magnet demand: EV sales * kg REE/EV + wind turbines * kg REE/wind turbine + other applications; IRENA WETO 1.5 C scenario assumptions EV & wind growth
- 3 kg magnets/EV, 750 kg magnets/MW wind (offshore + growing share for onshore)
- In practice, magnet improvements and product redesign can reduce this demand significantly – *this is not widely understood*
- REE mining 20% neodymium or 5% dysprosium deposits; Ne and Dy supply become REE mining drivers
- Mining need may quadruple by 2030, grow slower thereafter; EV trends are critical (assumption 70 mln EV sales 2030)
- Lower rate of energy transition reduces mining growth need



[kt/yr]	2021	2030	2050
Neodymium oxide	39	151	196
Dysprosium oxide	1	4	5
REE mining need for PM materials	210	841	1085
REE mining total	240	850	1100

Innovation and R&D into PM to reduce REE dependency

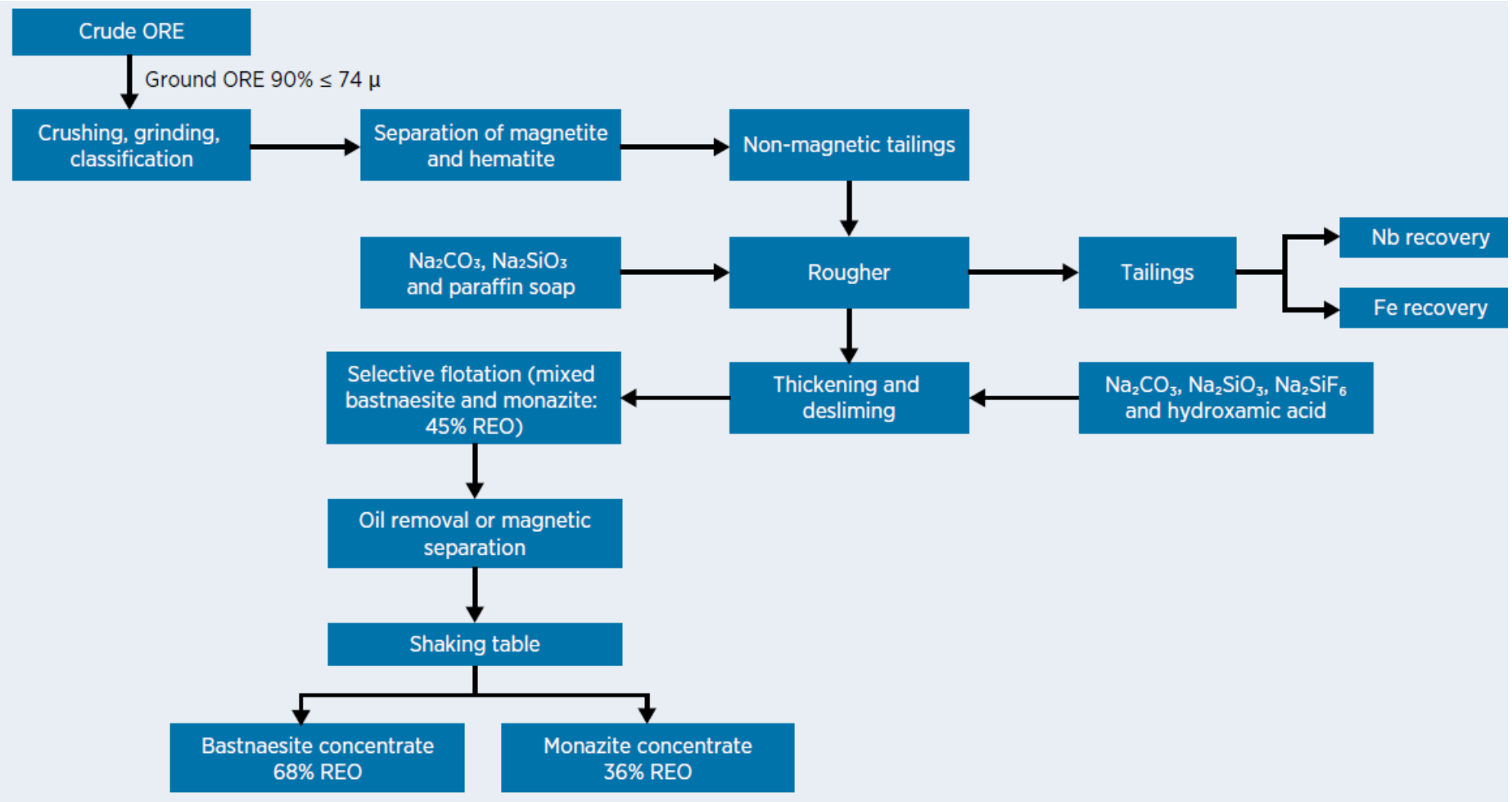
Innovation:

- **product innovation** in shaping future REE demand deserves more attention in decision-making and policy design

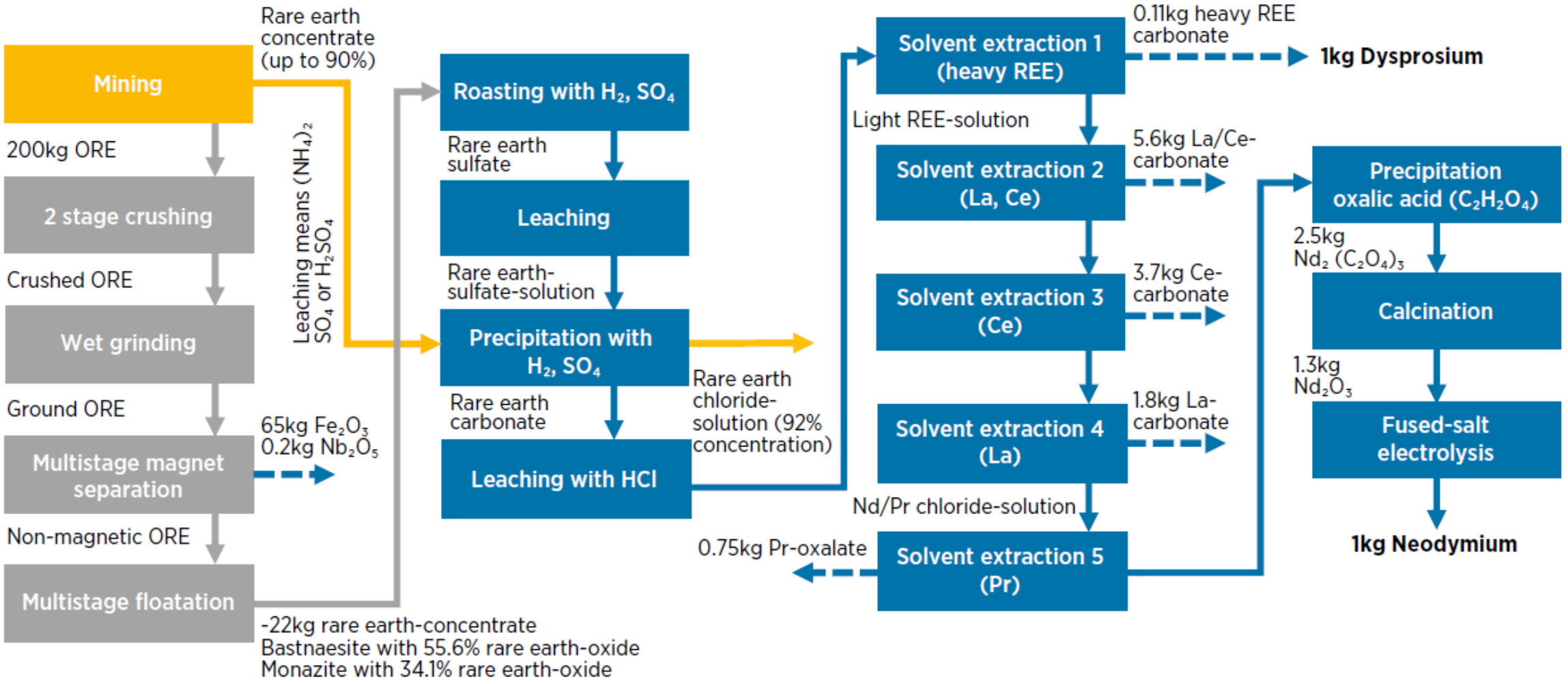
R&D into:

- **alternative motor designs** – but currently results in lower performance (e.g. reduced driving range)
- **new PM materials with no or less REE** but with adequate performance in applications where weight less critical
- **new PM processing technologies** to reduce dependency on sintered PM

Ore beneficiation, Bayan Oboo (largest REE mine worldwide)



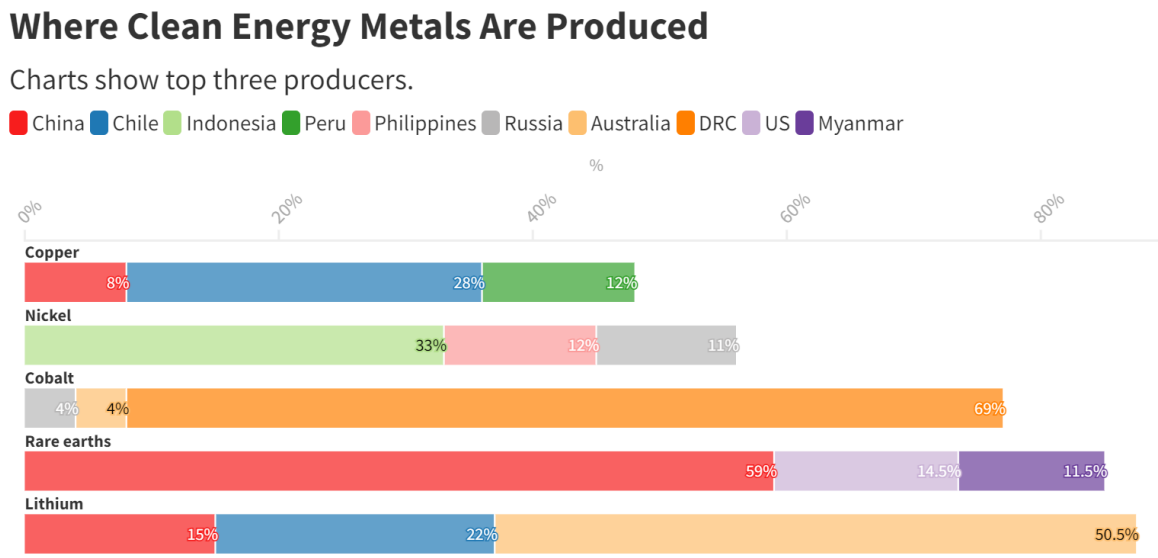
Complex REE processing

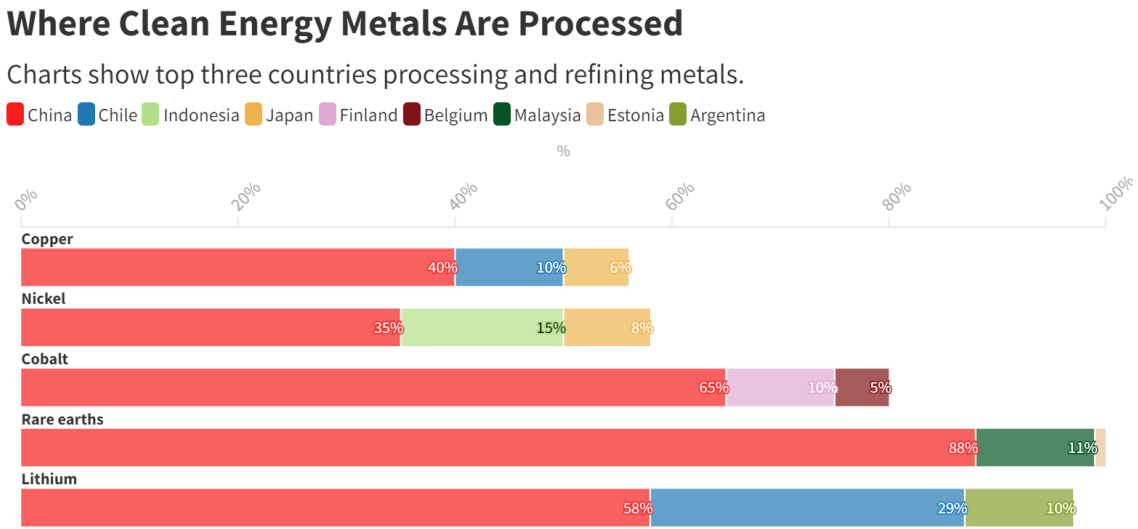


Supply structure – risk mitigation requires diversity

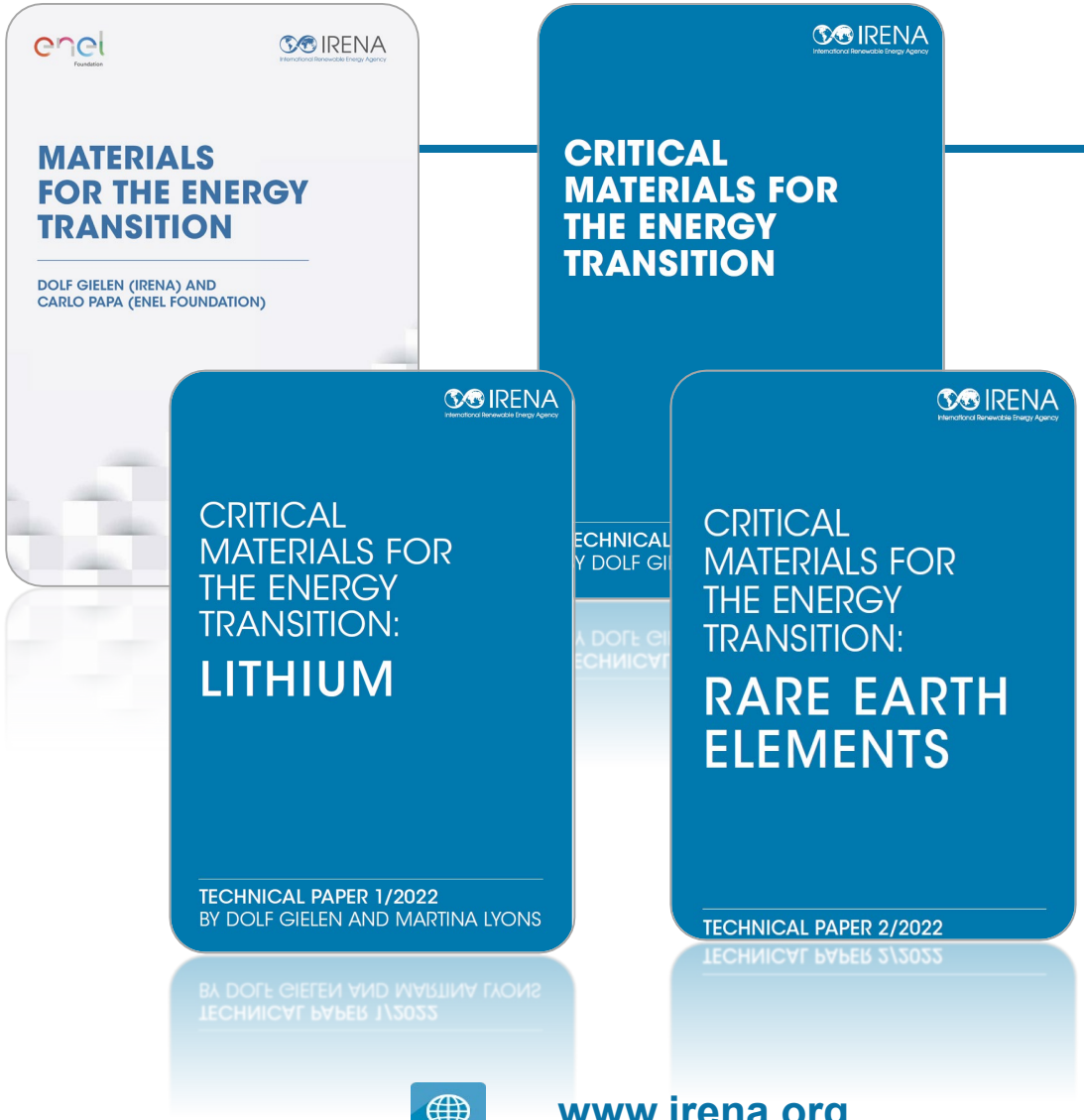
- Its **mining and processing** that must be considered
- **Processing** (refining) is concentrated in **China**
- Permanent magnet **production** is also concentrated in **China**
- Need to dig deep on permanent magnets to really understand **supply structures, trade statistics are not detailed enough**
- Radioactivity & technological complexity & scale effects have delayed or stopped REE processing elsewhere

- Efforts to **diversify the supply**, **processing close** to **mining** sites
- Need for **environmentally** and **socially sustainable** supply structure





Source: IRENA, IEA



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Part II:
Commentary from reviewers

European Commission

Michalis Christou
Senior Expert – Energy, Security and Transport
European Commission - Joint Research Centre

Overview of JRC work - here

Natural Resources Canada

Tyler Sommers
Acting Director,
Industry and Economic Analysis Division
Natural Resources Canada's Lands and Minerals Sector

Overview of NRCan work – here

ENEL Foundation

Silvia Burgos Rodríguez
Senior Researcher
ENEL Foundation

Latest joint ENEL Foundation and IRENA work:
Materials for the Energy Transition

Rare Earth Industry Association

Nabeel A Mancheri
Secretary General
Rare Earth Industry Association (REIA)

Latest work: Establishing EU-Domestic Rare Earth Supply Chains for Energy Saving Applications by Inclusion in Innovation Fund

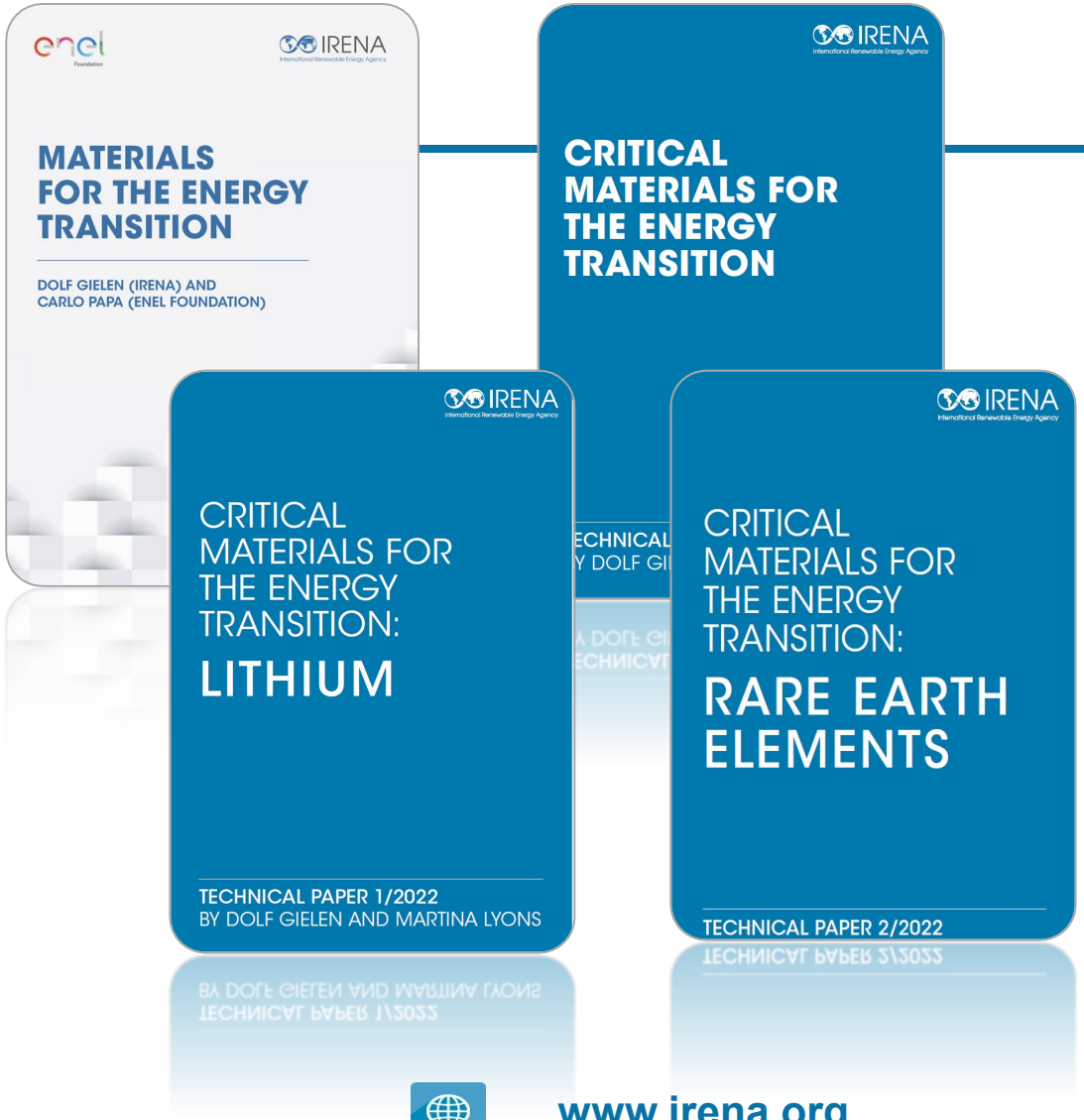
Global Wind Energy Council

Feng Zhao
Head of Strategy and Market Intelligence
Global Wind Energy Council (GWEC)

Latest work: GWEC | GLOBAL WIND REPORT 2022

Part III:
Q&A

Floor open for your questions



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