Natural Resources Canada | Ressources naturelles Canada



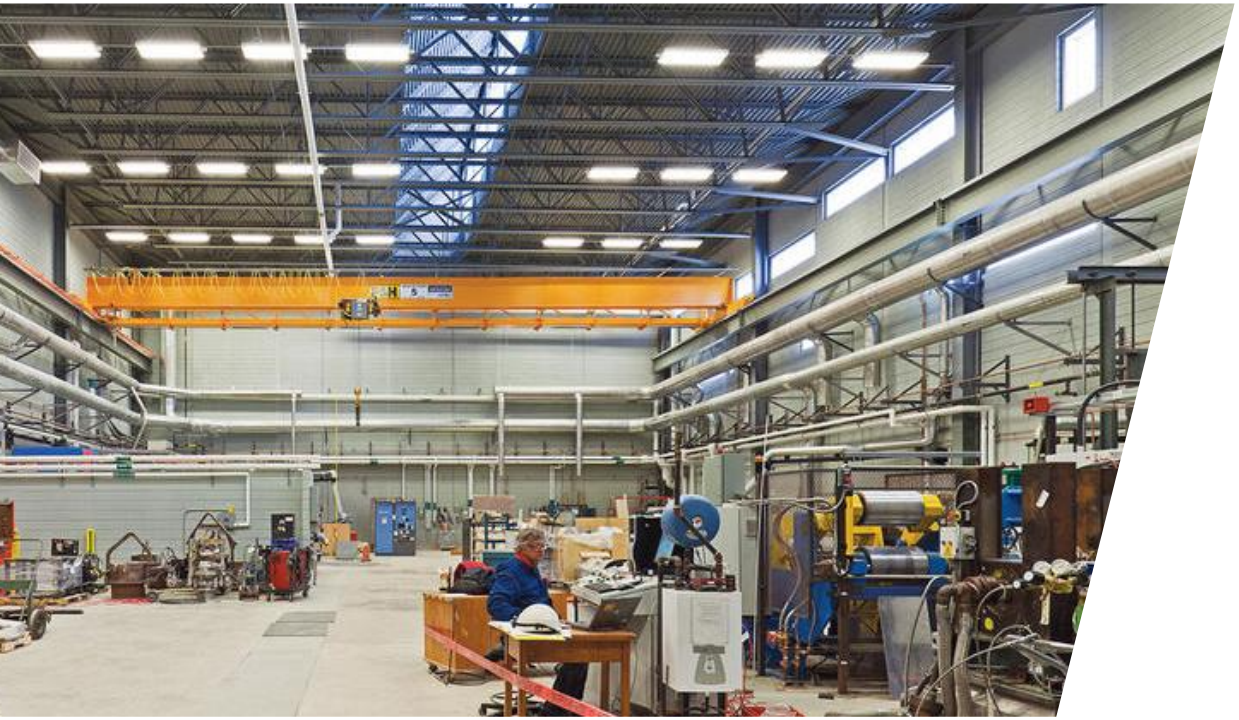
Alternate Materials & Technologies for Clean Energy

Kumar Sadayappan

CanmetMATERIALS, Energy Efficiency & Technology Sector

Canada

AGENDA



CONTEXT

- Critical Mineral Demand & Risks
- Options
- Canada's Approach

APPLIED R&D

- Innovation in Critical Minerals

TECHNICAL REVIEW

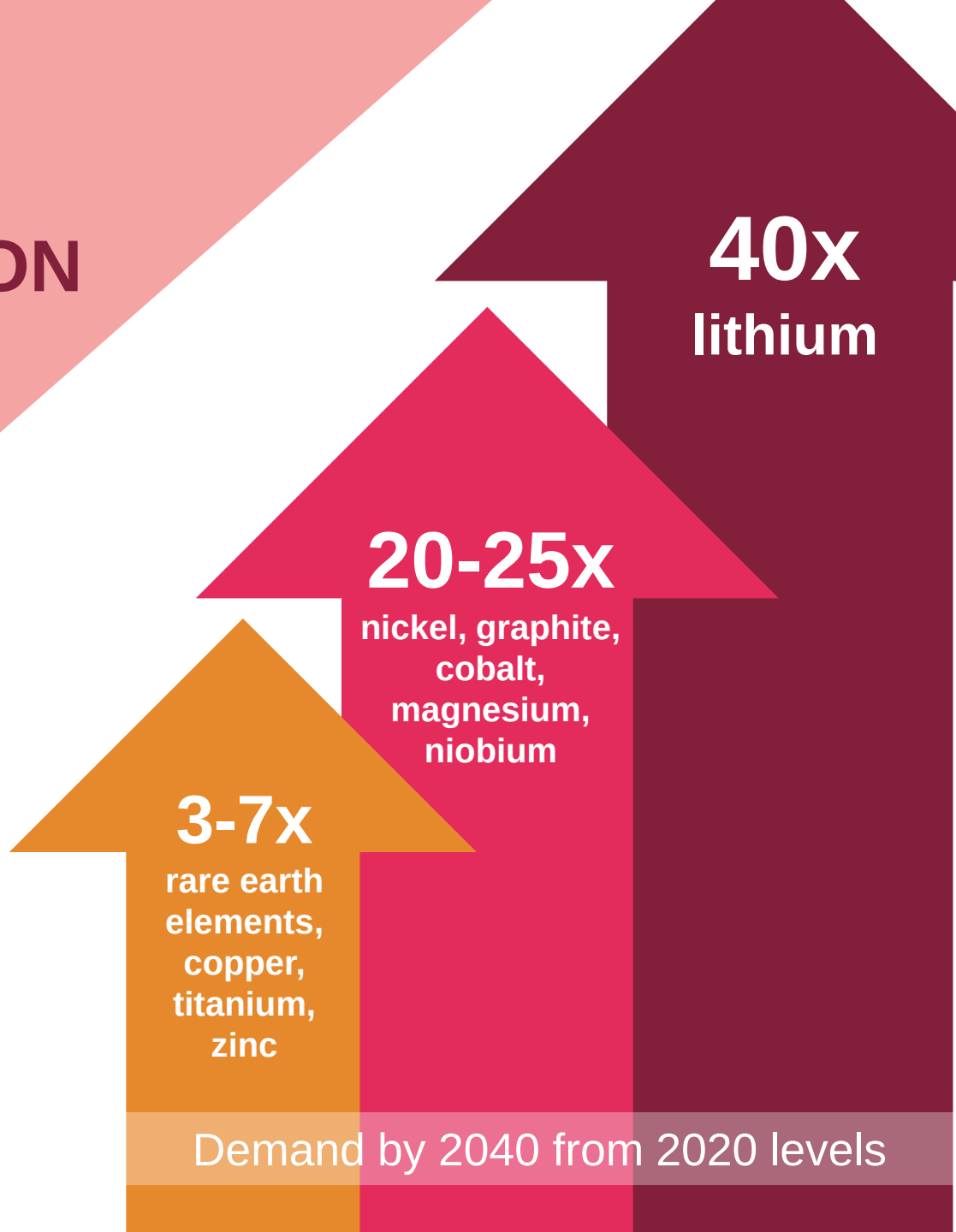
- Substitution Opportunities
  - Conductors
  - Magnets
  - Motor Technologies

CRITICAL MINERALS ARE ESSENTIAL TO TRANSITION TOWARDS CLEAN ENERGY

ENERGY SECURITY
- Synonymous with CM security

PARIS AGREEMENT GOALS
- Quadrupling mineral supply for clean energy technologies by 2040

DEMAND PREDICTED TO OUTPACE SUPPLY



GLOBAL CRITICAL MINERALS

GEOGRAPHICALLY CONCENTRATED

- Supply & price affected by geopolitical events

SUPPLY & PROCESSING

- Reliance on non-likeminded states

PRICE VOLATILITY

- London Metal Exchange suspended nickel trading in March due to surging prices
  - Russia is the 3rd largest exporter







	Production	Processing
REEs	60%	87%
Gallium	-	95%
Cobalt	-	65%
Vanadium	-	56%
Copper	8%	40%
Lithium	13%	59%

	Production	Global Rank
Nickel	5%	3
Titanium	13%	3
Vanadium	17%	2
Aluminum	6%	3
Potash	20%	2
Palladium	35%	2
Platinum	10%	2

OPTIONS

Several pathways to address demands of energy transition, supply chain security, and economic opportunities

PRIMARY SOURCE EXTRACTION

- Traditional mining: typically high cost, timelines, and environmental impact

SECONDARY SOURCE RECOVERY

- Processes to recover CMs from sources such as industrial waste, brines, mine waste, end-of-life (EOL) products

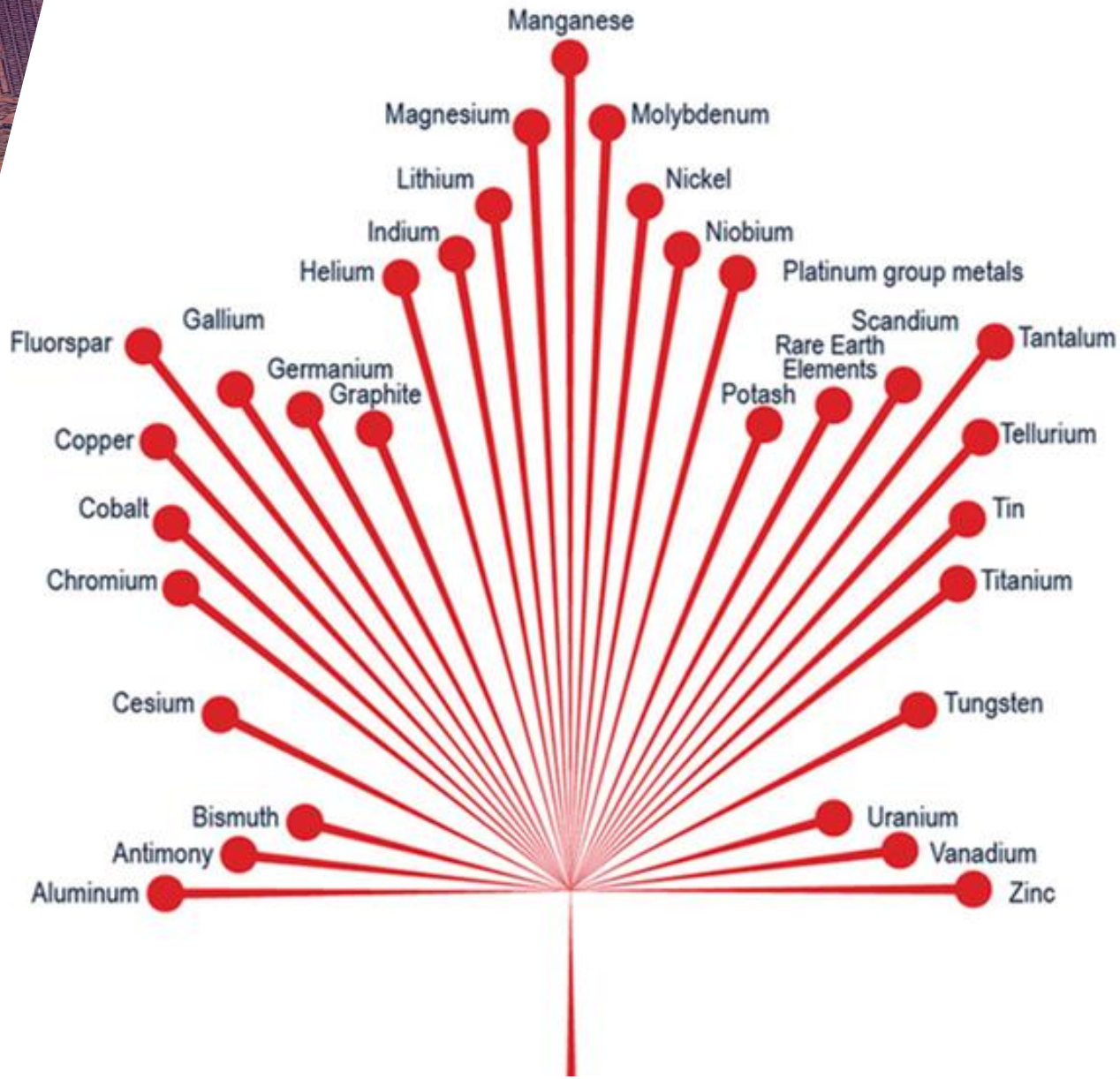
MATERIAL SUBSTITUTION

- Identify, develop & produce alternative materials/tech
- More environmentally friendly, earth-abundant, supply-secure, and/or affordable
- Achieve the same or better properties

CANADA'S CRITICAL MINERAL STRATEGY

Starting in Budget 2022, $3.8B in support over eight years, to **implement Canada's first Critical Minerals Strategy**. This will create thousands of good jobs, grow our economy, and make Canada a vital part of the growing global critical minerals industry. Elements include:

- Public Geoscience
- Indigenous Engagement & Capacity
- Research & Development
- Global Partnerships
- Large-Scale Demos & Deployments
- Infrastructure



CanmetMATERIALS
CRITICAL MINERALS R&D

Materials Science

Performance | Development | Substitution | Recovery | Manufacturing Processes



FOCUS

- Midstream R&D
- 18 priority Critical Minerals
- Key value chains

RESEARCH AREAS

- Battery, magnetic, and intermediate structural materials for clean technologies

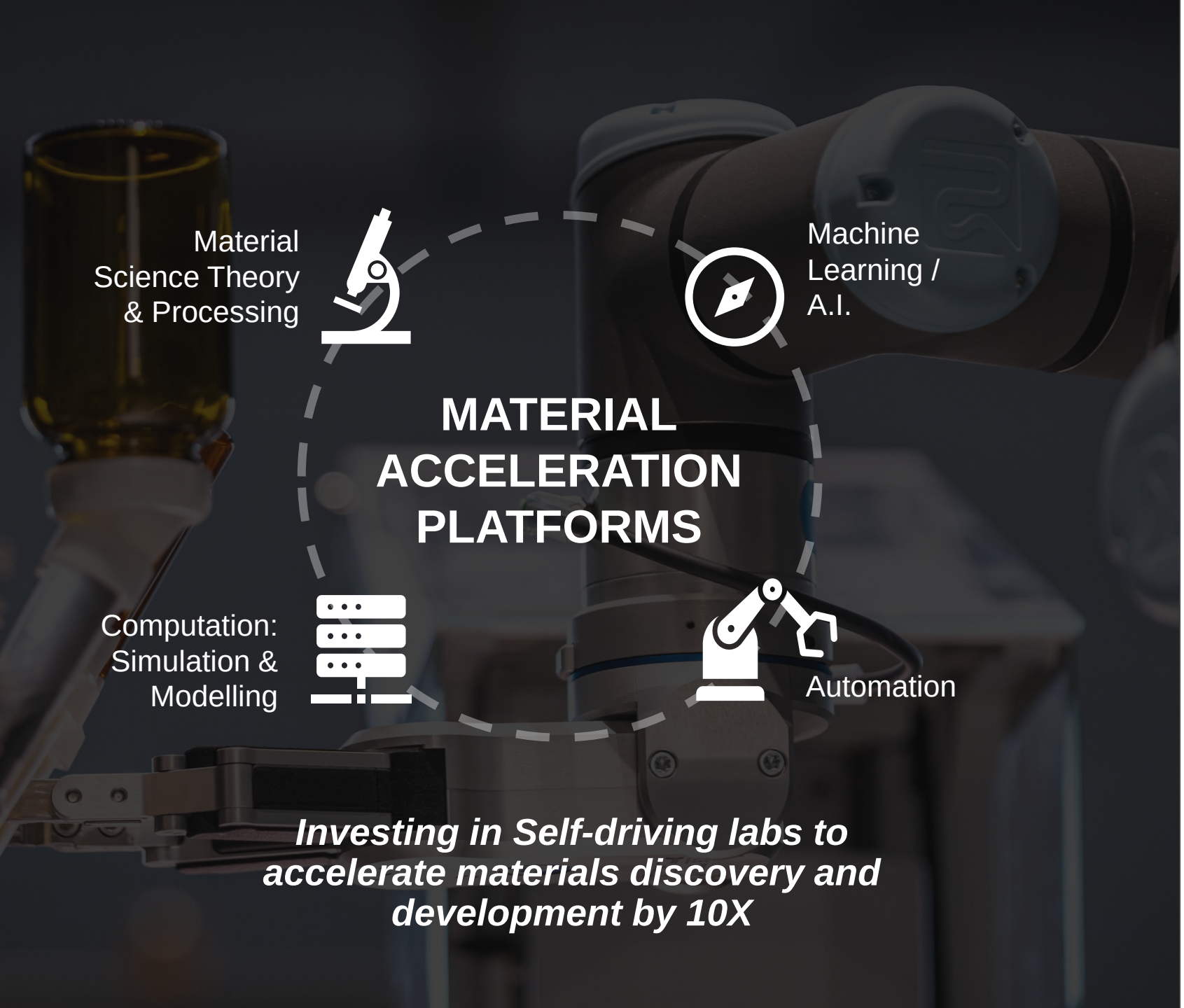
APPROACH

- Vertical integration
- Accelerated material discovery
- International collaboration



Natural Resources Canada | Ressources naturelles Canada

Canada



GERMAN-CANADIAN
MATERIALS ACCELERATION CENTRE

Acceleration Consortium

UBC

UNIVERSITY OF
TORONTO

National Research Council Canada
Conseil national de recherches Canada

MISSION
INNOVATION

MATERIAL SUBSTITUTION FOR CRITICAL MINERALS

CONDUCTORS



MAGNETS



MOTOR TECHNOLOGIES



DEMAND FOR CONDUCTORS

CONSTRUCTION

GRID INFRASTRUCTURE

- Power cables

EV COMPONENTS

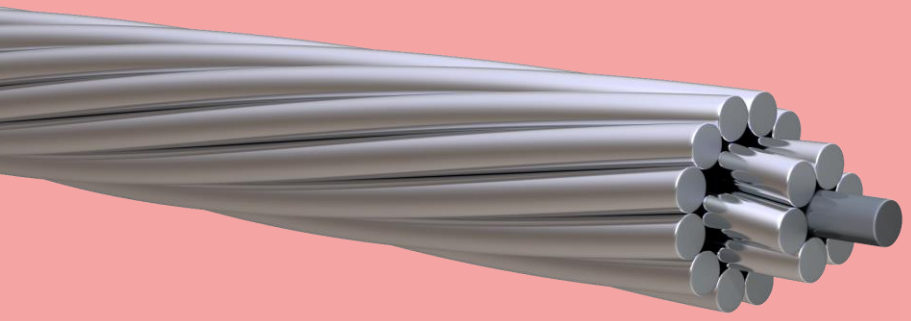
- Rotors
- Charging stations
- Harnesses



CONDUCTIVE MATERIALS

	CURRENT SUPPLY	PREDICTED DEMAND (2030)	
29 Cu Copper 63.55	24.9 M tons | 20.8 M primary (2021)	36.6 M tons; supply 30.1 M T | 24 M Ton primary	• No new large mines expected
13 Al Aluminium 26.98	94 M tons | 69 M Primary (2022)	119 M Tons * Conductors demand 4.5 M T	• Recoverable resources available ○ Energy and emission intensive ○ Potential for more recycling

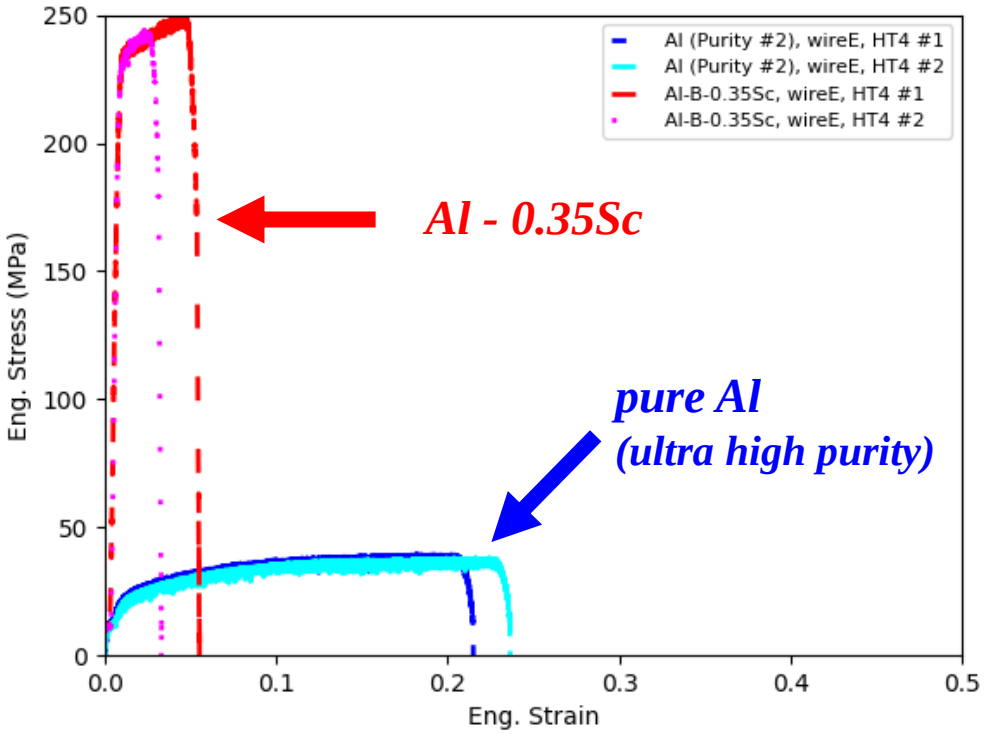
ALUMINUM CONDUCTORS



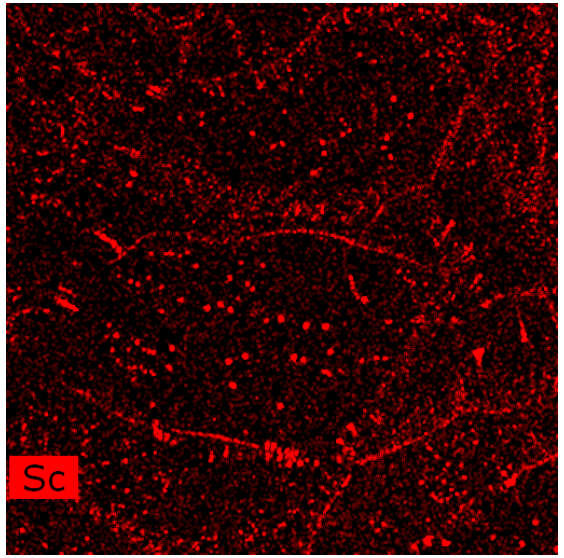
- Pure Al wire conductivity range: **62 – 65 %IACS**
- Lower strength & temperature stability (compared to Cu)
- Potential replacement for Cu in traction motors
  - Lower cost
  - Supply secure
  - Mass reduction (lower density)
- Induction Motors contain Al rotors

ALLOY DEVELOPMENT

- Conductors of pure Al with small Sc additions (<0.35 wt.%) for improved strength but slightly reduced electrical conductivity are being studied
- Al-Sc binaries conducted to-date have significant strength increase (>500%) but a conductivity of about **58 %IACS**
  - Al + Sc + Ce alloys
- Development of Cu-Graphite, Al-graphite with improved conductivity



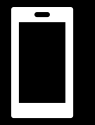
TEM-EDS image showing Al_3Sc nano-precipitates



DEMAND FOR RARE EARTH ELEMENTS (REEs)

43% - PERMANENT MAGNETS

- Largest end-use application of REEs



CELLPHONES



TELEVISIONS



COMPUTERS



WIND TURBINES



ELECTRIC VEHICLES



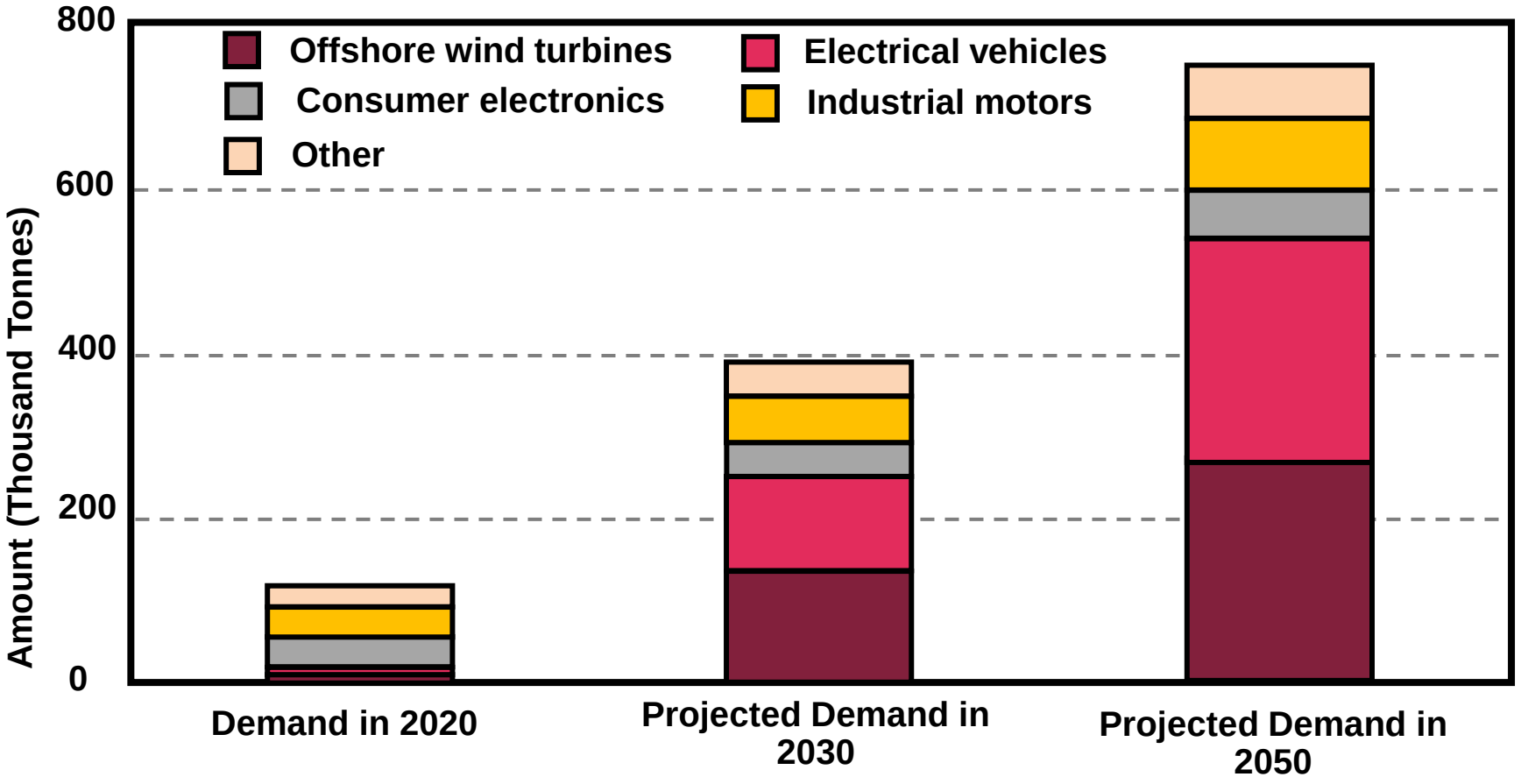
AIRCRAFTS

DEMAND FOR RARE EARTH ELEMENTS (REEs)

Symbol	Name	Typical Use
Sc	Scandium	Al-Sc alloys for aerospace
Y	Yttrium	YAG laser, YBCO high-temperature superconductor
La	Lanthanum	Hydrogen storage, battery electrodes, lens
Ce	Cerium	Hydrophobic coatings for turbine blades, oxidizing agent
Sm	Samarium	Rare earth magnets, lasers, nuclear reactors
Pr	Praseodymium	Rare earth magnets, lasers, electric motors
Nd	Neodymium	Rare earth magnets, lasers, electric motors
Tb	Terbium	Rare earth magnets, lasers, sonar systems, fuel cells
Dy	Dysprosium	Rare earth magnets, lasers, hard disk drives
...	...	...

NdFeB Magnets

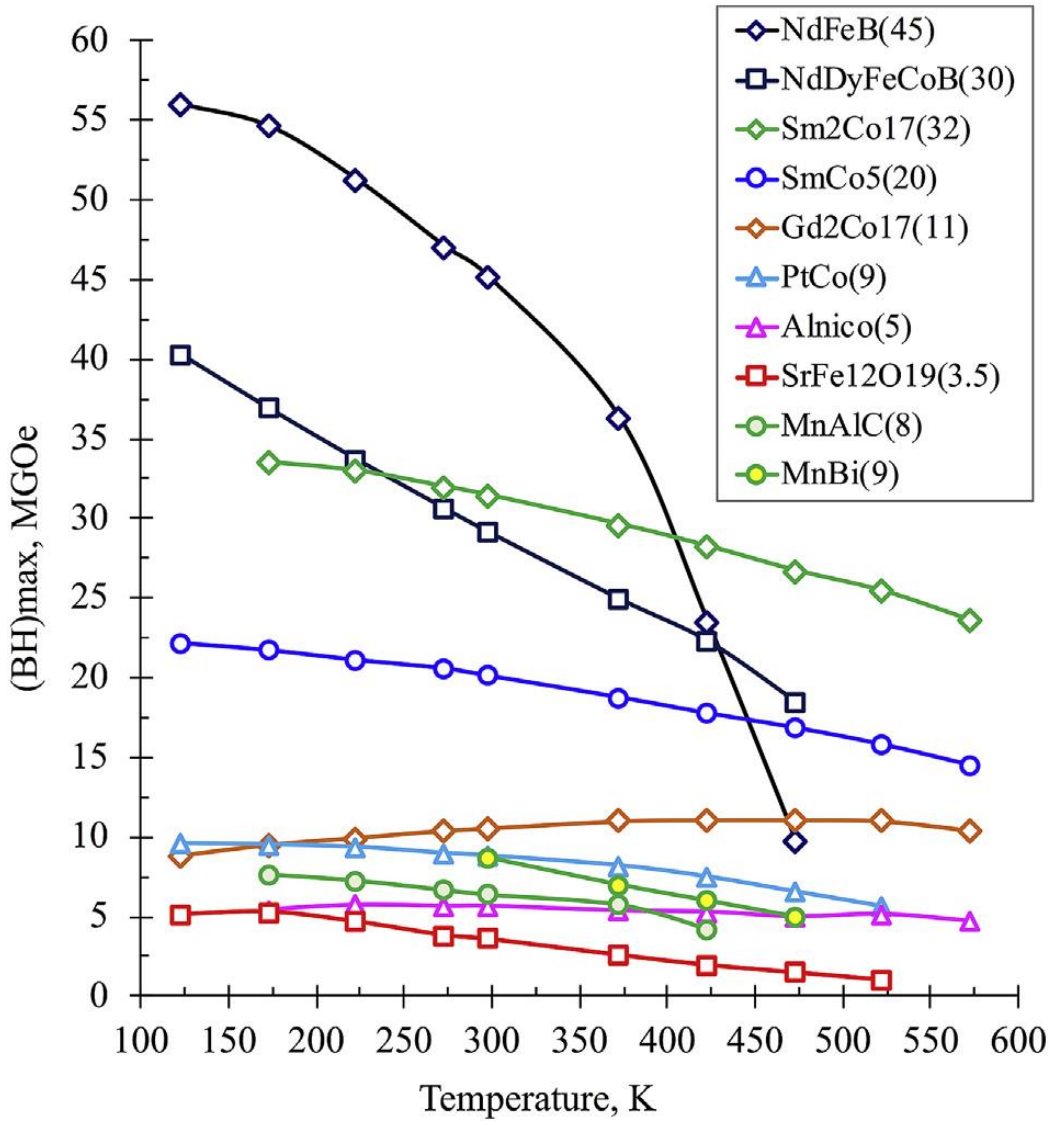
PROJECTED DEMAND FOR NdFeB MAGNETS



- Demand will increase from 119,000 tons in 2020 to 387,000 tons in 2030, and to 753,000 tons in 2050
- Offshore wind turbines (36.3%) and electric vehicles (35.3%) will use the majority of NdFeB magnets
- Increased demand for consumer electronics and industrial motors

Smith et al., "Rare Earth Permanent Magnets Supply Chain Deep Dive Assessment", U.S. DOE Response to Executive Order 14017, 2022.

MAGNETIC MATERIALS



- Fe-Nd-B
- Mn-x alloys (Ga, Bi, Al)
- Fe-Ni alloys (Tetrataenite)
- Fen-N
- Fe-Co

Temperature dependence of (BH)max for most commercial permanent magnets. The value in parentheses in (BH)max at 298 K.

Ref: Jun Cui et al, Acta Materialia, 158 (2018), 118-137

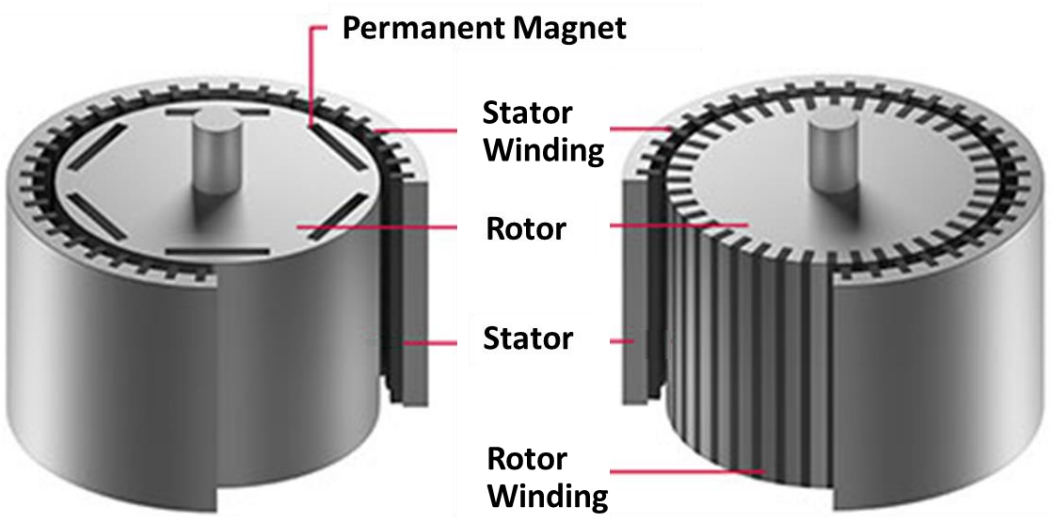
MOTOR TECHNOLOGIES FOR ELECTRIC VEHICLES



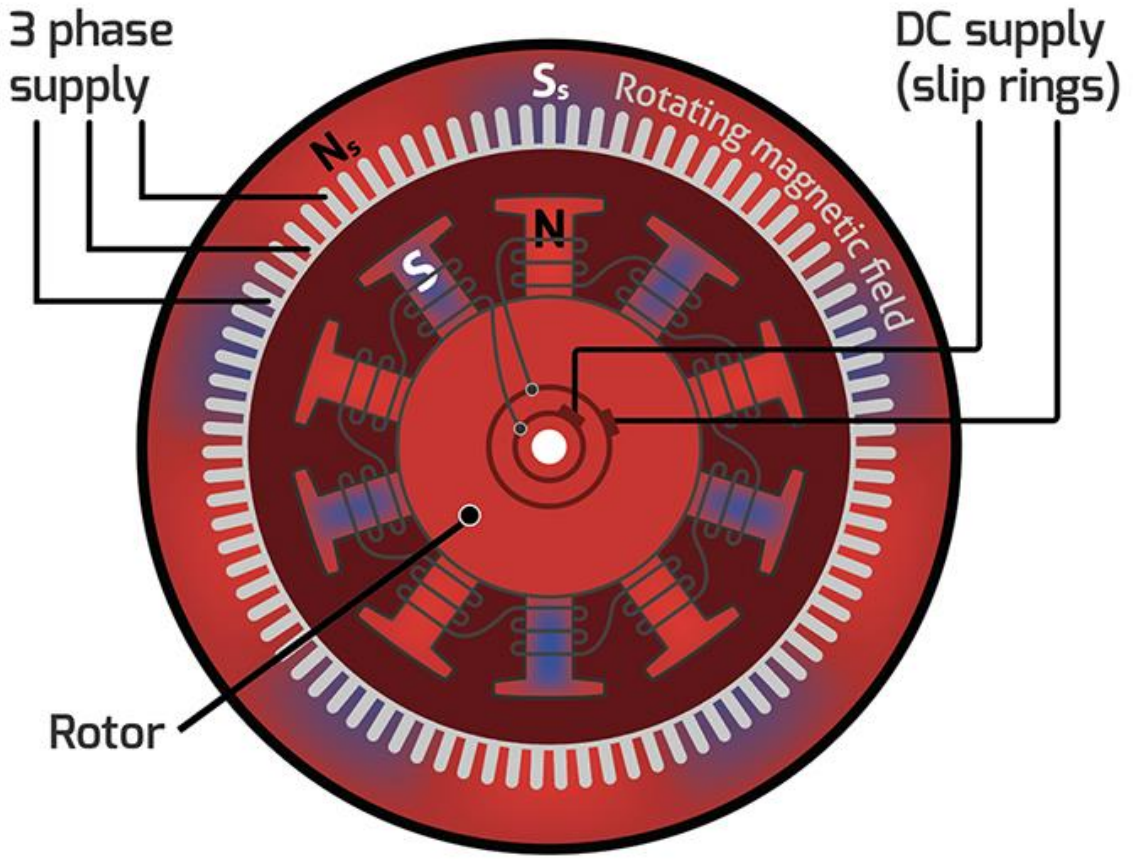
DC | INDUCTION | PM | SYNCHRONOUS RELUCTANCE | COMBINATION

	PM	DC	IM	SR
Power Density	H	L	M	M
Size	S	M	M	L
Torque	H	M	M	H
Cost	H	M	L	M

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INDUCTION MOTORS



Wound-Rotor Synchronous Motor, or WRSM

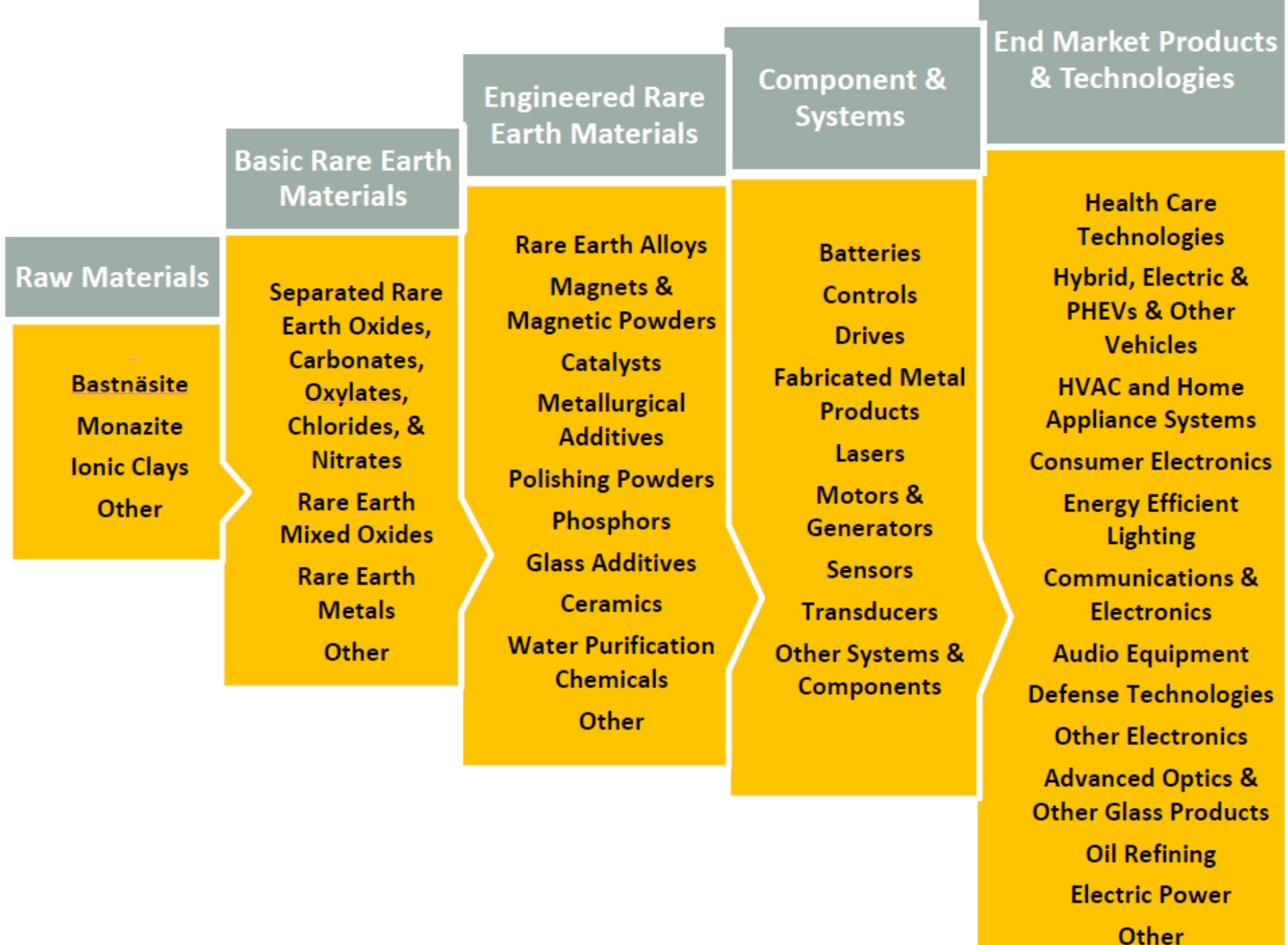
Use soft magnetic materials (windings) in both stator and rotor.

- No permanent magnet is needed.
- Lower power density and efficiency.

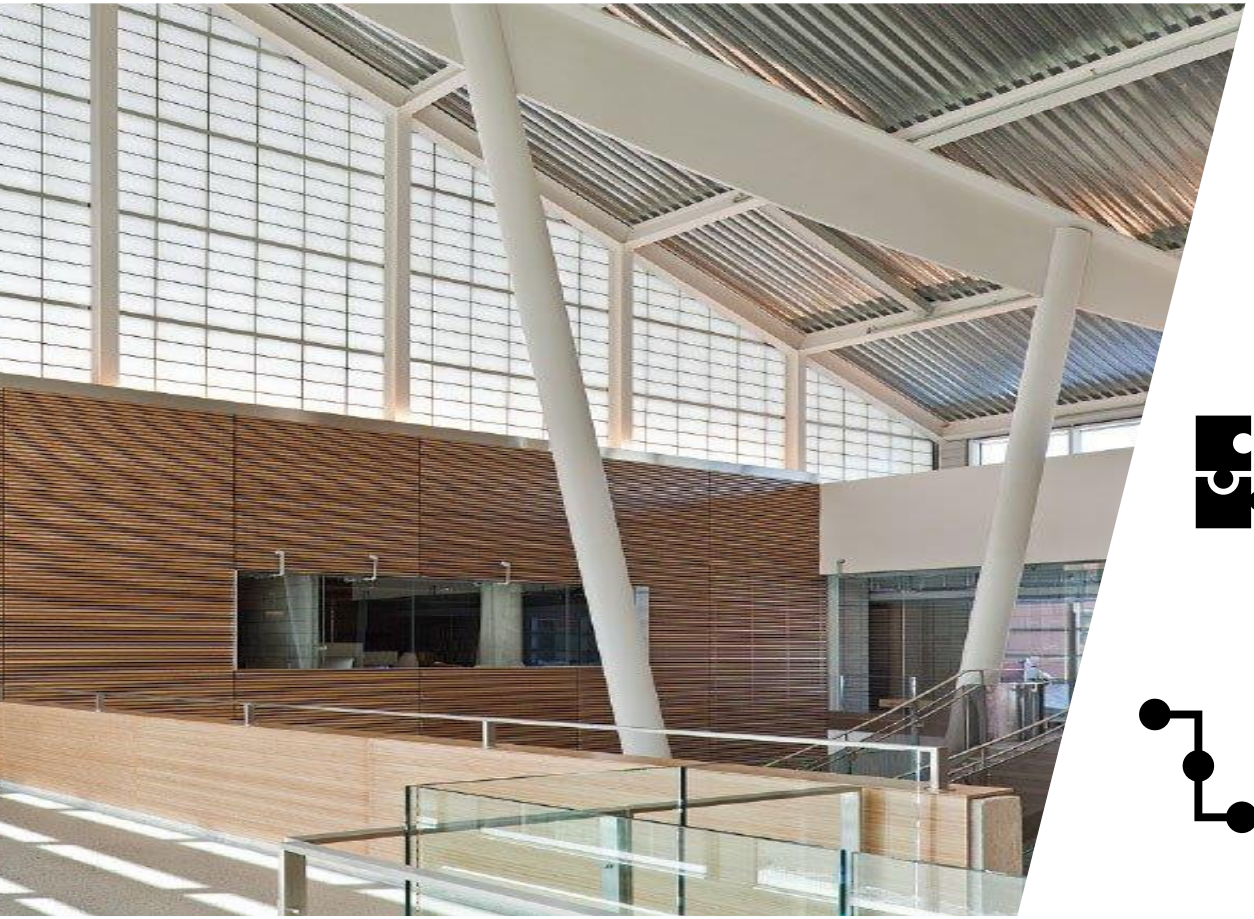
TECHNOLOGIES TO IMPROVE

- Dynamic Motor Drive (DMD) pulse density strategy as controlled by software
- In-Rotor Inductive-Excited Synchronous Motor
- Would-rotor synchronous motor (WRSM)

Jeffrey Jenkins, ”Alternatives to permanent magnet motors in EV traction applications”, Charged Electric Vehicles Magazine, April 13, 2023.


Raw Materials
Bastnäsite
Monazite
Ionic Clays
Other
Basic Rare Earth Materials
Separated Rare Earth Oxides, Carbonates, Oxylates, Chlorides, & Nitrates
Rare Earth Mixed Oxides
Rare Earth Metals
Other
Engineered Rare Earth Materials
Rare Earth Alloys
Magnets & Magnetic Powders
Catalysts
Metallurgical Additives
Polishing Powders
Phosphors
Glass Additives
Ceramics
Water Purification Chemicals
Other
Component & Systems
Batteries
Controls
Drives
Fabricated Metal Products
Lasers
Motors & Generators
Sensors
Transducers
Other Systems & Components
End Market Products & Technologies
Health Care Technologies
Hybrid, Electric & PHEVs & Other Vehicles
HVAC and Home Appliance Systems
Consumer Electronics
Energy Efficient Lighting
Communications & Electronics
Audio Equipment
Defense Technologies
Other Electronics
Advanced Optics & Other Glass Products
Oil Refining
Electric Power
Other

SUMMARY



SPECIFIC EXAMPLES

- This presentation focused on a few applications of CMs for energy technologies

SUBSTITUTION

- Alternate materials & technologies need to be developed to reduce the pressure on CMs

SUPPLY CHAIN

- Entire supply chain must be considered for each material (not just the energy applications)



Connect with us

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