# LOOKING BEYOND COAL AS A FUEL

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PRESENTATION FOR THE CLEAN COAL DAY OF JAPAN
1 SEPTEMBER 2024

INTERNATIONAL CENTRE FOR
SUSTAINABLE CARBON

# WHO WE ARE AND WHAT WE DO

- The International Centre for Sustainable Carbon is a Technology Collaboration Programme organised under the auspices of the IEA while being functionally and legally autonomous
- We are funded by national governments (contracting parties) and by corporate industrial organisations (sponsors)
- We provide independent information and analysis on how various carbon based materials can be cleaner sources of energy, compatible both with the UN Sustainable Development Goals and the need to achieve carbon net zero by 2050

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Technology Collaboration Programme
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# SCOPE OF PRESENTATION

- Who we are and what we do
- What are rare earth elements are why are they important?
- Current REE extraction challenges and opportunities
- Extraction of REE from coal and coal by-products for an alternative supply route
- Key findings

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General Manager

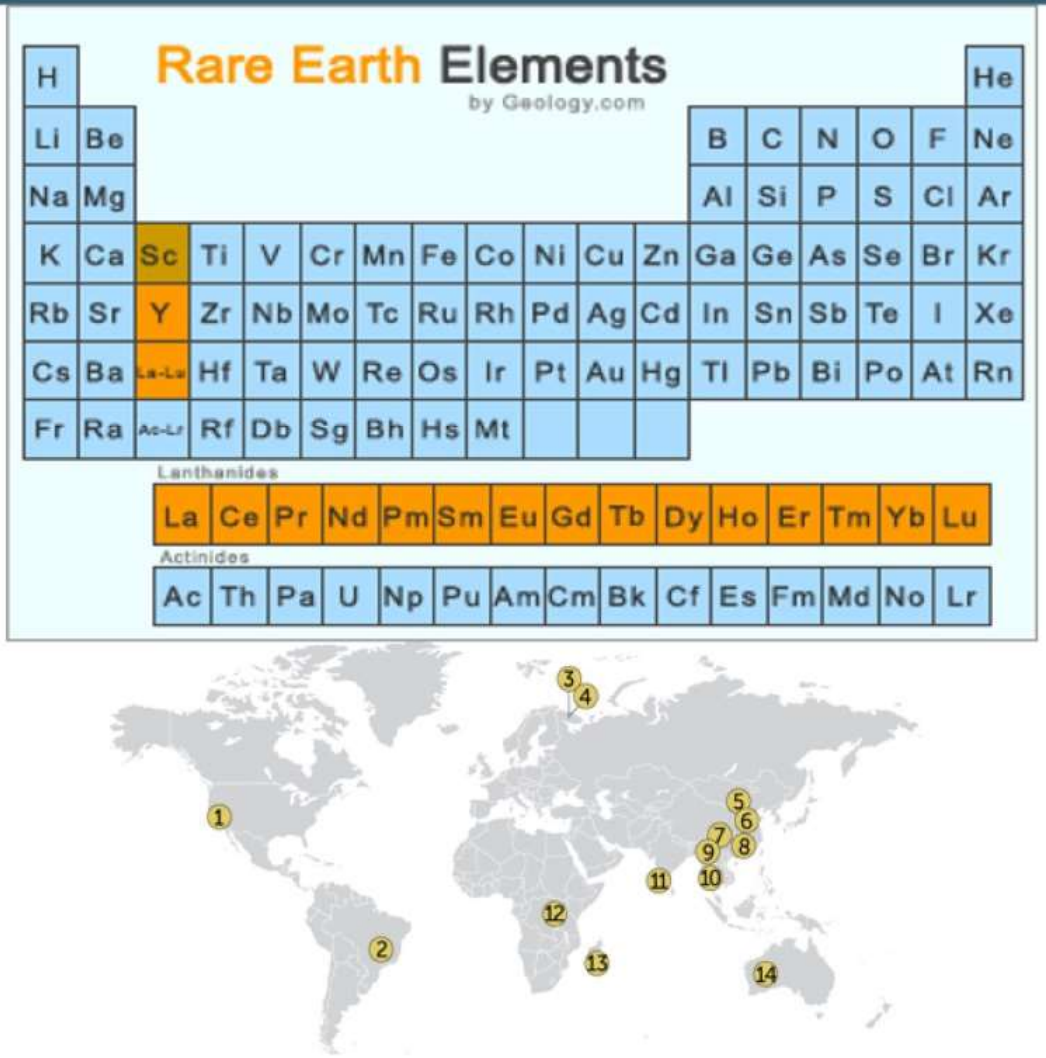
# GROWING IMPORTANCE OF RARE EARTH ELEMENTS

REEs comprise seventeen metallic elements highlighted on the periodic table - fifteen lanthanides, plus yttrium and scandium

- REEs are relatively plentiful in the earth's crust, but primarily occur as specific minerals amongst many, which can make their economic recovery very challenging
- The figure on the lower right shows major REE locations, most of which are in Asia

REEs are categorised as:

- Light rare earth elements
- Heavy rare earth elements
- All have uses, with the currently most favoured being for permanent magnets that can be used in a wide variety of critical electronics and defence applications



# WHY REES ARE SO IMPORTANT

- Multiple uses in industry, commerce, defence, aerospace, medicine, electronics, lasers, computers.....
- Crucial in the '**Green Transition**' and possible moves towards reaching net-zero emissions – e.g. wind turbines, electric vehicles, hydrogen electrolysers, solar panels and energy-efficient lighting (1MW of wind energy capacity requires 171 kg of REES)
- A single US F-35 fighter jet requires some 427 kg of REES
- A Virginia-class nuclear submarine uses nearly 4.2 tonnes of REES (ref USDOE 2024)
- The global market turnover for REEs was **US$ 5.3 billion** in 2021
- Estimated to be **US$ 6 billion** in 2024
- Projected to increase to **US$ 9.6 billion** by 2026 , which should be encouraging for suppliers
- **But** price is vulnerable to Chinese pressure, which can manipulate and hurt Western companies

# GLOBAL REE PRODUCTION

- Global reserves of REEs estimated to be >130Mt
- Global production has increased significantly during the past decade:
- In 2013 it was around 100 kt/y
- In 2022 it was 300 kt/y
- In 2023 it rose to 350 kt/y
- Chinese domination of REE mine production and supply

- Europe has no rare earth mines in operation. However, two major REE deposits recently discovered in Sweden and Norway (2024), which are suitable for processing, subject to extensive development work

- Massive REE deposit also found in deep seabed off Japan (2024)

# REE MINING: SELECTED DATA FOR 2020/21

| Country | Mine production (tonnes) | Reserves (tonnes) | Percentage of total reserves |
|---|---|---|---|
| China | 140,000 | 44,000,000 | 38.0% |
| Vietnam | 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% |
| USA | 38,000 | 1,500,000 | 1.3% |
| Greenland | - | 1,500,000 | 1.3% |
| Tanzania | - | 890,000 | 0.8% |
| Canada | - | 830,000 | 0.7% |
| Others | 40,600 | 11,000,000 | 0.7% |
| **World Total** | **243300** | **115,820,000** | **100%** |
| | | | |

# CHINA'S PLANS (ALLEGEDLY) FOR ADDRESSING REE FUNDING CHALLENGES

- USA and Australia have proven REE mining procedures, but quantities that currently can be mined are relatively limited
- Most countries that have surveyed reasonable deposits are developing countries, which may limit their scope to develop the REE extraction due to funding limitations and lack of sufficient experience
- Also, China's dominant position can make it difficult for some countries to initiate such a major venture
- China has a superior market position and can control events. This includes controlling this market, addressing production and global availability plus adjusting international prices allegedly

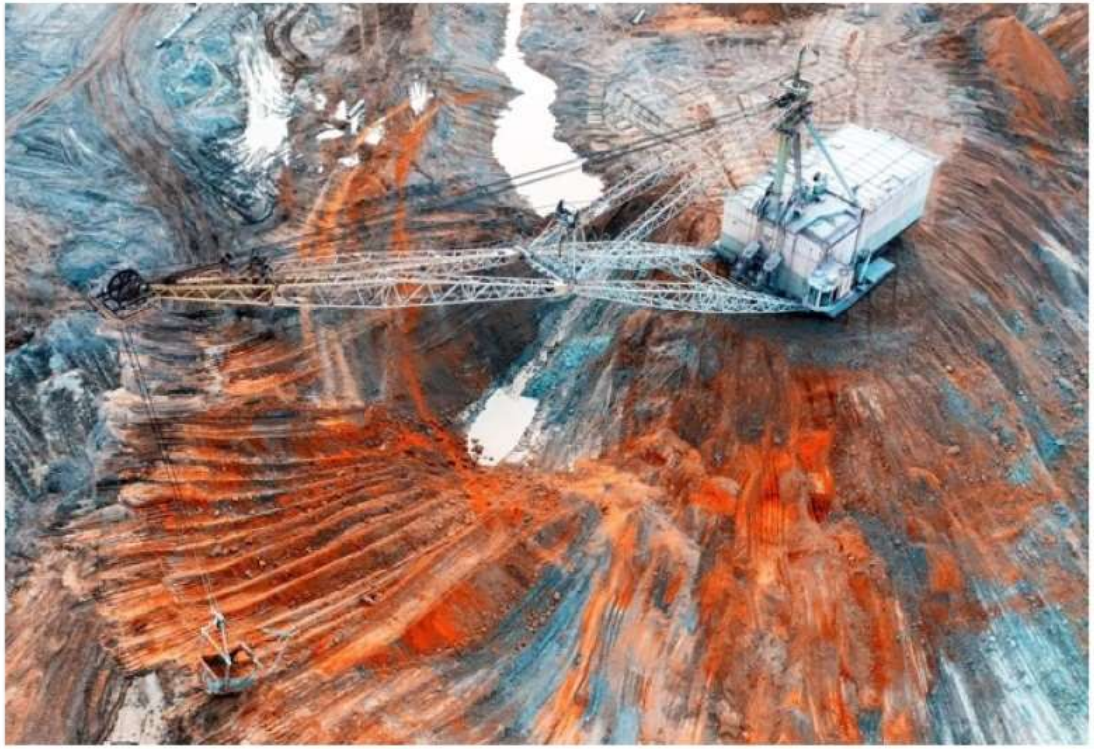


Photo: mykhailopavlenko/Shutterstock

# CHINA'S REGULATORY FERVOUR?

- China intends to protect its REE market through a combination of focused regulations and controlled prices. At the same time, it limited China's annual output but this was considered a price worth paying to preserve its overall market

- Since then, China has restructured its REE activities by strengthening its regulatory approach as a longer-term deterrent, while taking action to directly prevent adverse impact from other national companies

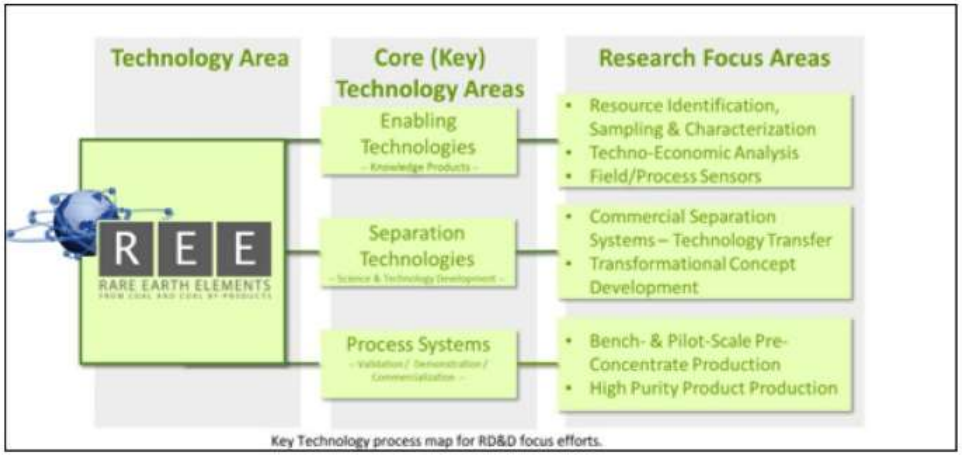
- However, this heavy-handed approach may be just the push needed for those countries that might work in partnership with US and Australia to establish alternative REE chains at a scale that could severely limit China's current activities

# A PROMISING OPTION

- Brazil has massive REE deposits but probably lacks the necessary skillset and financial basis to establish a complete process train
- This would need to cover extraction of Brazil major ore from source, to maintain a reliable supply for process at the US plant to produce separated ores that subsequently could be treated to provide the actual REEs
- Brazil has been publicly declaring that it would like to be part of any international consortium, subject to appropriate financial remuneration. The US and Australia would presumably then take forward the REE extraction stage
- An obvious issue to be addressed is establishing how China will react to what it is likely to view as an outrageous provocation

# RENEWED US PROGRAMME AT MOUNTAIN PASS MINE

- US seeking practical, viable technologies capable of maximising REE resource development and recovery from domestic sources
- Action drivers include the US Military
- This may create a problem as China will probably cut off the US and partners from access to its final products



Key Technology process map for RD&D focus efforts.

# CAN CHINA STRENGTHEN ITS MARKET POSITION?

- China appears to have reaped what it has sown.
- It has a strong foothold in the supply chain that in the past allowed it to produce 85% of the world's refined rare earths in 2020. But it doesn't appear to have taken into account that other countries would move forward with their own projects, especially those with support from OECD countries, namely Brazil with help from US and Australia


- Now, with the start of mining operations in other countries, China's share of **global production** has fallen from 92% in 2010 to 58% in 2020

- Entrepreneurs/traders are seeing further opportunities, There are massive deposits available that are not even being processed, which if they were addressed could readily boost REE supplies

# RESTRUCTURING THE NATIONAL REE BUSINESS

- China Minmetals, Chinalco, and the People's Government of Ganzhou (largest supplier of light REEs by capacity)

- China Northern Rare Earth Group (largest supplier of heavy REEs by capacity)

Image: Shutterstock

# REE MANAGEMENT RESTRUCTURE IN CHINA

- China has achieved dominance of REE production and processing through a combination of early moves into the industry, state investment along the supply chain, export controls, low labour costs, and decades of weak environmental regulation
- Demand for REEs is expected to continue to rise dramatically through 2030 and beyond, driven by their use in permanent magnets for electric vehicle motors (including hybrid vehicles) and wind turbines
- But alternative technologies could substitute or reduce REE consumption in both EV and wind turbine drives, including improved materials utilization and lower waste, perhaps magnet technologies without REE

# REE MANAGEMENT RESTRUCTURE IN CHINA

- Given the potential of these options, the future demand for REE could be subject to high uncertainty
- These uncertainties on the demand side exacerbate supply-side challenges: investments in mining require long lead times as well as hard-to-find skilled workforce, among other issues.
- Efforts are underway in Europe and the USA to reduce China's 90 per cent dominance of REE processing
- All that said, China will probably remain the global leader in processing REEs through 2030, given the scale of its existing processing industry and position in global battery and electronics supply chains. But uncertainties will certainly arise.....

Image: Shutterstock

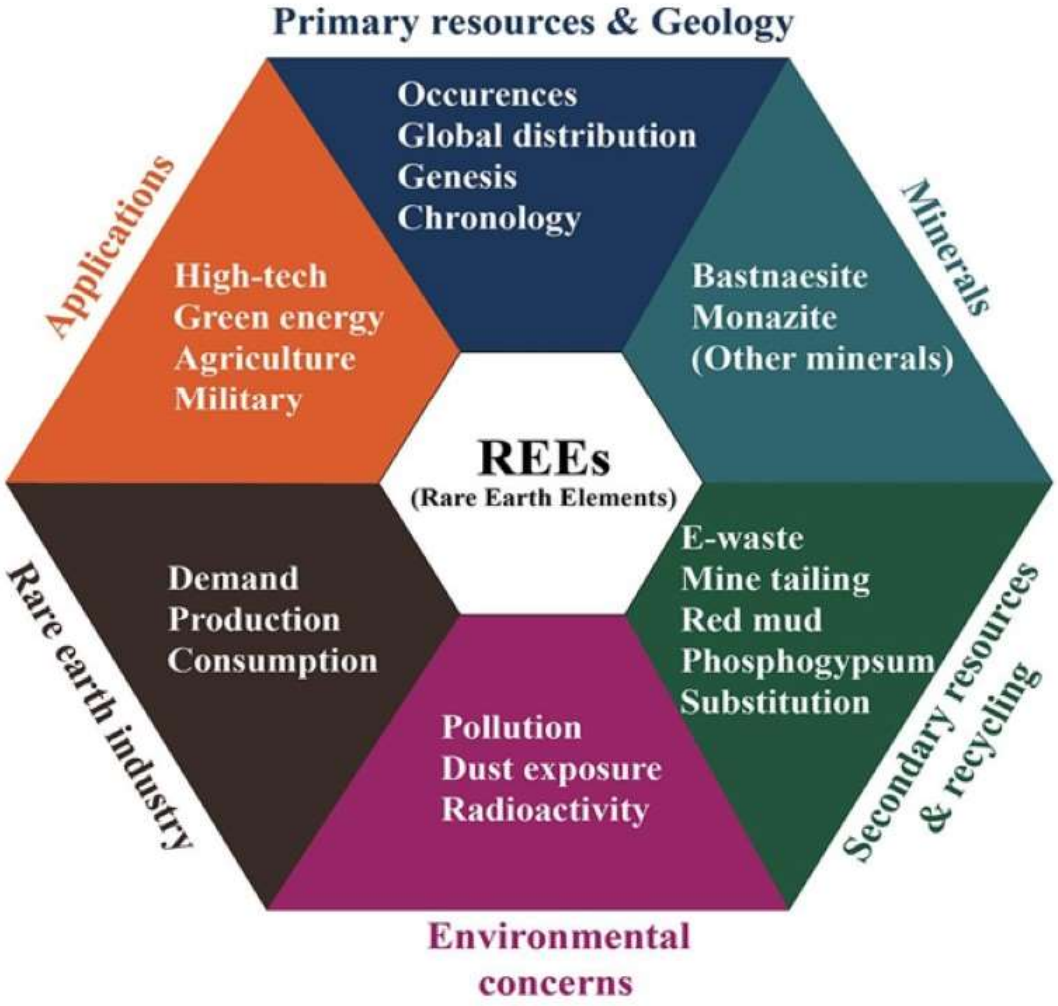
# WHERE DO WE GO FROM HERE?

- In contrast, Australia/US will most likely establish a similar arrangement but perhaps with higher environmental standards and presumably corresponding higher costs. This will be in another country that does not have close links with China. At present, the most likely location is Brazil where the President has already declared his willingness to cooperate with the suggested OECD partners
- However, the time required to establish a fully operational ore processing plant and to manufacture the required pieces of equipment will be significant
- It seems China has the edge for some time before US/Australia will be able to avoid the need to deal with them on this critical issue, which is the point of no return

Image: Shutterstock

# REES ISSUES TO CONSIDER

(NIMILA DUSHYANTHA AND OTHERS, 2020)



| Elements | Industrial uses | | | | | | | | Example products and uses |
|---|---|---|---|---|---|---|---|---|---|
| | Catalysts | Ceramics | Defense | Glass and polishing | Metal alloys | Magnetics | Phosphors (Luminescent materials) | Cell phones (and mobile devices) | |
| Sc | | | | | | | | | Aerospace aluminum alloys |
| **Y** | | | | | | | | | LCD dislpays, LED lights |
| La | | | | | | | | | Batteries, catalysts |
| Ce | | | | | | | | | Catalysts, glass polishers, steel |
| Pr | | | | | | | | | Strong magnets, aircraft engines |
| **Nd** | | | | | | | | | Strong magnets, lasers, speakers |
| Sm | | | | | | | | | Strong magnets, cancer treatments |
| **Eu** | | | | | | | | | LCD displays |
| Gd | | | | | | | | | MRIs, shielding in nuclear reactors |
| **Tb** | | | | | | | | | LCD displays, metal alloys |
| **Dy** | | | | | | | | | Computer hard drives, transducers |
| Ho | | | | | | | | | Strong magnets, cubic zirconia |
| Er | | | | | | | | | Optical fibers, lasers, glass coloring |
| Tm | | | | | | | | | Portable x-ray machines |
| Yb | | | | | | | | | Nuclear medicine, stainless steel |
| Lu | | | | | | | | | Catalysts, petroleum refining |
| Th | | | | | | | | | Arc welding, radiometric age dating |
| Ur | | | | | | | | | Nuclear fuel and weapons |

# • KEY PRODUCTS THAT INCLUDE RARE EARTH ELEMENTS IN THEIR CONSTRUCTION

# GLOBAL LOCATIONS OF THE MAJOR OPERATIONAL REE SITES (REF)


| | |
|---|---|
| 1 Mountain Pass, Calif. (USA) | 8 Longnan (China) |
| 2 Araxá (Brazil) | 9 Northern Myanmar |
| 3 Lovozero (Russia) | 10 Thai Peninsula (Thailand) |
| 4 Khibiny (Russia) | 11 Chavara (India) |
| 5 Bayan Obo (China) | 12 Karonge (Burundi) |
| 6 Weishan (China) | 13 Mandena (Madagascar) |
| 7 Maoniuping (China) | 14 Mount Weld (Australia) |

# BAYAN OBO REE MINE IN INNER MONGOLIA, CHINA

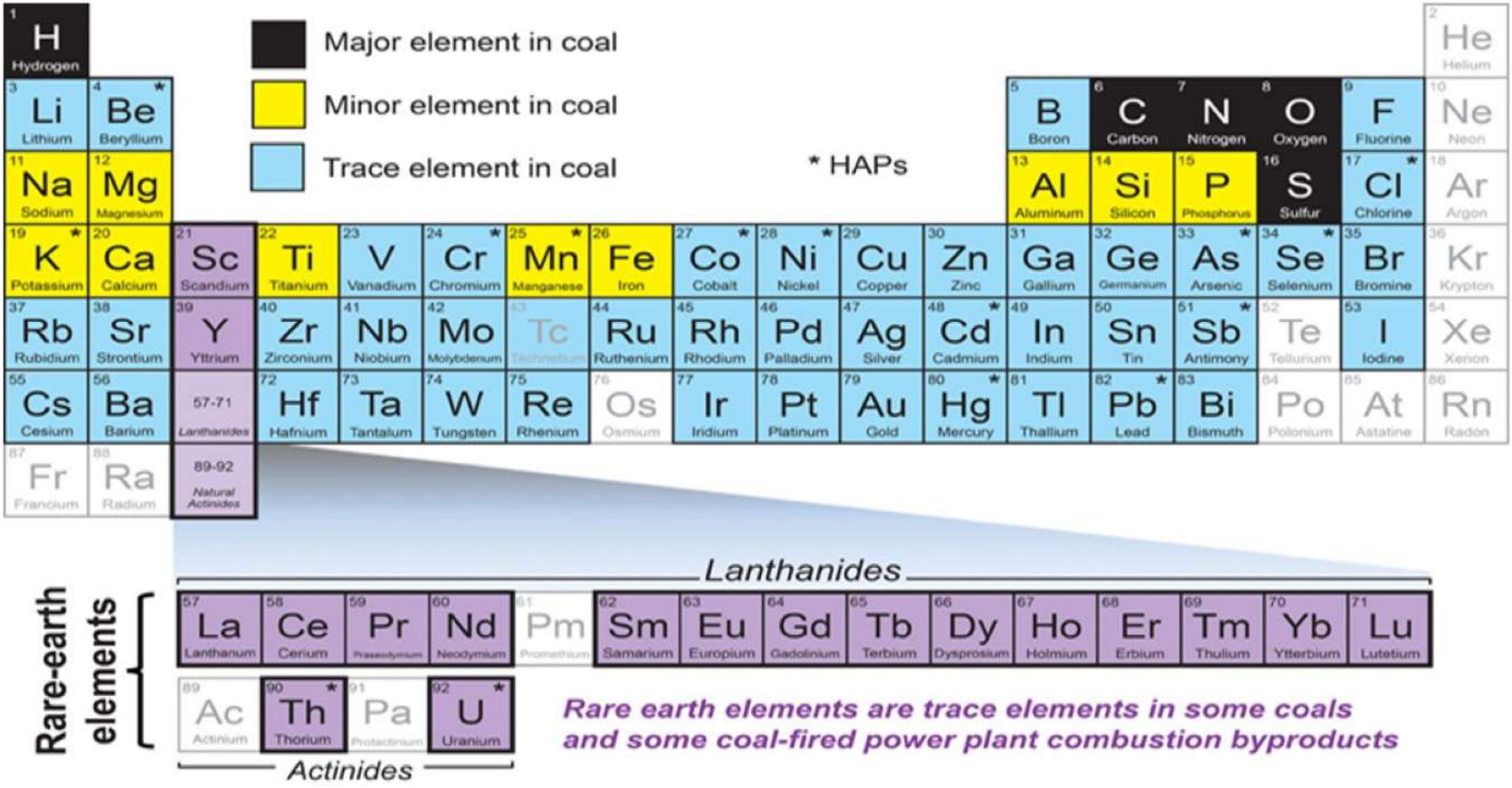
| Country | Reserves (tonnes RE Oxide basis) | %Share | 2022 production |
|---|---|---|---|
| Australia | 3,400,000 | 2.56 | 18,000 |
| Brazil | 22,000,000 | 16.67 | 80 |
| Canada | 830,000 | 0.63 | 10,000 |
| China | 44,000,000 | 33.33 | 210,000 |
| Greenland | 1,500,000 | 1.14 | 0 |
| India | 6,900,000 | 5.23 | 2900 |
| Malaysia | 30,000 | 0.02 | - |
| Malawi | 140,000 | 0.11 | - |
| Russia | 18,000,000 | 13.64 | 2600 |
| South Africa | 860,000 | 0.65 | - |
| Vietnam | 22,000,000 | 16.67 | 4,300 |
| USA | 1,400,000 | 1.06 | 43000 |
| World Reserves | 132,000,000 | | --------- |

# WORLD RESERVES OF REE BY PRINCIPAL COUNTRIES (USGS, 2018) AND ASSOCIATED PRODUCTION

DATA UPDATED 23 FEBRUARY 2023 (RARE EARTHS INVESTING NEWS, 2022)

# INDICATIVE RELATIVE CONCENTRATIONS OF RARE EARTH ELEMENTS IN COAL

(KENTUCKY GEOLOGICAL SURVEY 2023),

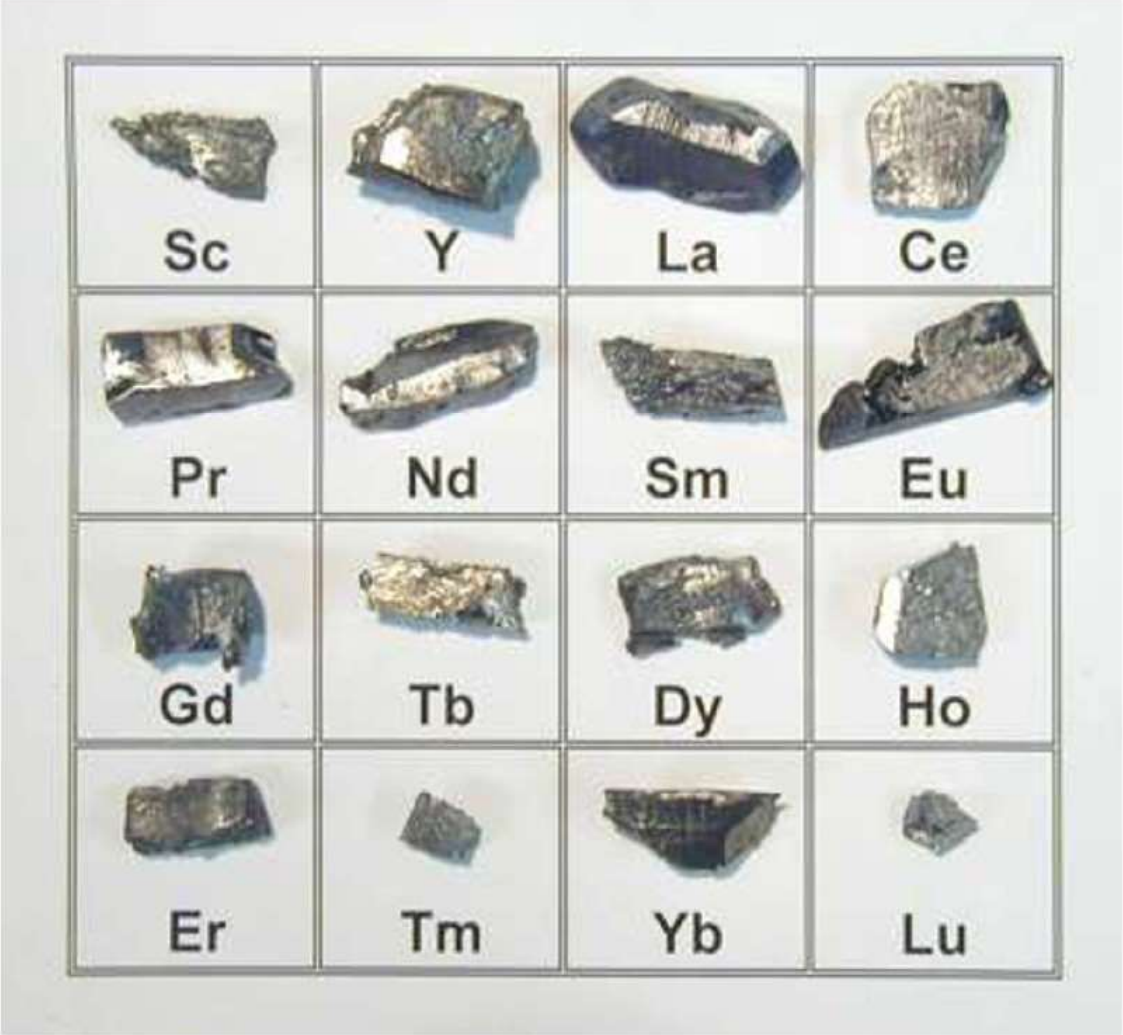



***Rare earth elements are trace elements in some coals and some coal-fired power plant combustion byproducts***

# SAMPLES OF RARE-EARTH OXIDES

(US DEPARTMENT OF AGRICULTURE 2005)

# EXAMPLES OF RARE EARTH ELEMENTS IN METALLIC FORM (PUBLIC MEDIA 2023)



# EXTRACTION OF REE FROM COAL AND COAL BY-PRODUCTS

- Extraction possible from coal, coal fly ash, tailings, coal waste
- Quantities of extractable REEs vary significantly, depending on source, previous treatment
- Still need to enrich, leach and extract but new processes under development
- Environmental issues
- Initial results encouraging and scale-up to pilot scale processes underway

# GOVERNMENT AND PRIVATE COMPANY INITIATIVES TO ESTABLISH THE CARBON ORE

# The New Target Markets

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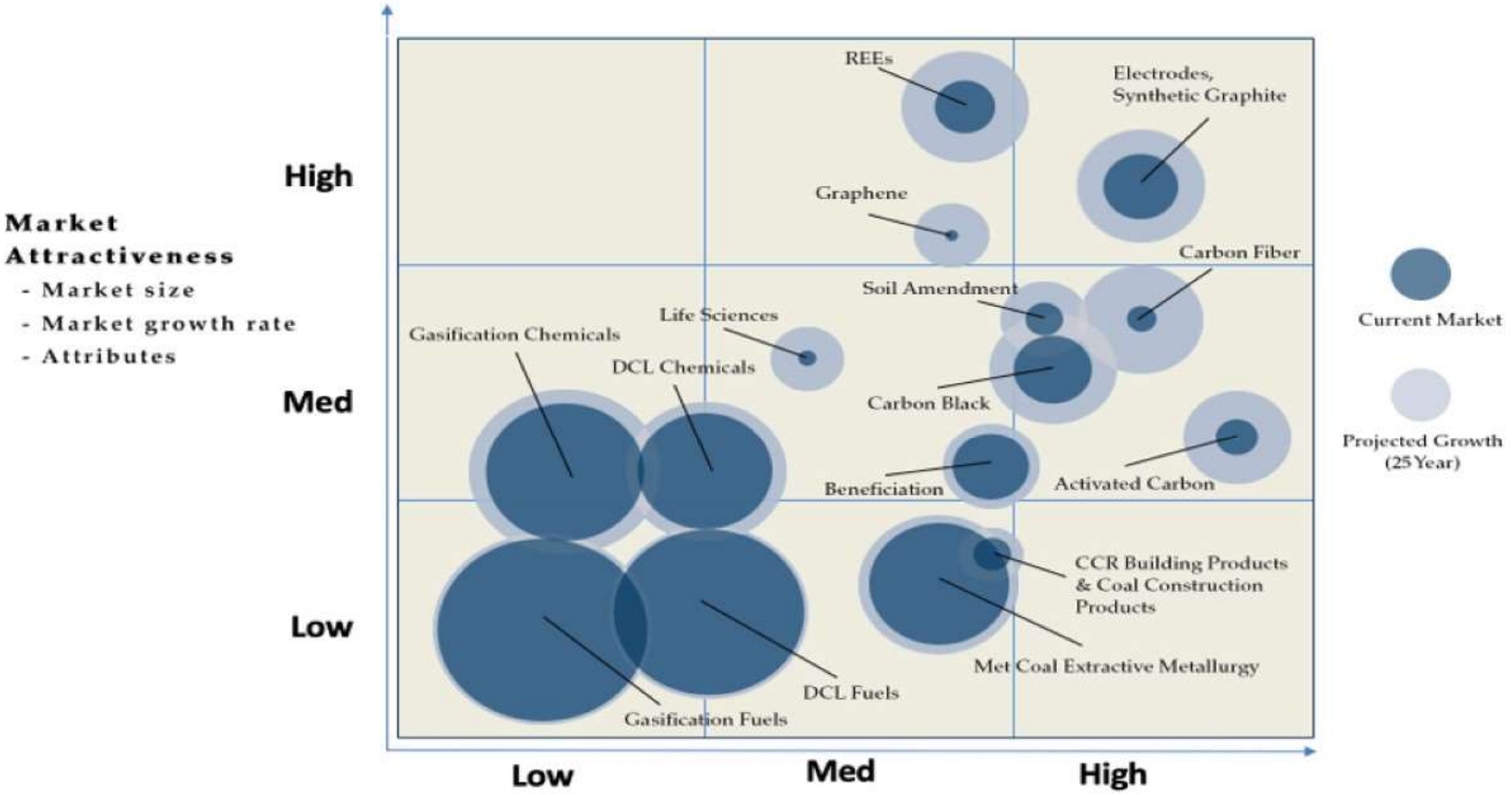
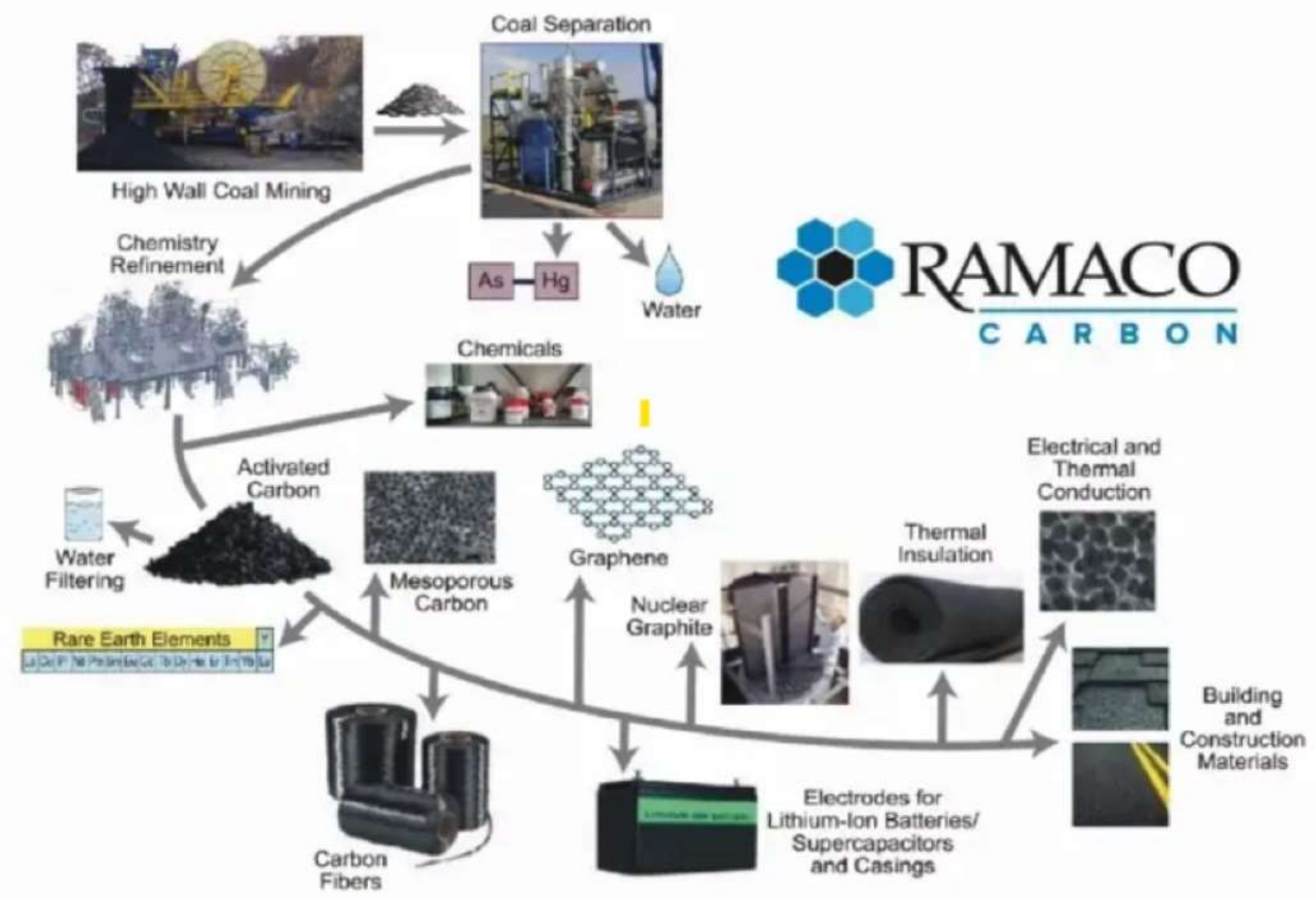


# COAL TO PRODUCTS

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# KEY FINDINGS

- Rapidly growing global demand for REEs, which are critical for secure and effective operation of a wide range of technologies in various sectors.
- Conventional approach is to extract REE is by opencast mining of raw product followed by leaching and purification of REE products
- Based on current data, the theoretical availability of REEs that can be obtained in this way is inadequate to meet even near term global projected demand.
- Extraction of REEs from coal and its by-products offers a potentially attractive way forward
- Rates at 98% by processing coal waste have been achieved. Scale up to pilot plants now underway
- This is part of a potential new era for coal, for those brave enough to go for it!

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# THANK YOU FOR LISTENING



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