On the Global Rare Earth Elements Utilization and Its Supply-Demand in the Future

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Abstract: Rare Earth Elements (REE) refers to 17 minerals with similar characteristics. Rare earth is in the limelight as a key material for future industries because of their unique chemical, electrical, magnetic, and luminescent properties and excellent radiological shielding effects. The scarcity of REEs cannot be imagined in the successful execution of the fourth industrial revolution and the sustainable economic development, which is now in front of humanity. Therefore, it is very urgent for each country and each enterprise to understand the global rare earth production situation and take measures against the future prospects. Therefore, the paper first addresses the definition and importance of rare earths and attempts to analyze their reserves, countries and global production in detail. Next, based on the analysis of development trends in the electric vehicle industry, renewable energy and the modern electronic industries where the use of rare earths is essential, this paper suggests a rare earth supply and demand strategy that can be referred to in the rare earth resources scarce developed countries including Europe.

1. Introduction
What is rare earth and why they are important is known in the previous literatures, but here I will first highlight it again.
Rare earth elements are generic names of 17 chemical elements in the periodic table, and include 15 elements of scandium, yttrium, and lanthanum from lanthanum to ruthenium. The reason why they are collectively called rare earths is because they have similar chemical properties to each other and exist together as a group in a mineral. Rare earth is divided into light rare earth and heavy rare earth according to the atomic weight of each element. Elements with a smaller atomic weight than gadolinium are classified as light rare earth elements (lREE) and elements with a larger atomic weight as heavy rare earth elements (hREE). Although rarely named, it is relatively abundantly distributed in the earth's crust except promethium, an unstable element. These substances are similar in chemical properties, making them difficult to separate by ordinary chemical analytical operations. They are mixed with each other and produced in very small amounts.
Rare earth elements, like the term, are not rare, but are common in the earth's crust. Everyone knows mercury, bismuth, indium, cadmium, selenium, which are lower in content than the lowest content of the rare earth element, thulium, but it appears to be concentrated or recovered along with other minerals.
REEs are divided into light rare earths (La ~ Sm) and heavy rare earths (Sc, Y, Eu ~ Lu) according to the atomic arrangement.
About 200 rare earth minerals have been discovered so far, among which industrially useful minerals are Bastnaesite ((Ce, La) (CO₃) F) and Monazite ((Ce, La, Nd, Th) PO₄), Xenotime (YPO₄), Fergusonite ((REE) (Nb, Ti) O₄).

The REEs and the main minerals are shown in Table 1, Table 2.

### Table 1. REEs

| Element   | Symbol | Atomic Number | Atomic Weight | Density (g/cm³) | Melting Point (°C) | Vicker's Hardness (10Kg load, kg/mm²) |
|-----------|--------|---------------|---------------|-----------------|--------------------|--------------------------------------|
| Scandium  | Sc     | 21            | 44.95         | 2.989           | 1541               | 85                                   |
| Yttrium   | Y      | 39            | 88.90         | 4.469           | 1522               | 38                                   |
| Lanthanum | La     | 57            | 138.90        | 6.146           | 918                | 37                                   |
| Cerium    | Ce     | 58            | 140.11        | 8.160           | 798                | 24                                   |
| Praseodymium | Pr | 59            | 140.90        | 6.773           | 931                | 37                                   |
| Neodymium | Nd     | 60            | 144.24        | 7.008           | 1021               | 35                                   |
| Promethium | Pm    | 61            | 145.00        | 7.264           | 1042               | 57                                   |
| Samarium  | Sm     | 62            | 150.36        | 7.520           | 1074               | 45                                   |
| Europium  | Eu     | 63            | 151.96        | 5.224           | 822                | 17                                   |
| Gadolinium | Gd   | 64            | 157.25        | 7.901           | 1313               | 57                                   |
| Terbium   | Tr     | 65            | 158.92        | 8.230           | 1356               | 46                                   |
| Dysprosium | Dy | 66            | 162.50        | 8.551           | 1412               | 42                                   |
| Holmium   | Ho     | 67            | 164.93        | 8.795           | 1474               | 42                                   |
| Erbium    | Er     | 68            | 167.26        | 9.066           | 1529               | 44                                   |
| Thulium   | Tm     | 69            | 168.93        | 9.321           | 1545               | 48                                   |
| Ytterbium | Yb     | 70            | 173.04        | 6.966           | 819                | 21                                   |
| Lutetium  | Lu     | 71            | 174.97        | 9.841           | 1663               | 77                                   |

(Source: [7])

### Table 2. The main REEs minerals

| Mineral          | Chemical Composition | REO Contents, wt% |
|------------------|----------------------|-------------------|
| Bastnaesite      | ((Ce,La)(CO₃)F)     | 74.77             |
| Monazite         | ((Ce,La,Nd,Th)PO₄)  | 65.13             |
| Xenotime         | (Y,Ce,Er)PO₄        | 61.40             |
| Fergusonite      | YNbO₄               | 39.94             |
| Gaggarinite      | NaCaYF₆             | 56.75             |
| Gadolininite     | YFeBeSi₂O₁₀         | 51.51             |
| Euxenite         | (Y,Ce,Ca,U,Th)(Nb,Ta,Ti)₂O₆ | 20.82 |
| Yttrian Fluorite | (CaY)F₂             | 17.50             |
| Parisite         | Ca(REE)₂(CO₃)₂F₂     | 60.89             |
| Xingganite       | (YCe)BeSiO₄(OH)     | 54.57             |
| Allanite         | (REE,Ca,Y)₂(Al,Fe⁺³)₃(SiO₄)₄(OH) | <25 |
| Apatite          | Ca₄(PO₄)₃(F,Cl,OH)  | 12                |
| Britholite       | (REE,Ca)₃(Si,PO₄)(OH,F) | ~60 |
| Ancylite         | Sr(REE)(CO₃)₂(OH)H₂O | 47.98             |
| Florencite       | (REE)Al₃(PO₄)₂(OH,F) | 31.99             |
| Halloysite       | Al₃Si₂O₅(OH)₄       | <0.5              |

(Source: Rare Earth and Application)
The use of rare earth can be categorized into metal industry, catalyst, glass and lens industry, new ceramic, permanent magnet, fluorescent material, laser industry, superconductor, and other industries. Specifically, it is widely used in the following fields such as mobile phones and personal computers, ceramic products, condensers, filters, sensors, permanent magnets of rare earth, hydrogen storage alloy batteries, automotive exhaust catalysts, glass abrasives, automotive glass, and the high-tech industries such as UV absorbers and CRT glass coloring materials. In addition, rare earths are widely used in almost all fields of human life, such as absorption and emission of laser materials and electromagnetic waves, superconductor manufacturing, optical disc manufacturing, nuclear reactors, artificial jewelry, fertilizer, and medical fields. Table 3 shows the main industrial applications of REEs.

| REE       | Symbol | Application                                                                 |
|-----------|--------|-----------------------------------------------------------------------------|
| Scandium  | Sc     | Aerospace lightweight high-strength Al-Sc alloys, electron beam tubes        |
| Yttrium   | Y      | Capacitors, phosphors, microwave filters, glasses, oxygen sensors, radars,   |
|           |        | lasers, superconductors                                                      |
| Lanthanum | La     | Ceramics, car catalysts, phosphors, hydrogen storage, special optical glass, |
|           |        | accumulators                                                                 |
| Cerium    | Ce     | Polishing powders, ceramics, phosphors, glasses, catalysts, pigments, misch  |
|           |        | metal, UV filters, abrasives                                                 |
| Praseodymium | Pr   | Ceramics, glasses, pigments, high strength magnesium alloy, lasers           |
| Neodymium | Nd     | Permanent magnets, catalysts, IR filters, pigments for glass, lasers         |
| Promethium | Pm    | Sources for measuring devices, miniature nuclear batteries, phosphors       |
| Samarium  | Sm     | Permanent magnets, microwave filters, nuclear industry                       |
| Europium  | Eu     | Phosphors (red and blue), lasers, fluorescent glass                         |
| Terbium   | Tb     | Green phosphor, permanent magnets, laser                                    |
| Dysprosium | Dy    | Phosphors, ceramics, nuclear industry, permanent magnets                    |
| Holmium   | Ho     | Ceramics, lasers, reactor control rods, pigments                            |
| Erbium    | Er     | Ceramics, dyes for glass, optical fibers, lasers, nuclear industry          |
| Ytterbium | Yb     | Metallurgy, chemical industry, lasers                                       |
| Lutecium  | Lu     | Single crystal scintillators, petrochemical catalysts, high refractive lenses, |
|           |        | positron tomography                                                         |
| Thulium   | Tm     | Electron beam tubes, visualization of images in medicine                    |
| Gadolinium| Gd     | Visualization of images in medicine, optical and magnetic detection, ceramics, |
|           |        | glasses, crystal scintillators                                               |

2. The global rare earth reserves and production

2.1 The global rare earth reserves

According to the US Geological Survey (USGS) Mineral Product Summary 2020 data, as of the end of 2019, world rare earth resource reserves are 120 million tons. Among them, China’s reserves are 44 million tons, the world’s largest rare earth resource country, and Brazil and Vietnam ranked second with 22 million tons. Russia (12 million tons), India (6.9 million tons), Australia (3.3 million tons), Greenland (1.5 million tons), USA (1.4 million tons), Canada (83 million tons), South Africa (790,000 tons), Tanzania (890,000 tonnes) ranking[2].

Looking at the situation in Brazil, as of 2018, it was not a major rare earth producer, and its production was only 1,000 MT. However, with a reserve of 22 million MT, Brazil ranks second in Vietnam and the world.

Vietnam, like Brazil, has a rare earth reserve of 22 million MT. Data show that Vietnam has several rare earth deposits along the coastline of the northwestern border.
Russia's rare earth production in 2018 was 2600 MT, higher than Brazil and Vietnam, but its reserves are small, at 12 million MT. According to the US Geological Survey, the Russian government recently revised its rare earth reserves smaller than before, making it less than 1800 MT.

India's rare earth reserves are 690 MT and production in 2018 was 1,800 MT. However, according to the Economic Times' October 2016 report, the country's rare earth industry has strong potential. According to this report, about 35% of India's beach and sand mineral reserves are a major source of rare earths.

Australia's rare earth production in 2018 was 20,000 MT, which was the world's second-largest rare earth production country, but was 6th in the world with 3.4 million tons in reserves.

In the United States, it was reported that rare earth production was 15,000 MT in 2018, which was higher than the previous year. The country's rare earth reserves are fairly rich with 1.4 million MT.

![Global REEs Reserves](image)

**Fig 1. Global REEs Reserves in 2019**

### 2.2 The global rare earth production

Rare earth elements are not much smaller than other elements in the earth's crust, but only a few regions are concentrated and economically available for mining. Rare earths were first produced commercially in the 1880s with the mining in Sweden and Norway of the rare-earth thorium phosphate mineral monazite. At that time, rare earth production was so small that it was only used locally in the country, and the use of rare earth was negligible on a global scale. As the economy developed rapidly in Western countries after World War II, demand for rare earths began to increase in many industrial areas. In addition, the development of ion exchange separation technology, the solvent exchange separation technology and the discovery of Mountain Pass deposits in the United States promoted rare earth production [3].

The United States mined Bastnaesite ore from the Pass mountain mine from the 1960s to 2001, but has not produced any rare earth since 2002 due to environmental pollution and deterioration of profitability around the mining area. Since China first began mining in Bayan mines in 1984, China has steadily increased its production, producing 97% of the rare earth metals produced worldwide. The ore produced in China is more than half of the total production in the form of Bastnaesite-Monazite with 6-10% purity, and 10% in the form of Bastnaesite and about 40% ore in the form of ion adsorption with 0.1-0.3% purity. In the 2000s, mass production of low-purity ion-adsorbed ores has been carried out in six regions, including the remining of Pass Mountain, where the rare earths have been suspended. Related projects are also underway in Australia, Greenland, Canada, Mongolia.
and South Africa. Fig.2 and Fig.3 shows the global rare earth production from 1951 to 2019 and the production status by countries from 2013 to 2019[2].

3. The development status of the main REE application industries

3.1 Electric vehicles

Eco-friendly vehicles include nickel-hydrogen batteries (lanthanum (La), cerium (Ce)), motor magnets (neodymium (Nd), dysprosium (Dy), praseodymium (Pr), etc.), sensors (yttrium (Y)), LCDs, Rare earth-related components such as LED screens (Europium (Eu), yttrium (Y), cerium (Ce), etc.) are essentially used. Therefore, the development situation of the eco-friendly vehicle industry reflects the use of rare earths. According to the report of the International Energy Agency, as of 2017, the development situations of the global eco-friendly vehicle industry is as follows[4].

Electric vehicles set new sales records in 2016 with more than 750 million units sold worldwide. Norway's global market share is 29%, most successful in EV production. Next, the Netherlands' market share is 6.4% and Sweden's 3.4%. The market share in China, France and the UK is close to
1.5%. In 2016, China's electric vehicle sales amounted to 40% of the world, more than double the United States.

![Fig.4. Evolution of the global electric car stock, 2010-2016](image)

### 3.2 Renewable energy

The renewable energy industry is the one where the use of rare earth is essential, and its prospects for development have a decisive effect on the rare earth industry.

According to the New Policies Scenario (NPS), electricity generation from renewable energy is projected to reach nearly three times in 2040, accounting for more than 40% of total power generation. The use of renewable energy directly in transportation and thermal applications also increases, but the proportions are still limited.

Looking at the global heat supply forecast, it is expected that by 2040, the share of renewable energy will increase by 5% to 15%. About 60% of this increase is expected to happen in China, the European Union, India and the United States today, the largest consumers of renewable heat.

The demand for biofuels is expected to increase to 4.7 mboe/d, which will account for 6% of the transportation sector's renewable energy use by 2040, with the remainder being EV powered by renewable energy.

The contribution of renewable energy to heat supply in SDS reaches 1100 Mtoe by 2040 at a much faster rate. Demand for biofuels grows to over 7 mboe/d in 2040[5].

The growth trend of the electric vehicle and renewable energy industry is based on the stable supply of the essential material-rare earth, and thus, the rare earth industry is expected to grow further in the future.
4. Supply and demand strategy of REEs

In Europe, as of 2010, no rare earths are produced. However, the importance of rare earth metals in the field of wind power generators and electric vehicles is emerging. In addition, as some country's restriction on the export of rare earth metals comes to reality, it is necessary to prepare stable supply and demand measures for rare earth metals. In reality, the government should support policy development and recycling to reduce the use of rare earth metals. The reasons why rare earth resources scarce countries such as Europe have to develop recycling technology and rare earth use reduction technology are as follows.

- Europe is the world's No. 1 rare earth metal importer. In addition, it is a region where a lot of waste including rare earth occurs. Recovery of rare earths from discarded products can be viewed as a kind of "urban mine" development.
- Recycling and mitigation technologies are essential to minimize the impact of the rare earth metals supply market when some countries have almost monopolized rare earth production.
- In the rare earth metals related technology, the technical level of European countries is very low.
- Rare earth metals obtained through recycling have no problem with radioactive materials.

As mentioned in REE Properties, the biggest problem in the production of rare earth metals from primary materials is the treatment of radioactive materials including uranium and thorium. In order to promote the rare earth metal recycling in Europe, it is suggested to have the following system.

- It organizes network groups that include policy makers, recyclers, producers and scientists.
- Identify the route of waste containing rare earth metals.
- Develop pilot-scale recycling facilities.
- Rare earth metal recycling facilities are potentially financially risky because changes in market prices for rare earth metals are currently very difficult to predict. Therefore, there is a need to reduce financial risk through the support of the European Investment Bank (EIB).
- There is a need for legislation and guidelines for recycling.

Cooperation with China, the world's largest producer of rare earth metals, should be sustained and much attention should be paid to the effective and environmentally friendly development of Greenland Kvanefjeld, where rare earth veins have been found. Just as oil buried in Norway is responsible for oil security in Europe, the Kvanefjeld region is the only alternative to guaranteeing the security of rare earth resources in Europe.
5. Conclusion
The stable supply and demand of rare earth metals used in the high-tech sector is approached with interest in most developed countries. China, which produces 97% of the world's rare earths, announced that it would control rare earth production, and China's almost 100% of the world's monopolized world is dominated by rare earth mining and smelting. Only Japan has a market share of about 20% in the production of magnetic materials using rare earths. The importance of rare earth metals is particularly emphasized in the field of electric vehicles and wind power generation, and the demand for rare earth metals in these industries is expected to increase rapidly. Therefore, in this paper, we discussed the supply and demand strategies of rare earth resources that can be referenced by the rare earth resources scarce countries including Europe in response to the changes in the rare earth industry.

References
[1] Georgios Charalampides et al, Rare Earth Elements: Industrial Applications and Economic Dependency of Europe, Procedia Economics and Finance 24 (2015) 126 – 135
[2] USGS, Mineral Commodity Summaries, 1951-2020
[3] J. C. OLSON, D. R. SHAWE et al. Rare-Earth Mineral Deposits of the Mountain Pass District San Bernardino County California, UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1954
[4] Global EV Outlook 2017, INTERNATIONAL ENERGY AGENCY
[5] World Energy Outlook 2018 (Renewables), https://geocluster.pw/reports/world-energy-outlook-2018/renewables? cpo=aHR0cHM6Ly93d3cuaWVhLm9yZw#abstract
[6] CHEN Zhanheng, Global rare earth resources and scenarios of future rare earth industry, JOURNAL OF RARE EARTHS, Vol. 29, No. 1, Jan. 2011
[7] Rare Earth Elements, British Geological Survey, November 2011
[8] TACKLING THE CHALLENGES IN COMMODITY MARKETS AND ON RAW MATERIALS, Brussels, 2.2.2011
[9] Hobart M. King, Ph.D., RPG, REE - Rare Earth Elements and their Uses, https://mathcore.site/articles/rare-earth-lements/? cpo=aHR0cHM6Ly9nZW9sb2d5Lm9yZw#abstract
[10] Jianliang Wang et al. Long-term outlook for global rare earth production, Resources Policy 65 (2020) 101569
[11] BAOLU ZHOU et al. Rare Earth Elements supply vs. clean energy technologies : new problems to be solve, Mineral Resources Management 32(4)(2016), 29–44
[12] CRITICAL MATERIALS STRATEGY, U.S. DEPARTMENT OF ENERGY, DECEMBER 2011
[13] OSAMU TAKEDA and TORU H. OKABE , Current Status on Resource and Recycling Technology for Rare Earths, METALLURGICAL AND MATERIALS TRANSACTIONS E, VOLUME 1A, JUNE 2014—171