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Japan's Policies to be adopted on Rare Metal Resources

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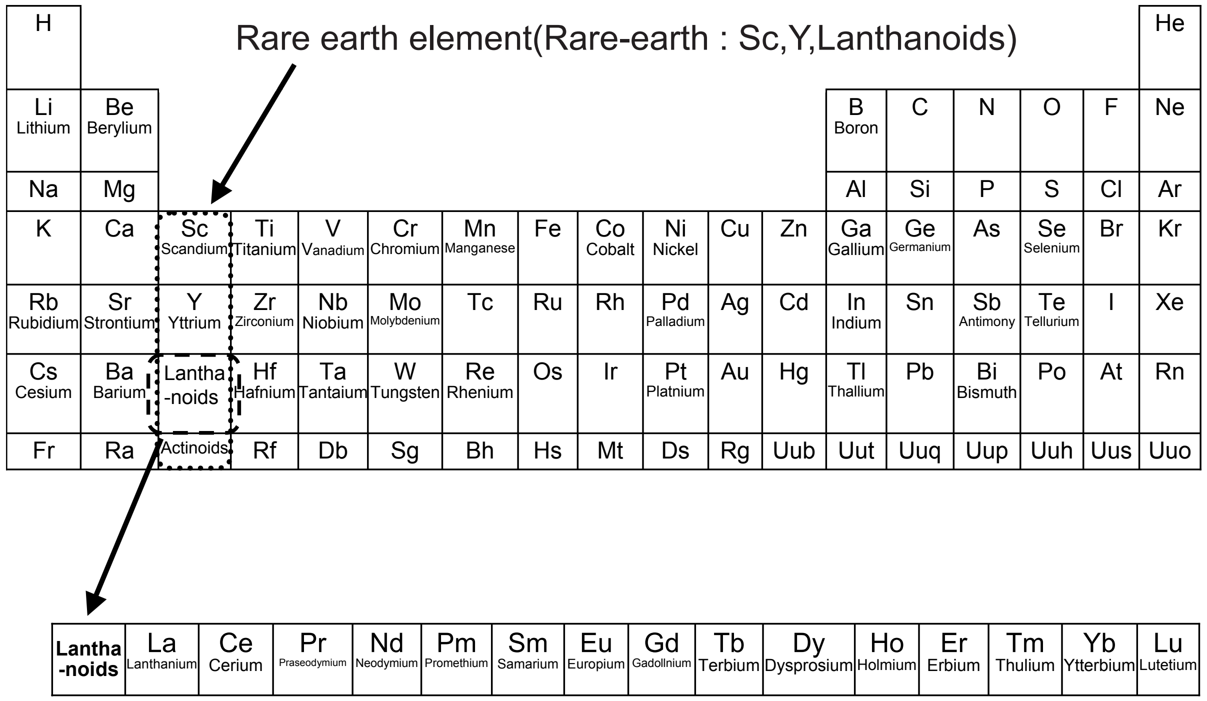
1 Introduction

The term rare metal is often used to indicate non-ferrous metals that are found only in rare amount and used in various industrial applications even in small quantities. The term rare amount, rather than indicating deposits that are scarce, more strongly implies that the production volume or supply volume is very small, and therefore, it is difficult to economically or technologically acquire these materials in the quantities that are required. Although not strictly defined, generally rare metals mean 31 types of metal elements as shown in Figure 1.[1]

Rare metals are utilized in a broad range of manufacturing areas that include materials machineries and electronics production. These are the raw materials for high value added products that sustain sectors of Japan's manufacturing industries. In recent years, the demand for rare metals has exploded. Due to the significant growth in demand in the emerging countries and scarce amount of existence in comparison to other metals, as well as Japan's characteristic high dependency on specific producing countries in unevenly distributed production areas, there is a growing anxiety for securing a mid-to-long-term stable supply.[2, 3] The balance of rare metal supply and demand is linked to various problems of product



Rare earth element(Rare-earth : Sc,Y,Lanthanoids)

H																	He
Li Lithium	Be Berylium											B Boron	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc Scandium	Ti Titanium	V Vanadium	Cr Chromium	Mn Manganese	Fe	Co Cobalt	Ni Nickel	Cu	Zn	Ga Gallium	Ge Germanium	As	Se Selenium	Br	Kr
Rb Rubidium	Sr Strontium	Y Yttrium	Zr Zirconium	Nb Niobium	Mo Molybdenium	Tc	Ru	Rh	Pd Palladium	Ag	Cd	In Indium	Sn	Sb Antimony	Te Tellurium	I	Xe
Cs Cesium	Ba Barium	Lantha -noids	Hf Hafnium	Ta Tantaium	W Tungsten	Re Rhenium	Os	Ir	Pt Platnium	Au	Hg	Tl Thallium	Pb	Bi Bismuth	Po	At	Rn
Fr	Ra	Actinoids	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo

Lantha -noids	La Lanthanium	Ce Cerium	Pr Praseodymium	Nd Neodymium	Pm Promethium	Sm Samarium	Eu Europium	Gd Gadollnium	Tb Terbium	Dy Dysprosium	Ho Holmium	Er Erbium	Tm Thulium	Yb Ytterbium	Lu Lutetium

Notes: The non-ferrous metal elements (30 types), Scandium, Yttrium and the Lanthanoids (15 types) that are indicated in bold type (with their chemical names written underneath) are all rare metals.

Figure 1 : List of rare metals in the periodic table

Modified by the STFC based on Reference[1] recycling and substitute material development that are unlikely to be solved quickly. While these are not problems that can only be solved by people involved in research and development of material resources, other research fields such as material science are also starting to feel the impact.

On the other hand, on the subject of securing rare metals, it has been pointed out for a long time that there is a possibility of various mineral resources to be found in the sea areas within Japan's interests such as Japan’s Exclusive Economic Zone (EEZ) and at the small-scale mines that have been developed hitherto. However, during times when demand was low, mines were forced to close as they became economically unviable or new developments were overlooked. With recent increase in demand, the necessity to reexamine such matters has become increasingly apparent.

The development of seabed resources, from here on in particular, is also considered to be an important issue from the viewpoint of ensuring a stable supply of rare metal resources. The ‘Basic Ocean Law’ enforced on July 20, 2007, cites the development of socioeconomic health in Japan by comprehensive and systematic promotion of ocean-based strategies as the objective, and the positive utilization of oceans for satisfying marine related scientific knowledge and the development of ocean resources, etc., are also included.[4]

This article hopes to point out the future considerations that Japan in particular should take from both a short-term and long-term perspective by reviewing the present situation of rare metals with respect to the current background.

2 Rare metals and Japan’s industrial technology

As Japan’s external trade balance depends largely on manufacturing fields such as materials production, machineries and electronics manufacturing industries, Japan has become a world leading consumer of non-ferrous metals. Base metals such as copper, lead, and zinc, etc., in addition to rare metals such as tungsten and cobalt, etc., are mineral resources that are indispensable to Japan’s socioeconomic and industrial activities. Any obstruction to the supply of these rare metals would have a great impact on a part of Japan’s staple industries.

Indium, which is used in LCD televisions, mobile phones, and transparent electrodes of solar batteries, etc., is one such rare metal for which the supply and demand has become an issue. The applications and supply and demand status of indium are indicated in Figure 2.[5-7] Since France, a former principal source of indium ingots, ceased production, China has virtually become the only supplier of new ingots. In addition, due to the increasing demand for plasma screen televisions, the price of indium is expected to continue to go up. On the other hand, as will be discussed later, indium is an associated ore of lead and zinc (a byproduct of lead and zinc ores). Therefore, due to China’s heavy demand for lead and zinc, the amount of lead and zinc mined globally will increase in response to China’s growing demand. This situation will lead to increased production of

[Glossary]

Rare metals: metals that exist in limited amounts in the earth’s crust, or 31 types elements of non-ferrous metals (30 ore varieties and 1 rare earth ore type) that are economically or technologically difficult to extract in pure form despite being found in ample quantities and utilized in industry. However, these do not include non-ferrous base metals used in large amounts and high-value precious metals.

Rare earth: These are elements referred to as rare earth elements of which there are two group-III elements in the periodic table (scandium, yttrium) and 15 types of lanthanoids (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium). There are 17 rare earth elements that are summarized as one ore type.

Base metals: Non-ferrous metals such as copper, zinc, and aluminum, etc., that are used in large quantities following iron.

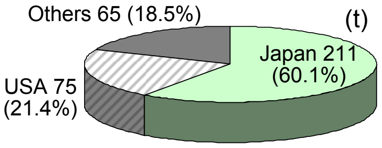
Key applications	○Transparent electrodes (LCD TV's, plasma TV's, solar batteries) ・Metals required in LCD displays (indium oxide is an efficient, high-transparency electrical conductor) ・Used extensively in large LCD TV's for which Japan is technologically renowned ・90% of total consumption is used in transparent electrodes for large LCD TV's ○Bonding (sputtering target bonding adhesives) ○Low melting point alloys(solder containing indium)

World indium ingots production volumes (t)

Country / Year	2001	2002	2003	2004	2005
China	100	85	100	200	250
Japan	55	55	70	70	70
Canada	45	45	50	50	50
Belgium	40	40	40	30	30
Russia	15	15	15	15	15
France	65	65	65	10	10
Other	29	30	30	29	30
Total	349	335	370	404	455

Source: Mineral Commodities Summaries

World consumption amount (2002)



Sourced: "Rosskil Indium 2003"

Japan's demand and raw material supply (t)

Year		2001	2002	2003	2004	2005
	Transparent electrodes	260	300	360	470	—
	Bonding agents	19	21	25	35	—
	Low melting point alloys	6	6	6	8	—
	Battery, contact materials	5	5	5	5	—
	Fluorescent materials	8	8	8	8	—
	Compound semiconductor	17	4	7	7	—
	Other	8	11	8	8	—
	Total	323	355	419	541	634 (Estimated)
Raw material supply	Production	70	70	70	70	70
	Imported amount	171	141	264	421	422
	Recycled scrap	127	158	159	249	329
	Total	368	369	494	721	821
Features	• China accounts for approx. 70% of total imports • Approx. 30 – 40% of total supply obtained from recycled scrap, etc. • Due to the closure of the Toyoha mine (March, 2006), domestic production is predicted to decrease to 1/3					

Source: Industrial Rare Metals

Figure 2 : Applications and supply and demand status of indium

Modified by the STFC based on References[5-7]

indium as byproduct that will have a calming effect on the price. Due to this complex arrangement, the future price trend is uncertain, and the impending balance of supply and demand is something that must be looked at more carefully.

Among rare metals, rare earth elements tend to be used in specific applications only. The applications and current supply and demand situation of rare earth are shown in Figure 3.[5-7] Rare earth magnets (in particular neodymium-iron-boron (Nd-Fe-B) magnets) are, for example, used in hard disks and hybrid car motors and due to the growth in demand for rare earth magnets, the importance of not only the main component neodymium but also dysprosium and terbium, elements that are added to increase the coercive force and magnetic flux density in the high-temperature region, has also increased. Dysprosium is a particular element that has become essential for enhancing these characteristics. Presently, no ground-breaking substitute magnets that can rival its high performance is found even in research stage.

Rare earth raw materials are 100% imported, and imports from China account for approximately 90%. Conversely, Japanese industries and component manufacturers that utilize rare earth products, such as manufacturers of household electric appliances, electrical tools, mobile phone devices, and automobiles, are increasingly transferring production to China. While its high economic growth continues, the market in China for products that utilize rare earth elements is considered to expand accordingly. In contrast, Japanese industries linked to products utilizing rare earth elements that are not moving into China will need to obtain a stable supply of raw materials from China while developing products that are different from those currently swelling the markets inside China.

3 Rare metal resource consumption, present and future

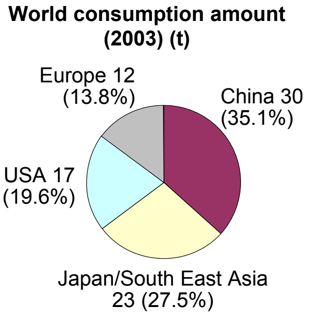
3-1 Uneven distribution of rare metal resources

The rare metal resource producing territories

Key applications	○Rare earth magnets (neodymium, samarium, praseodymium, dysprosium, terbium) ・Used in hybrid cars ・Used in technical fields in which Japan is technologically advanced ○Abrasives (cerium) ○Optical glass (lanthanum) ○Nickel hydrogen batteries (mischmetal, lanthanum) ○Fluorescent materials (yttrium, europium, terbium, gadolinium) ・Color TV Braun tubes

Japan's demand and raw material supply (t)

Year		2000	2001	2002	2003	2004
Demand	Abrasives (CeO_2)	3,738	2,544	3,721	4,061	4,228
	FCC catalysts (crude rare earth metal chlorides)	702	776	814	682	710
	Braun tubes (CeO_2)	1,500	1,098	1,020	907	944
	UV glass (CeO_2)	1,332	1,283	1,346	1,350	1,406
	Optical glass (La_2O_3)	526	409	384	437	455
	Exhaust gas catalysts (CeO_2 + La_2O_3)	670	646	677	680	708
	Desulfurization catalysts (CeO_2)	533	533	555	603	628
	Condensers (Nd_2O_3 + Sm_2O_3)	1,139	633	762	942	981
	Fluorescent materials (Y, Eu, Gd, Tb)	-	-	850	1,200	1,249
	Sintered rare earth permanent magnets (Nd_2O_3 + Sm_2O_3)	3,753	3,065	3,365	4,058	4,225
	Bonded magnets (Nd_2O_3 + Sm_2O_3)	165	139	118	127	132
	Mischmetal (MM + La)	2,360	1,490	3,920	3,560	3,707
Raw material supply (metal amount)		27,671	19,737	22,570	25,704	26,762



Sourced: "Rosskil Rare Earth 2004"

Figure 3 : Key rare earth applications and supply and demand status

Modified by the STFC based on References[5-7]

of the world appear to be unevenly distributed throughout the earth. However, the information concerning the supply of rare metals that are used in comparatively large amounts is noticeably clear (Figures 2, 3, and Table 1). Nickel, for example, in the past was extracted from deposits in Russia and Canada. As newly developed extraction methods have recently made it possible to extract and recover such rare metals from low-grade ores in tropical Indonesia, the Philippines, and New Caledonia, there is little concern regarding the future supply of these resources. South Africa produces approximately half of the world's chromium output and, since Japanese industries are also producing chromium in South Africa, there is relatively little concern in Japan regarding the supply of this element. Cobalt, which is recently supplied by countries such as the Congo, Zambia, and South Africa, is also available on the market, so for the time being, there are no supply concerns regarding this resource. On the other hand, due to acute geographical mal-distribution, there is a great concern regarding the supply of tungsten and dysprosium, for examples, in Japan. China produces and exports 90% of the world's tungsten. In addition, 93% of the rare earth elements including dysprosium are also produced by China.

Indium, for example, is an element for which reserves are not so small and there are many producing countries (Figures 2, 4) of which Japan was formerly a world leader. Rare metal elements like indium are vulnerable to supply factors such as the closing of a single mine, etc., and are consequently prone to large swings in their supply and demand status. Therefore, the recycling of scrap materials has become an important source for stabilizing supplies.

When viewed geographically, presently, China is the world's overwhelming producing nation of not only rare metals, but metal resources in general. China is regarded as the number one ore deposit for antimony, bismuth, cadmium, lead, magnesium, molybdenum, rare earth elements, tin, tungsten, vanadium, yttrium, zinc, and titanium. China is also the world's second largest source of silver and indium, and the third largest source of copper, gold, and lithium.

Table 1 : Rare metal key producing countries and the Japan's import origins

Mineral type (Reserves: Yes/No)	Producing country (2005)	Key import origins (2005)	China's trend	Comments	Japan's world share (Ranking)
Nickel (Reserves: Yes)	Russia 22% Canada 15% Australia 14%	Indonesia 44% Philippines 14% New Caledonia 13%	Imports increasing rapidly due to stainless steel production expansion	• LME listed metals • Mining development by Japanese industries	No. 2 No. 1: China No. 3: USA
Chromium (Reserves: Yes)	South Africa 43% India 19% Kazakhstan 19%	South Africa 49% Kazakhstan 26% India 9%	Import amount increasing annually	Examples of Japan's ferrochrome producers making inroads into South African market	-
Tungsten (Reserves: Yes)	China 90%	China 79%	Domestic demand is a priority	Sudden reduction of ore imports due to China's value-added policy	No. 4 No. 1: China No. 2: USA
Cobalt (Reserves: Yes)	Congo 31% Zambia 17% Australia 13%	(Post-fabrication products procured from Finland, Australia, Canada)	Demand for rechargeable batteries is growing rapidly, sharp rise in imports from Congo	• Byproduct of copper, nickel • Mining development by Japanese industries	No. 1 No. 2: Europe
Molybdenum (Reserves: Yes)	USA 34% Chile 27% China 17%	Chile 45% China 15%	China is one of the exporting countries	•Mainly byproduct of copper •Mining development by Japanese industries	No. 3 No. 1: Europe No. 2: USA
Manganese (Reserve: Yes)	South Africa 22% Australia 14% Gabon 13%	South Africa 47% Australia 23% China 19%	Imports increasing rapidly	• Cooperation with South African industries in securing ores • Examples of China's industries advancing silicon manganese production	No. 5 No. 1: China
Vanadium (Reserves: Yes)	South Africa 42% China 34% Russia 21%	South Africa 49% China 25%	90% production by domestic major companies	Examples of Japan's ferrovanadium producers making inroads into South African market	No. 4 No.1: Europe No. 2: USA
Indium (Reserves: No)	China 55% Japan 15% Canada 11%	China 70% (Extracted in China from foreign zinc ores)	(Details unclear)	Byproduct of zinc	No. 1 (60%) No. 2: USA
Rare earth metals (Reserves: No)	China 93%	China 90%	Produced in Inner Mongolia, China	-	No. 2 No. 1: China

Modified by the STFC based on References[2,7]

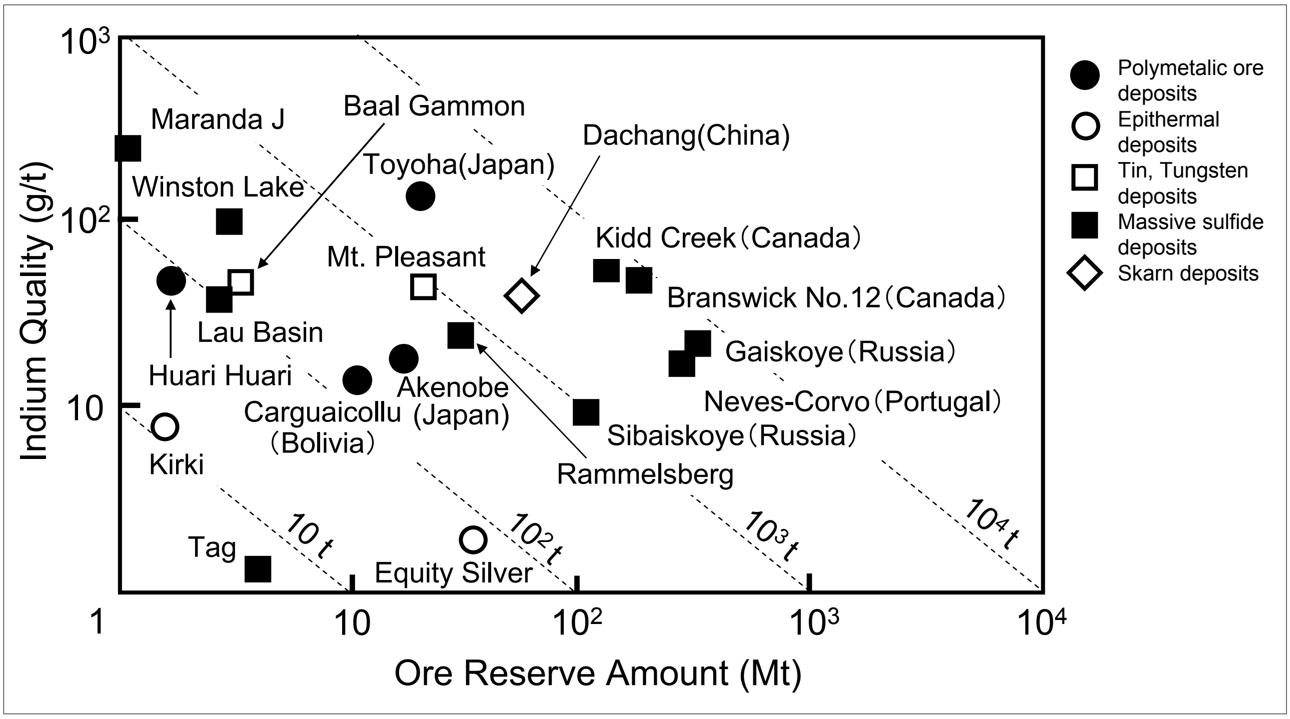


Figure 4 : Location and scale of the key indium deposits (2002)

Modified by the STFC based on References[2,8,9]

3-2 Rare metal consumption status and supply disruption issues

The only mineral resource that Japan is self-sufficient in is sulfur and is therefore reliant on imports for all other metal mineral resources. More recently, amid the sudden increases in consumption of the world's non-ferrous metals among the emerging nations, many supply problems have been highlighted. For consumer countries like Japan, circumstances are becoming increasingly

Table 2 : Price escalation of important metals and resources

Metal type (bullion)	Unit price	July 2003		July 2005		July 2007		Key applications
		Price	Percent (%)	Price	Percent (%)	Price	Percent (%)	
Copper	US$/t	1710	100	3614	210	7540	440	Electrical wires, electronic devices, machineries
Zinc	US$/t	827		1194	140	3384	410	Galvanized steel, alloys
Platinum	US$/oz	690		879	130	1280	190	Vehicle exhaust catalytic converters, electronic instruments
Nickel	US$/kg	8.8		14.6	170	52	590	Stainless steel, rechargeable batteries
Tungsten	US$/MTU	46		145	320	165	360	Carbide tools, high speed steels
Cobalt	US$/kg	23.5		30	130	70	230	Heat resistant alloys, rechargeable batteries
Molybdenum	US$/kg	11.5		66.6	580	65	570	Construction alloys, pipes
Indium	US$/kg	183		899	490	700	380	Transparent electrodes (LCD, solar batteries)
Neodymium	US$/kg	6.8		11.7	170	24	350	Rare earth magnets
Dysprosium	US$/kg	25		65	260	90	360	Rare earth magnets

Note: Created from Japan Oil, Gas and Metals National Corporation (JOGMEC) website.
MTU: Metric Ton Unit also referred to as Kilo Ton. The market quotation price of tungsten (W) ore is indicated by 1% (1kg) pure WO_3 in 1 ton of ore.

Modified by the STFC based on Reference[2]

difficult for ensuring a stable supply of resources.

Historically, during the past 50 years or so, while the international price of non-ferrous metals has fluctuated greatly, in relative terms the monetary value has come down. Over the course of this period, as mines in western countries have been closed due to falling prices and there has been a downturn in mine exploration activities, a sudden recovery in production seems highly unlikely. On the other hand, in recent years, the rate of consumption in the BRICs countries beginning with China has rapidly grown to the extent where an inversed supply and demand trend is evident. Even for base metals, Japan's ranking as a world consumer is falling, and its controlling influence is weakening. For example, by looking at the consumption of copper, which runs parallel to the scale of Japan's economy, for a long time Japan has been consistently second behind that of the USA. However, China has overtaken Japan, followed by the USA to become the current world's largest consumer country.

With this current background, monopolization of supply resources has started due to the buying up and merging of the major overseas non-ferrous metal resource refining companies and, in recent years, resource nationalism has become noticeable in some countries. China, for example, has been quick to adopt the resource protection policies particularly for rare earth elements by imposing export restrictions. The resource nationalism and the major non-ferrous corporations have started to control this supply and demand. These are the factors why consumer-only countries such as Japan have lost their controlling influence, and the impact that this will have on universally scarce rare metals is likely to escalate.

In terms of consumption – especially in rare metals – Japan accounts for more than half of the global consumption for some kinds of these elements. For example, Japan consumes 60% of the world's supply of indium. Besides Japan, and with the exception of the United States, the only several other key consumer countries of indium are entirely in Asia. Since indium is the main constituent in the transparent electrode material applications, utilized in display devices, etc., it follows that the key indium consumer countries are also the key producing countries of these types of electronic devices. Therefore, from a global viewpoint, the consuming regions are also geographically acutely mal-distributed. A similar situation also applies to dysprosium. Because dysprosium is used extensively as an additive in rare earth magnets found in information communication tools, mobile phones, computers, and drive motors in hybrid cars

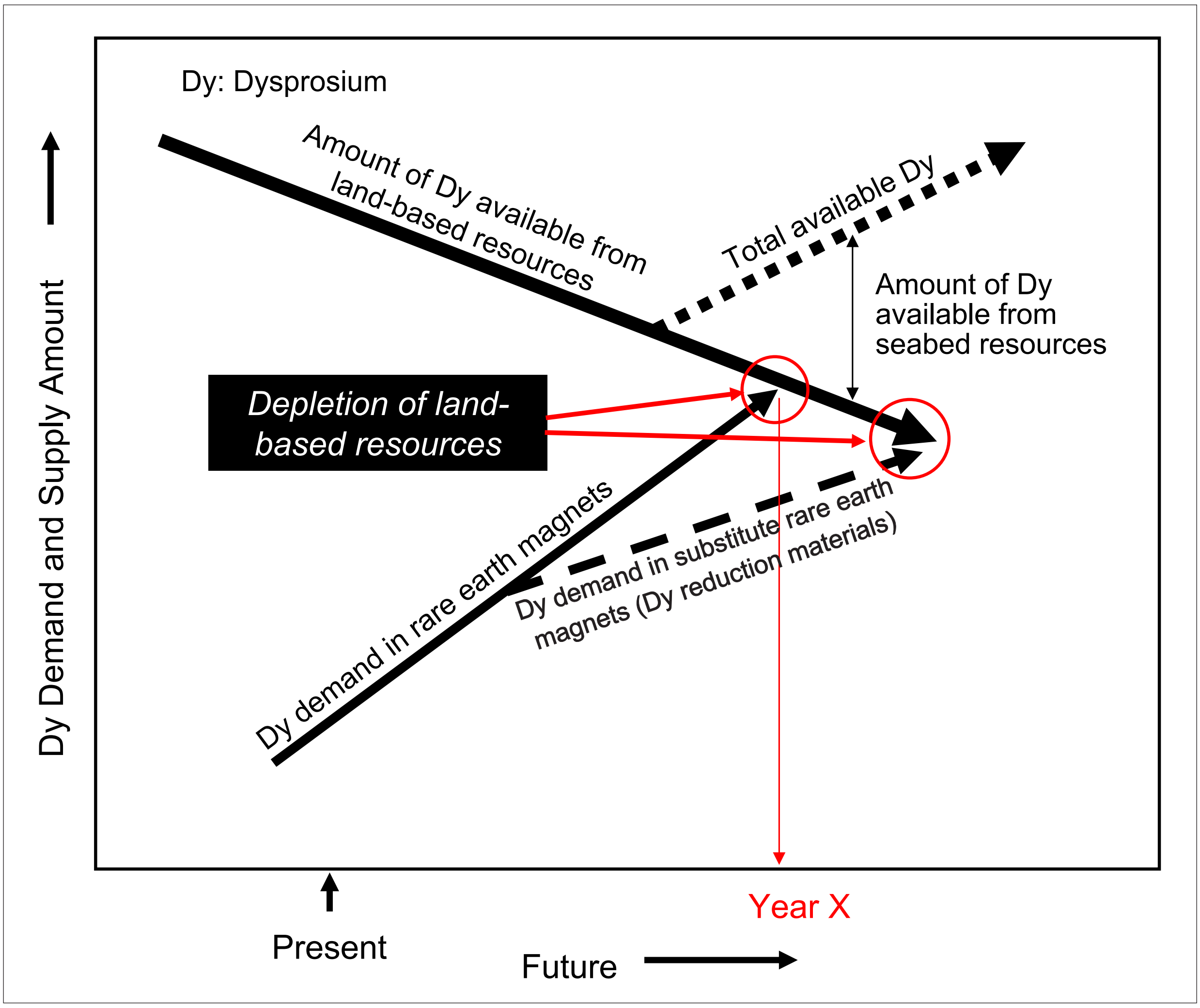


Figure 5 : Anticipated view of the supply and demand relationship of dysprosium in rare earth magnets

Prepared by the STFC

(vehicles that are powered by a combined gasoline engine and electric motor power source),[1] it stands to reason that the world's biggest consumer is Japan; whereas consumption in other countries is comparatively low. The soaring situation regarding the key metals and resources is indicated in Table 2.[2, 10] The prices of dysprosium and nickel have gone up by four to six times during the past four years. In the past there have been instances where the supply of rare metals was actually disrupted in Japan. In 1997, vanadium became difficult to obtain for a period lasting twelve months, and reserves from the national resource stockpile were released for the first time. Also, in 2000, due to a shortage of tantalum, domestic manufacturers of condensers issued a formal plea for shipments to be suspended.[3]

Figure 5 shows an anticipated view of the supply and demand relationship for dysprosium as a rare earth magnet. As the recoverable reserves of dysprosium are limited, the chart diagrammatically indicates the risk of resources depletion should the future demand for dysprosium suddenly increase. Presently, rare earth magnets are used in hard disks, industrial motors, and hybrid cars, etc., and the application for hybrid cars is expected to expand particularly rapidly from here onwards. The domestic demand for dysprosium in 2004 was approximately 260t.[11] On average 2kg of rare earth magnets are used per vehicle. Since the annual production of hybrid cars is expected to reach 1.2 million units by the year 2010,[12] the annual demand for dysprosium will be 240t assuming the amount of dysprosium in magnetic is 10%.[1] In specific terms, the amount of dysprosium that will be required for use in hybrid cars alone in the year 2010 will be close to the total amount utilized in 2004. By considering the use of rare earth magnets in factory products other than hybrid cars, the supply and demand of dysprosium will

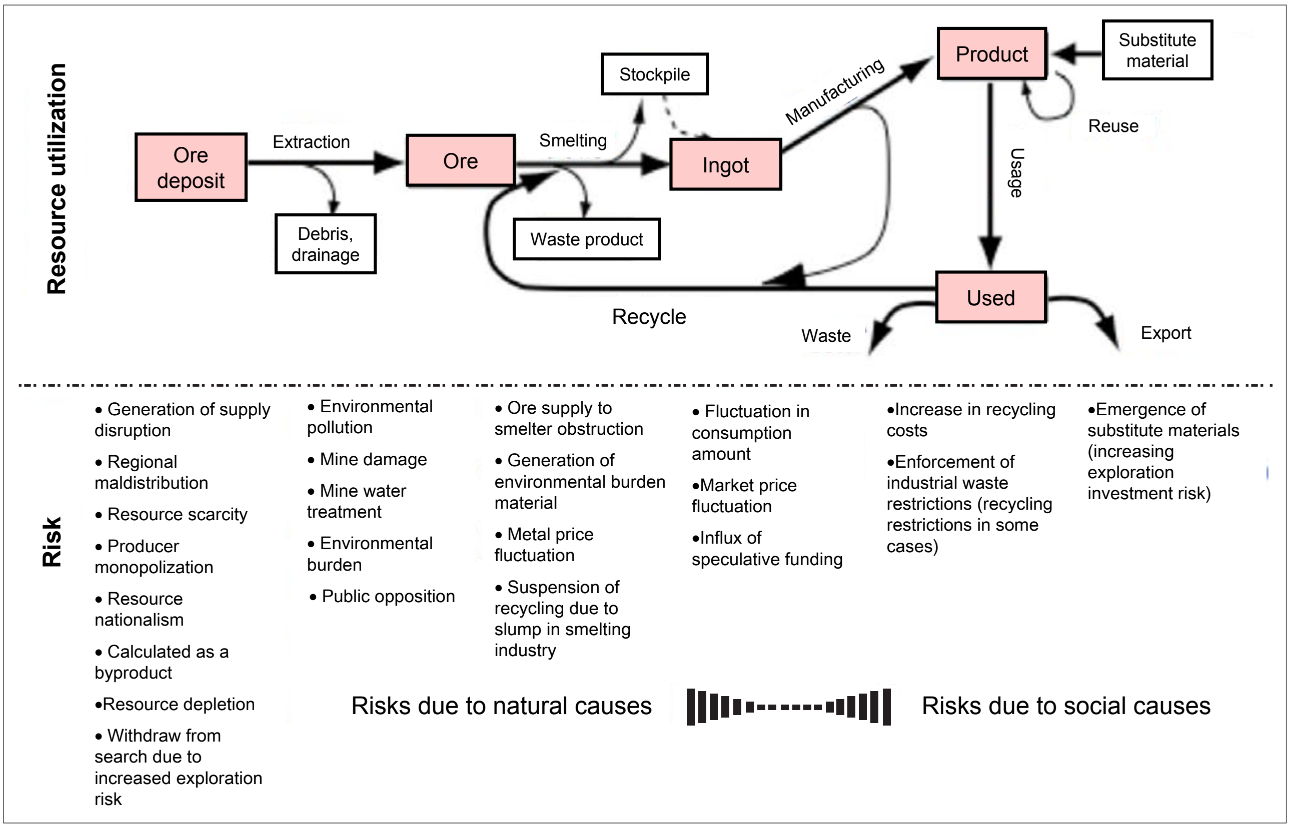


Figure 6 : Supply, recycling, and risks of mineral resources

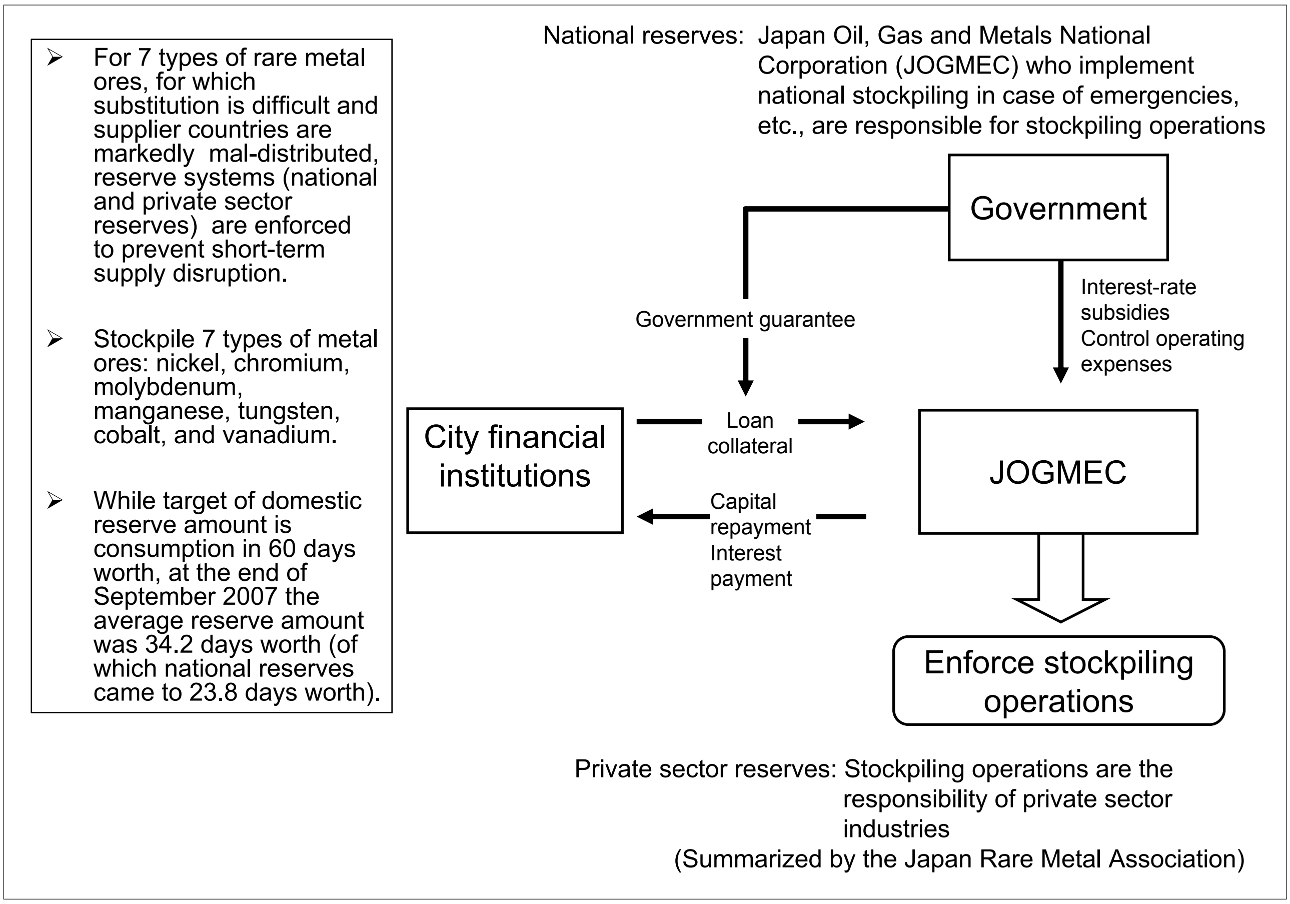
Soruce: References[2,3]

become inevitably tight. By simply calculating the recoverable amount and the assay amount of dysprosium contained in ore obtainable from rare earth deposits[13] as well as the yield when refined, a problem of supply should not be encountered for several decades. However, by considering the growth in demand for industrial products other than hybrid cars, future efforts will be essential to speed up the development of magnets in which the amount of dysprosium used is reduced and to increase recoverable reserves. Since it is highly unlikely that technology for substituting dysprosium, which is necessary for enhancing the coercive force of permanent magnets, will become available in the short-to-mid term future, the development of magnets in which the amount of dysprosium used is reduced is perhaps the only viable solution.

3-3 Status of rare metal recycling and reducing the consumption

Unlike energy resources, there are reuse and recycling processes for mineral resources which are beneficial for increasing the utilization efficiency of these resources. In addition, although only applicable to certain rare metals, Japan has its own private sector and national reserves. However, there are certain rare metals for which recycling is not economically viable. Also, if primary substitute materials emerge, there may be an immediate, sharp decrease in the economies of scale, which will result in an increase risk in exploration investment. The only workable solution for securing a stable supply of resources is by combining the multiple risk reductions at each stage.

The risks associated with the supply and recycling of mineral resources are indicated in Figure 6.[2,3] The residues from ingot manufacturing processes including ore deposit exploration, ore production by mining, and ore dressing as well as spent products are all recycled. In addition to this, there are various processes such as stockpiling and limiting supplying of reserves and searching for substitute materials, etc. These activities are accompanied by certain inherent risks such as risks due to uncontrollable natural forces, risks due to social factors, and exploration risks, etc. For example, on upstream risks such as skyrocketing prices, the supply disruption, etc., are not generated.



- For 7 types of rare metal ores, for which substitution is difficult and supplier countries are markedly mal-distributed, reserve systems (national and private sector reserves) are enforced to prevent short-term supply disruption.
- Stockpile 7 types of metal ores: nickel, chromium, molybdenum, manganese, tungsten, cobalt, and vanadium.
- While target of domestic reserve amount is consumption in 60 days worth, at the end of September 2007 the average reserve amount was 34.2 days worth (of which national reserves came to 23.8 days worth).

National reserves: Japan Oil, Gas and Metals National Corporation (JOGMEC) who implement national stockpiling in case of emergencies, etc., are responsible for stockpiling operations

Private sector reserves: Stockpiling operations are the responsibility of private sector industries

(Summarized by the Japan Rare Metal Association)

Figure 7 : Overview of rare metal stockpiling system

Source: Reference[23]

4 Securing a future stable supply of rare metal resources

4-1 Present day mineral reserve policies

In December 2005, the Agency for Natural Resources and Energy set up the 'Resources Strategy Committee' which examined the medium term measures considering the characteristics of ore production, the types of anticipated risks, and ways of implementing actions for rare metals such as tungsten, rare earth elements, and indium, etc., from upstream to downstream shown in Figure 6. These discussions are ongoing in the discussions in 'Mining Subcommitteee for the Advisory Committee on Energy and Natural Resources'. In June 2006, in the report on 'Strategies for Securing a Stable Supply of Non-Ferrous Metal Resources' from the Agency for Natural Resources and Energy, specific current measures arranged and based on (1) Promoting exploration development, (2) Promoting recycling, (3) Development of substitute materials, and (4) Stockpiling are already underway.[14] A summary of the rare metal stockpiling system is outlined in Figure 7.[23] The mineral resources policy budget for the year 2006 was 6.46 billion JPY, and for 2007 it becomes 7.07 billion JPY.

The keyword that represents Japan's resource policy is "Securing a Stable Supply". Various policies have been implemented by Japan Oil, Gas and Metals National Corporation (JOGMEC), which include aid and finance loans for mine exploration at home and abroad, tectonic surveillance, dispatching of specialists and technological cooperation to developing countries, development of technologies relative to domestic recycling, exploration funding reserve system, and the compiling of mining information from overseas for the purpose of "Securing a Stable Supply". As non-ferrous metal prices are thought to remain high, from 2007 a new budget was allocated for the development of recycling technology and substitute materials. A further new budget has also been allocated for the development of resources in the 2008 budget request.

In order to secure a stable supply of rare metals to Japan, the implementation of the following mid-to-long-term policies centering on the Ministry of Economy, Trade and Industry have been activated. Firstly, in order to bolster the securing of overseas resource development interests, direct relations with resource producing nations should be strengthened by adopting a diplomatic approach of resources, while at the same time taking measures to support exploration development. Next, to ensure internal availability, promotion of material recycling with backflow of resources from downstream to upstream together with developing recycling technologies related to waste materials that have hitherto made recycling problematic are underway. The development of substitute materials for those that are anticipated to be supply restriction has also been promoted.

4-2 Problems to be tackled in the short term: Recycling, information, and market issues

(1) In the case of rare metals in particular, a confluent resource system that will share the risks with three groups in the upstream position of resources (provision of geological and resource information, etc.), downstream position (consumption, etc.), and backflow position (recycling, etc.) is required. In addition to establish this kind of system, Japan must quickly and precisely grasp the present state of affairs of the world's mining industries through gathering and analyzing resource data for those industries concerned. In more specific terms, by engaging the government agencies to advance the preparation of geological and resource information, the detailed and exact survey analysis of the production amount and material flow would be continuous thereby enabling clarification of the price setting mechanism. For example, a detailed examination of the indium recycling system has recently begun.[15] Although the recycling of display panels, etc., is too inefficient and therefore not viable, the examination shows the estimation result that recycling during manufacturing is promising. Figure 8 shows a case example of a recycling study for indium

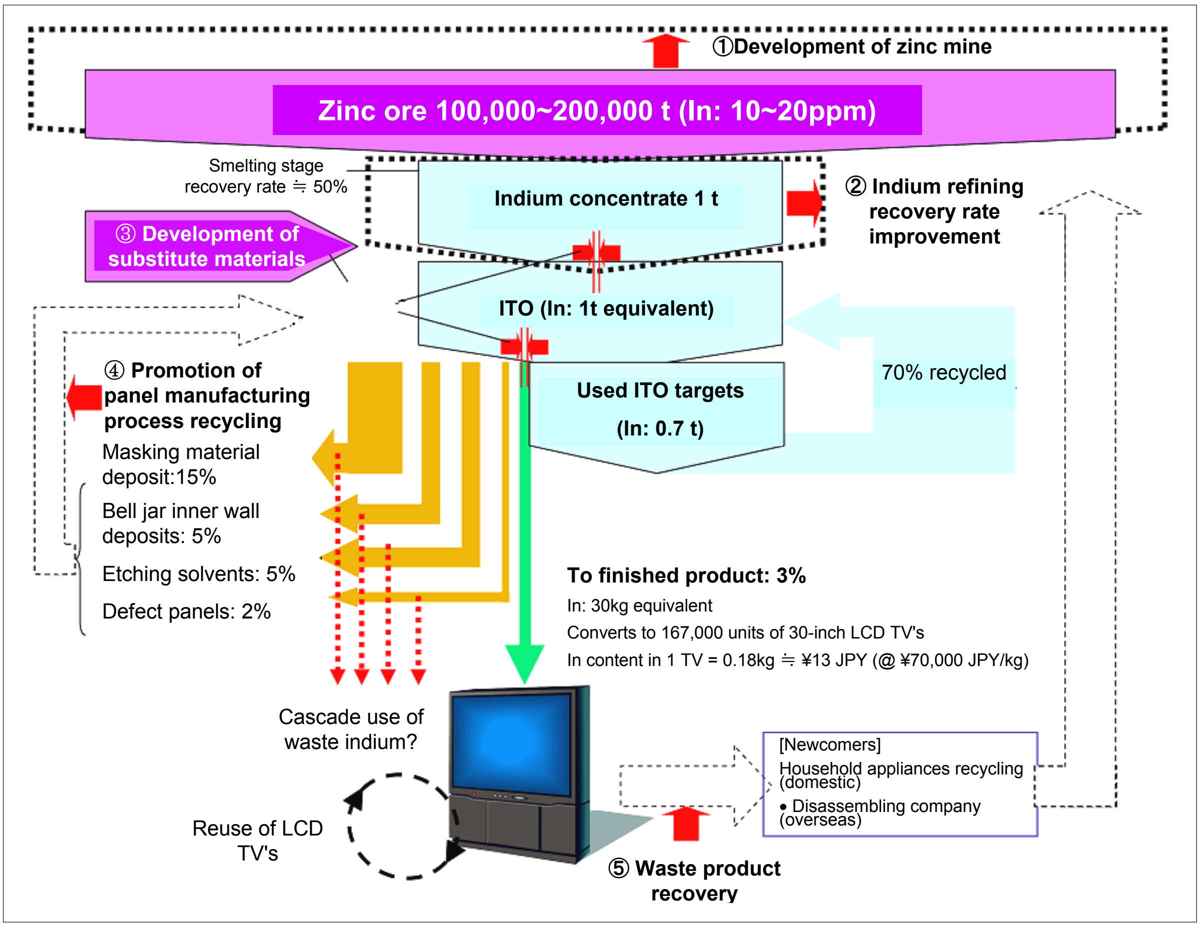


Figure 8 : Recycling study for indium in the lifecycle of a display panel

Source: Reference[15]

in the lifecycle of a display panel.[15] Here, the recovery of ITO (Indium Tin Oxide) from scrap LCD televisions, LCD computers, and mobile phone display screens, etc. and the recovery of ITO deposited on machines in the panel manufacturing processes, etc., are being studied. Since the amount of indium incorporated in LCD panels is small, recycling from panels is not profitable. Therefore, together with technological difficulties, recovery of indium has not progressed. Consequently, targets that are consumed in the LCD panel production processes are the main source of material recovery. However, the indium recovery rate from spent panels is expected to increase further due to the recent rise in indium prices.

(2) Heavy consumer nations like Japan should prepare accurate information about certain rare metals that cannot always be supplied from overseas. While requirement of stable supply of rare metals changes from large amounts at traditionally low prices to small amounts of high-quality metals, radical technological developments have generated an unforeseen sudden change in supply and demand. Information about supply and demand, including recycling, has not been adequately prepared. In the case of rare metals in particular, experience and instinct about base metals alone cannot control the markets. An abundance of available information is the only way to prevent an inflow of speculative money, and holds the key of independent circulation. In addition, if Japan's domestic reserves can be maintained based on this type of data, it will potentially counteract any unforeseen disruption of supply. In the case of rare metals, unlike base metals, their supply sources are limited, and there is a possibility of creating ambiguity without sufficient data. Furthermore, since it normally takes about 10 years to develop a mine, recovering a supply is not that straightforward. Since the majority of rare metal producing nations are extremely unevenly distributed, supply companies are becoming increasingly monopolistic. In addition to this, another factor affecting supply is that the majority of metals are not available as byproducts. In particular, in response to resource nationalism, the customary, "Even though the price is a bit high, if we hand over the money we'll be able to buy." will no longer hold true from here onwards and we shall have to assume the worst case scenario: "Despite it exists, we can't get it…!" For reasons of economic incompatibilities, a need has also occurred to reexamine resource developments that are consigned to domestic resources. In order to advance this kind of argument, first of all the accurate information must be prepared.

(3) Related to (2) above, no stabilized market has been established for rare metals at the lower end of the economic scale, therefore the mechanism for setting prices is unclear. In addition, there is also no global stable market for rare metals that are consumed in small amount and in unevenly distributed areas. In this regard, the issue of rare metals such as indium and dysprosium is fundamentally different from that of base metals. For example, world leading consumers of indium such as Japan will become increasingly dependent on China in which consumption increases from here onwards. Indium is one such element that carries an extremely high mechanism of risk for Japan. In fact, at the present moment Japan is probably the only country that is troubled by a sense of growing crisis regarding the obstruction of rare metal supplies owing to these imbalances of supply and demand, and this is not a globally common problem. The problems peculiar to Japan must be addressed by the Japanese people. We must derive some sort of mechanism that can sidestep soaring prices that will at least prevent a disruption of supply even if a small fluctuation in prices occurs. For these reasons, setting up a metal exchange for rare metals in Japan is very attractive idea.

4-3 Problems to be tackled in the long term: Effective use of rare metal resources and development of substitute technologies

The above-written short-term actions are means to evade supply disruption for the time being.

However, for elements which the mid-to-long-term absolute amount is anticipated to be undersupplied, a radical rethink of materials research and development is required. From 2007, the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Economy, Trade and Industry respectively launched the 'Elements Strategy Project' and the 'Development Project on Rare Metals Substitution'. Both projects are ranked as the research on 'Innovative Technologies on Rare Resource and Scare Resource Substitute Material for Determining Solutions to Resource Issues' in the 'Strategic Emphasis on Science and Technology' which is cited in the field of 'Nanotechnology and Materials' - one of the four key fields promoting the '3rd Science and Technology Basic Plan'.[16] Relative to this research domain, the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Economy, Trade and Industry have undertaken both projects by obtaining cooperation from the public subscription stage, mentioned blow, in order to implement effective research and development through establishing a support system that can be developed over a broad range from laying the groundwork to practical utilization. It is also hoped that they will be able to cooperate in advancing the follow-up to these findings.

Ministry of Education, Culture, Sports, Science and Technology: 'Elements Strategy Project'

The purpose of this project is to develop high-functionality substances and materials, without using rare or hazardous elements, by clarifying the formation mechanism of the functions and characteristics of substances and materials. It is anticipated that the research will look into the development of substitute materials from the abundantly available harmless elements, high practical utilization of the effective function of strategic elements, and practical material design technology for the effective element utilization. These projects are to run for a five-year fundamental research period after which they are expected to advance to practical applications. In principle, they will aim for the development of complete substitution technologies and to greatly reduce the amount of rare metal element usage.

As a result of reviewing the publicly subscribed research and development project themes, seven projects shown in Table 3 have been chosen from an initial 54 candidate projects themes.[18]

Ministry of Economy, Trade and Industry: 'Development Project on Rare Metals Substitution'

This project is a part of general measure to substitute and reduce the usage amount of rare metals aiming to achieve 'Innovative Technologies on Rare Resource and Scare Resource Substitute Material for Determining Solutions to Resource Issues' together with establishing a seamless support system from the basics to full practical application. The research and development objectives, until 2011, are to establish production technologies that will enable reductions in the unit consumption of the following three types of ores to the target percentage level, and to establish technologies to an extent to be able to provide laboratory samples for the purpose of functional evaluation by external organizations such as user industries and universities, etc. In addition, it is a prerequisite that product functionality and manufacturing costs do not deteriorate from current levels. The R&D project themes include technologies for reducing the usage amounts of indium for transparent electrodes (50% reduction from present levels), dysprosium used in rare earth metal magnets (30% reduction from present levels), and tungsten used in carbide tools (30% reduction from present levels). After the public subscription of the R&D project themes, five themes were selected from the initial 11 candidates.[18]

The research and development projects mentioned above are not expected to deliver immediate results, but are essential in Japan's science and technology policies for probing intrinsic solutions to the inevitable main issues.

These undertakings need to deliver mid-to-long-term groundbreaking transformations. Because the development of substitution technologies that will enable the substitution of specific rare earth elements with other rare earth elements is not linked to the fundamental solution to solving the problems, it has not been made an objective priority. Even though there are significant difficulties to be overcome, innovative results must be aspired to.

However, due to the resistance and stability of

Table 3 : ‘Strategic Elements Project’ adopted assignment list

Theme	Representative organization	Participating organizations	Summary of assignment
Development of steel plate surface treatment by molten Al alloy plating in place of zinc	Tokyo Institute of Technology	Tohoku University , National Institute for Material Science, JFE Steel Corporation, Nippon Steel Corporation, Nippon Light Metal Co. Ltd.	To develop surface treatment technologies by substituting zinc with aluminum alloy. To establish surface treatment technologies by abundant harmless elements Al-Mg-(Zn, Si) alloys by active use of current technology, manufacturing facilities.
Development of next-generation non-volatile memory using aluminum anodized film	National Institute for Material Science	GIT Japan	To substitute harmful rare elements such as praseodymium, cerium, ruthenium, and bismuth, etc., to produce promising candidates for next-generation variable resistance type memory (ReRAM) by aluminum anodizing.
New hydrogen induced function in subnano-lattice materials	Tohoku University	Fukuyama University, Iwate University, Kyushu University, Research Institute for Electric and Magnetic Materials, Toyota Motor Corporation, Nippon Mining & Metals Co., Ltd., Honda R&D Co., Ltd., Asahi Engineering Corporation, Future Products Co., Ltd., Shoei Chemical Inc., Toshiba Corporation	To understand the many facets of the effects of hydrogen and to drastically improve the characteristics of Al, Cu, and Ti alloys by grain refinement using hydrogen absorption and desorption heat treatment. Also, to study new functions induced by dissolved hydrogen in subnano lattices and to pursue the possibility of applying to materials.
New excavation of nanoparticle self-generating catalysts aimed at eliminating precious metals from catalysts	Japan Atomic Energy Agency (JAEA)	Daihatsu Motor Co., Ltd., Hokko Chemical Industry Co., Ltd., Osaka University	To greatly reduce the amount of precious metals (palladium, rhodium, and platinum) used in vehicle exhaust catalytic converters and organometallic compound catalysts, and furthermore achieving elimination of precious metals from catalysts. To develop the high-catalytic function peculiar to nanoparticles for the purpose of greatly reducing the usage amount of precious metals and for final elimination of precious metals from catalysts while at the same time establishing optimum nanoparticle synthesizing technology to serve the usage environment.
Creation of barium based new giant piezoelectric effect materials for developing piezoelectric frontirers.	Yamanashi University	Tokyo Institute of Technology, Kyoto University, Tokyo University of Science, National Institute of Advanced Industrial Science and Technology (AIST), Canon Inc.	To surpass lead-based piezoelectric materials, create new barium-based giant piezoelectric effect materials that do not include not only harmful lead and bismuth but also potassium, sodium, and lithium which are unsuited to silicon processing. To pioneer new applicable fields that straddle materials, electronics, and machinery for new device development based on the technology seeds of composition phase boundary design and domain structure control.
Development of TiO_2 based transparent electrode materials as a substitute for ITO	Kanagawa Academy of Science and Technology	Tokyo University, Asahi Glass Co., Ltd., Toyoda Gosei Co., Ltd.	To establish processes for depositing films of TiO_2 based transparent conductors (TNO) on glass using established practical methods (sputtering and CVD) for the purpose of substituting ITO needed in transparent electrodes with TNO. Also, to pursue the possibilities of using TNO as transparent electrodes for blue light emitting diodes.
Development of low rare element composition high-performance, anisotropic nancomposite magnets	Hitachi Metals Ltd.	Nagoya Institute of Technology, Kyushu Institute of Technology, National Institute for Material Science	To aim at developing completely new magnetic materials with low rare earth element inclusion compositions that do not use heavy rare earth elements such as dysprosium and reduce the usage amount of rare earth elements such as neodymium. To develop high performance anisotropic nanocomposite magnets by coupling high saturation magnetic flux density soft magnetic phase with high coercivity hard magnetic phase.

Modified by the STFC based on Reference[18]

indium thin film electrodes, no substitute of indium has yet been found. In addition, since there have been no recent discoveries of magnetic materials that can surpass present permanent magnet materials such as neodymium iron boron (Nd-Fe-B) developed more than 20 years ago, even if the additive elements that improve the thermal characteristics could be effectively substituted with only other rare metals, not other than rare metals, in the future, there is still a possibility that this will not fundamentally solve the problems facing these resources. These materials may have to be reverted back to having their basic physical properties researched again from scratch. Permanent magnet materials research in particular may need to be taken back again to look at characteristics such as the coercive force and squareness ratio of permanent magnets in the research of the fundamental physical properties of these materials. In order to do this, merely taking the traditional metallurgical approach may not be enough, and it will be necessary for researchers who have a completely new way of thinking, such as using computer simulation, to radically rethink the way in which elements are perceived. These types of research are issues concerning researchers of materials, physics, and chemistry fields that are outside of the scope of the projects mentioned above.

4-4 Reviewing resource development: Land-based resources –

Global efforts are underway in reviewing resource development in order to avoid the dangers of resource nationalism by reexamining the overconcentration of resource production. While it normally takes about 10 years to develop a mine, it is vital to rethink the situation particularly for indium and dysprosium for which their applications look set to expand and the expectation of finding substitute materials is for the interim more or less hopeless.

As discussed in section 3-2, since metal mines in western countries are, mainly for business reasons, closing one after another and exploration and development activities as a whole have been on the decline for a long while. Nevertheless, until very recently, Japan was a producer of some kind of rare metals. Furthermore, the Toyoha mine (Sapporo city, Hokkaido prefecture) in Japan was one of the few world indium mines. However, the mine was closed in March 2006 because it was technologically difficult to mine above the scale at that time. The Toyoha mine produced silver, zinc, lead, and indium, and after the mine closed Japan became almost entirely reliant on overseas supplies of base metals and rare metals. In addition, apart from the closing of the Toyoha mine, other mines such as Kunitomi(Hokkaido prefecture); No. 2 Ryuo (Nagano prefecture); Ashio (Tochigi prefecture); Tohgane, Kurokawa, Umakichi (Gifu prefecture); Akenobe and Ikuno (Hyogo prefecture); and Hoei, Obira (Oita prefecture) are known to have rich deposits of indium.[19]

Resource engineering has hitherto not been able to assess the total amount (ultimately, the total amount of mineral resources that will be available for future use) of non-ferrous metal mineral resources. There are some deposits in which a lowering of the grade increases the amount of ore available and others that do not, and there are some mines such as zinc, lead, and indium mines where lowering the grade does increase the amount of ore available. Although not necessarily highly efficient, in South East Asia and South America the use of low-grade ore is progressing due to new technological developments in refining techniques.

In the example of tungsten also, in 1993 all tungsten mines in Japan were closed and by 1994 nearly all tungsten mines in western countries were also closed. However, recently, due to fears of soaring tungsten prices and overconcentration in China, mines that were once closed in North America are being reopened and new exploration developments are taking place.

By looking at the rare metal producing centers overseas, the individual operations are comparatively small-scale and are often form the mainstay of local developments. In this regard, it might be time to reconsider rare metal production as local small-scale enterprises in Japan also.

4-5 Resource development; Expectation to the development of seabed rare metal resources

An additional long-term issue facing Japan is the development of seabed resources. Although the existence of seabed mineral resources is something which has been known about since the 19th century, surveys only began in the 1950’s becoming fully-fledged by the early 1970’s. With the exception of oil and natural gas, the development of seabed resources – despite commercial mining having once been considered to be too cost ineffective here in Japan – has very recently been attracting a lot of interest owing to the existence of precious metals and rare elements. Compared to the size of its land, Japan has an extremely large exclusive economic zone (EEZ). These territorial waters and adjacent seamounts are understood to be endowed with an expansive cobalt-rich crust containing some of the world’s highest grade platinum, cobalt, copper, and manganese. In addition, it also been proven that in the Okinawa Trough and territorial waters of Izu and Ogasawara, there are hydrothermal deposits containing gold, silver, copper, lead, zinc, and rare metals that, in terms of grade and scale, match any similar land-based mineral deposits. Japan’s land-based ore deposits were originally created from hydrothermal deposits, and many of these land-based deposits were formed due to uplifts in the earth's crust. As Japan is a volcanic country, this means that it has the advantage of being surrounded by many hydrothermal ore deposits. From here on also, detailed surveys of the seabed may indicate that there is also a possibility of the continental shelf expanding further out from the economic exclusion zone.[20] Therefore, the resources of this area are also attracting attention.

Regarding the use of ocean resource, on July 20, 2007 the 'Basic Ocean Law' was implemented.[4] A basic ocean plan is currently being drawn up for January 2008. Article 4 of this 'Basic Ocean Law' sets out the enrichment of marine related scientific knowledge as: "While scientific knowledge regarding oceans is essential in order to properly conduct ocean development, utilization, and conservation of the ocean environment, scientific understanding must also be enriched given the many ocean related fields that have not been revealed." In addition, Article 17 concerning the advancement of development and utilization of ocean resources states: "The development and utilization of mineral resources such as oil, combustible natural gas, manganese ore, and cobalt ore, etc. that exist on or below the ocean floor are to be promoted and the systems and other measures necessary for advancing the developments are to be provided." The promotion of the development in the exclusive economic zone and oceanographic surveys are also cited. The development of these related technologies is reported in detail in March's edition of 'Science and Technology Trends' (2007).[20]

5 Potential of seabed minerals as rare metal resources (in particular hydrothermal deposits)

Here, the potential of Japan's seabed minerals indicated in section 4-5 are mentioned in a little more detail. The seabed resources are largely divided into three categories, as shown in Table 4.[2]

These are manganese crust (also referred to as the cobalt-rich manganese crust or the iron manganese crust), manganese nodules, and seabed hydrothermal deposits. Figure 9 shows the main categories and deposit sites of the seabed mineral resources.[2] More noteworthy are the considerable differences in the locations and water depths due

Table 4 : Important seabed mineral resources components, deposit scales and locations

Type of mineral resource		Manganese nodules	Manganese crust	Seabed hydrothermal deposits
Mineral resources details	Shape	Spherical: 1 ~ 10 cm dia.	Thickness: 1 ~ 10 cm encapsulated	Chimneys, mounds
	Main component	Iron and manganese oxide	Iron and manganese oxide	Iron, copper, zinc oxide
	Target metals	Copper, nickel	Cobalt, platinum, rare earth	Gold, silver, copper, zinc, lead
	Origin	Chemical deposition from seawater	Chemical deposition from seawater	Precipitation from high-temperature thermal waters
	Scale of deposit	~ 100 km	~ 10 km	~ 1 km
	Amount of primitive resource	500 billion t (estimated)	50 billion t (estimated)	1 million t (per site)
	Formation period	< 80 million years	< 120 million years	< 1 million years
Mineral resource existence status	Water depth range	3500 ~ 6000 m	1000 ~ 3000 m	1200 ~ 3000 m
	Ocean areas	Pacific Ocean, Indian Ocean	Western Pacific Ocean	Mid-oceanic ridge 284, island arc 58
	Geological environment	Slow sedimentation rate, deep seabed	Exposed rock area of seamounts and plateaus	Mid-ocean ridge and island arc volcanoes
	Relationship to EEZ	Outer international waters	Japan's EEZ and international waters	Japan's EEZ and international waters
Development status of exploration methods		On-site testing completed	Undeveloped	Venture companies investigating

Modified by the STFC based on Reference[2]

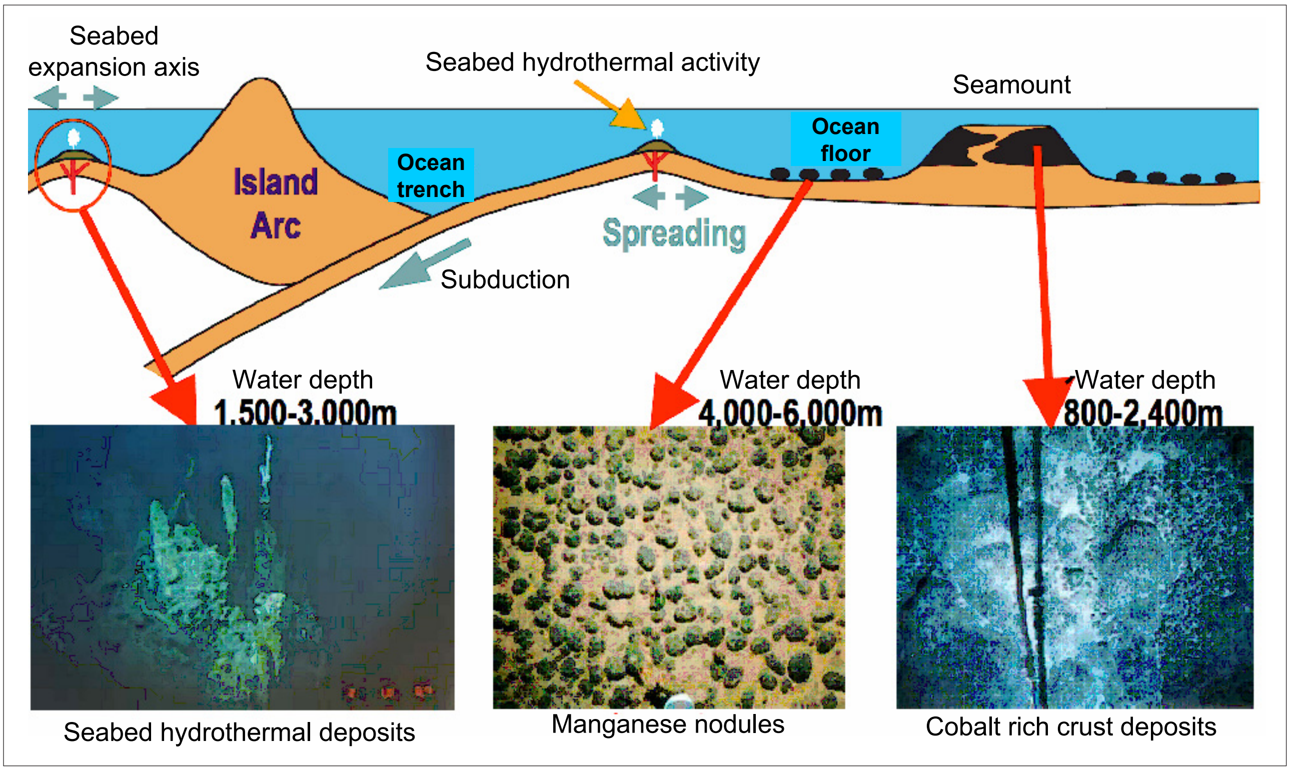


Figure 9 : Main types of seabed mineral resources and deposit sites

Source: Reference[2] (JOGMEC data modified by the STFC)

to various causes of formation. Figure 10 shows the distribution of seabed mineral resources in the Pacific Ocean.[21]

The existence of manganese crust and manganese nodules has been known about from a comparatively long time ago, and these have been vigorously surveyed and mining has been investigated. However as they are in deep seas, they will cost an enormous sum of money that is concluded to be incalculable to develop as a resource. Also, the high-grade manganese nodules are in international waters.

On the other hand, the seabed hydrothermal deposits, referred to as ‘chimneys’ and ‘mounds’, are a comparatively recent discovery, and as of yet, they have not been well surveyed. These exist on moderately shallow seabeds and are high-grade mineral resources. In addition, since these are regenerative deposits that can be repeatedly mined and, as the resource developments are anticipated to be profitable, foreign venture companies have already started developmental work.

Because hydrothermal deposits are formed over a comparatively short time period lasting only several decades, even after they have been mined there is a possibility of being able to re-excavate them after several decades. While seabed mineral resources are naturally more difficult to mine than land-based deposits, the possibility of repeatable mining is an incentive for development. The hydrothermal deposits are made up from iron, copper, and zinc sulfides whose composites are quite different from manganese crusts and manganese nodules. The important factor is that they contain precious metals such as gold and silver, etc. In addition, since these also contain copper, lead, and zinc, it is anticipated that they may also contain rare metals such as indium, etc. Japan’s land-based mines are also considered to originate from hydrothermal deposits on the ocean floor. By looking at their existing locations, up to now there are approximately 300 seabed hydrothermal deposits that are known around the world, and many also exist within Japan’s exclusive economic zone. Japan’s outlying seamounts are said to contain particular large quantities of gold and silver and have the advantage of being located in comparatively shallow sites. In addition, due to the extension of the continental shelf,[20] the range of speculative exploration is expected to increase.

The seabed hydrothermal deposits that have up until now been discovered in the seas around Japan

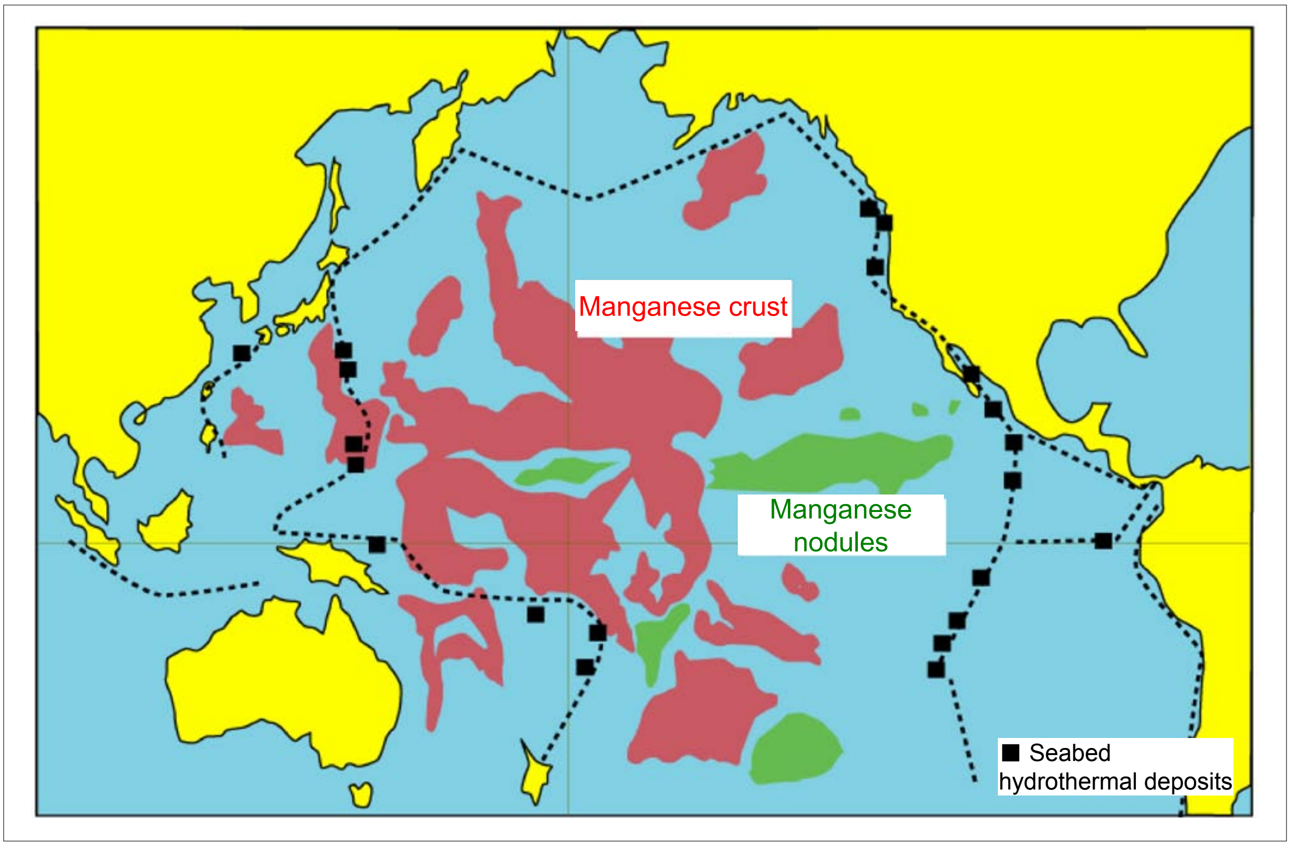


Figure 10 : Distribution of seabed mineral resources in the Pacific Ocean

Source: Reference[21]

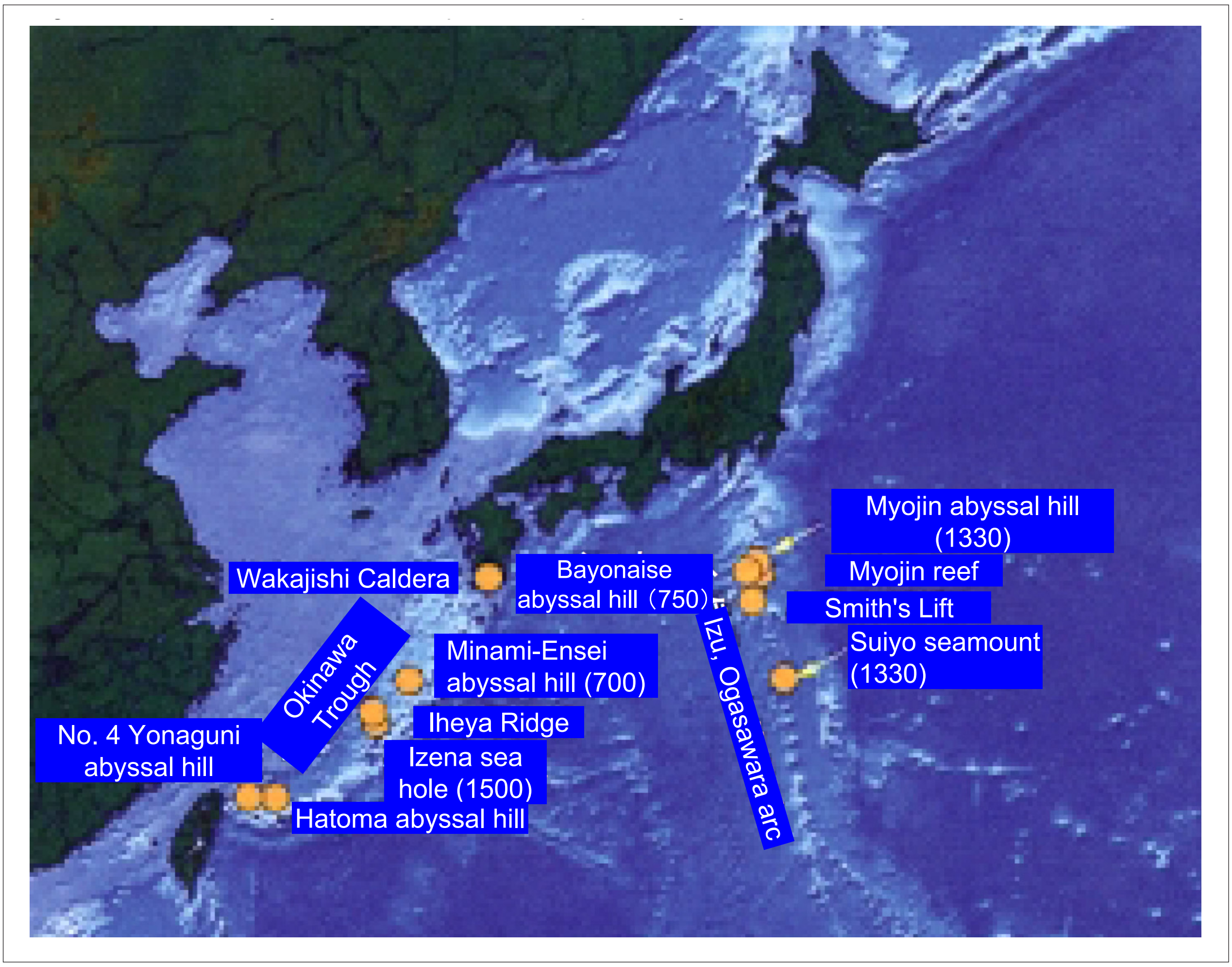
are shown in Figure 11.[21, 22] The Pacific Ocean hydrothermal deposits are found almost entirely in the mid-ocean ridge in relatively deep locations in comparison to Japan's exclusive economic zone. On the other hand, since Japan's outlying seabed hydrothermal deposits contain high quantities of gold and silver, as mentioned previously, and they are located in shallow places, that attracted a remarkable amount of interest of foreign venture companies and they have recently started applying for mining lots. The places that are attracting most interest in Japan's outlying waters are the hydrothermal areas of the Sunrise deposit, Hakurei deposit, and Okinawa's Izena hydrothermal holes. Presently, acting under the direction of the Agency for Natural Resources and Energy, resource surveys by JOGMEC are underway by commissioning the No.2 Hakurei-maru fitted with seabed excavation equipment. To ascertain the amount of reserves from the amount of deposits will require continuous surveying by concentrated boring in order to ascertain the depth and horizontal spread. If these surveys progress, it is likely that private sector companies will be able to decide whether or not to commit. The methods of lifting ore from the seabed will become developed as a mining technology. Although there are many other technological issues such as pollution control and metallurgical techniques, together with larger economic issues, the systematic excavation of a number of hydrothermal ore deposits once the system has been established will be possible. However, because many rare species of living organisms have also been discovered in the hydrothermal deposit fields, there is also interest in researching the origins of life on the earth. From the survey stage of investigating exploration methods, adjustments may have to be made in relation to accommodating research into these living organisms.

6 Conclusions

The matters that this article wishes to emphasize are as follows.

Securing functioning market

As the international market function operates for base metals, even though there may be temporary price hikes, there is a high possibility that given time a balance of supply and demand



Note: The numerical data in parentheses ( ) indicates the depth (m) of mineral endowment of the hydrothermal deposits

Figure 11 : Seabed hydrothermal deposits of Japan's adjacent seas

Modified by the STFC based on the images published in Reference[21,22]

can be achieved. However, there are no healthy functioning international markets for quantitatively or regionally scarce rare earth elements. For example, because indium and dysprosium, etc., are elements which hold interest only in Asian countries, there is no scheme to achieve a naturally stabilized international market. For these several types of rare metals, even though the suppliers and consumers are relatively limited, Japan should consider taking the lead in securing a small-scale functional market capability.

Rethink towards Japan's land-based resource development

The overall scale of the world's rare earth market is primarily small. Taking a global perspective of mining developments, because reserves in each region are small, large-scale development is unnecessary. While diversification of risk is important for the resource supply origins, under these sorts of conditions there is enormous scope for rethinking rare metal resource developments as small-scale local industries for Japan's land-based and coastal rare earth resources.

Exploration of seabed mineral resources and creating a business scheme

The exploration of seabed mineral resources is a field in which Japan should become a world leader through its geological advantage of being a volcanic archipelago nation. By investigating business models such as private sector venture capital funding and NPO contributions, etc., once this type of scheme has been established, an entirely new research mechanism needs to be considered in order to simultaneously facilitate a scientific exploration of seabed resources. For those that will be able to establish such mechanisms, it is worth for states considering offering support in the form of priority free-of-charge equipment loans, etc.

Material science research based on extensive findings

If innovative materials such as thin-film electrode materials that are not indium based or permanent magnet materials that are not Nd-Fe-B based are found to exist, then it is hoped that Japan will be the first country to discover these materials. For material technology fields which have guaranteed future large markets, such as displays and hybrid cars, we would like see Japan become a world leader in making free use of material scientific techniques that have reverted back to fundamental condensed matter physics.

Researchers who are engaged in material science can no longer be disinterested in the supply and demand of resources concerning the components from which certain materials are constructed. Materials researchers will not be able to merely focus on individual substances and materials,but they will need to consider a wider range of substances and materials that will incorporate the demands of research findings and a stable supply of resources. At the very least, there will be very little possibility of developing research in target applications utilizing large quantities of substances or materials that are not estimated to exist in quantitatively adequate resources or to be available through a guaranteed stable supply. Research utilizing substances or materials for which the supply is uncertain will have to search for potential substitute materials that are more readily available. It is inevitable that the later will supersede the former. Researchers who are engaged in material science will have to become involved in reforming the disruptive innovations of past findings without becoming fixated on temporal research results perse.

Acknowledgments

This article is written based on the subject of the lecture: “Development of Seabed Rare Mineral Resources and Japan’s Strategy" by Professor Tetsuro Urabe, School of Science, The University of Tokyo that took place at the meeting of National Institute of Science and Technology Policy on July 3rd 2007. Further studies relating to mineral resources policies, the effective utilization of resources and development of substitution technologies as activities concerning the future stable supply of rare metal resources has been added and summarized at the Science & Technology Foresight Center. I would like to thank Professor Tetsuro Urabe for providing information.

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(Original Japanese version: published in October 2007)