Rare Raw Material

— Overview on issues and opportunities —

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Chairman of the Workshop 1: Rare Raw Materials Issues

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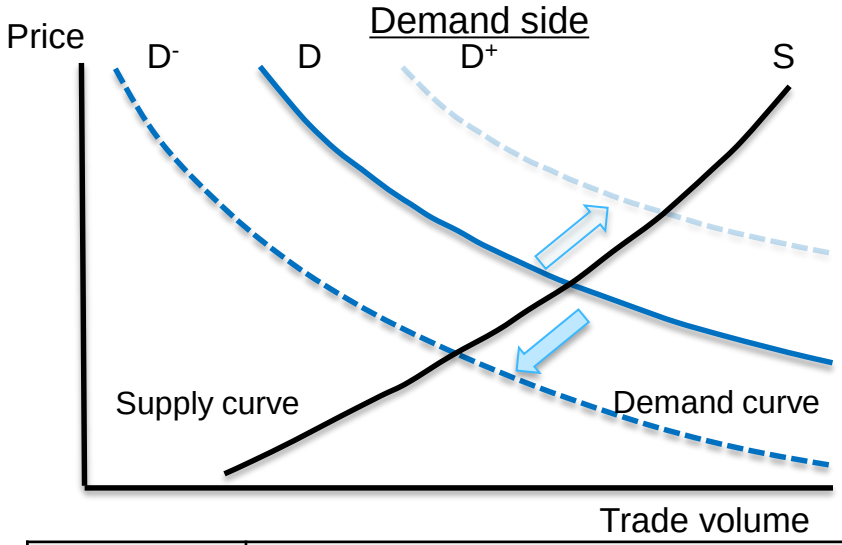
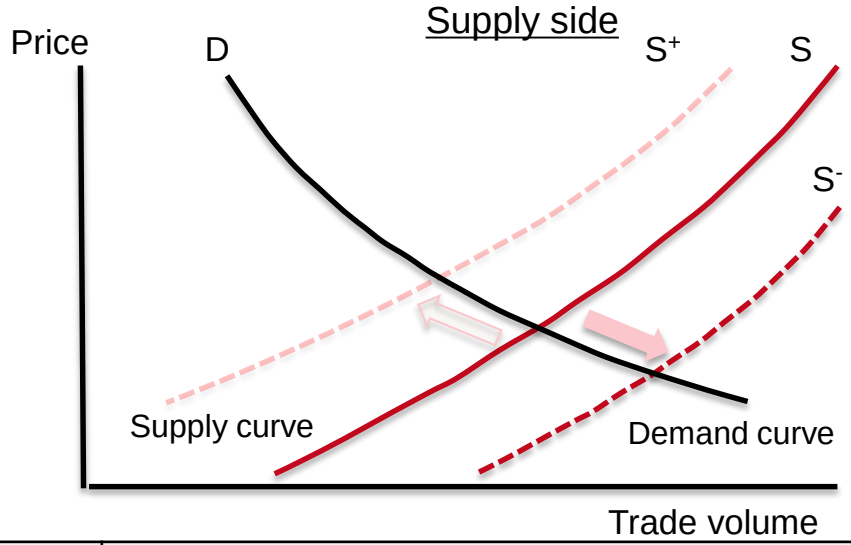
Factors affecting the prices(demand-supply) of mineral resources

The following supply/demand curves are prepared for the better understanding of the correlation of the various factorslusables with rather a simple and bold assumption.

○【Inevitable】As the world economy develops, demand for mineral resources increase, thus the prices of mineral.

○【Possible】Need innovation to control price rise by supply increase and usage reduction.

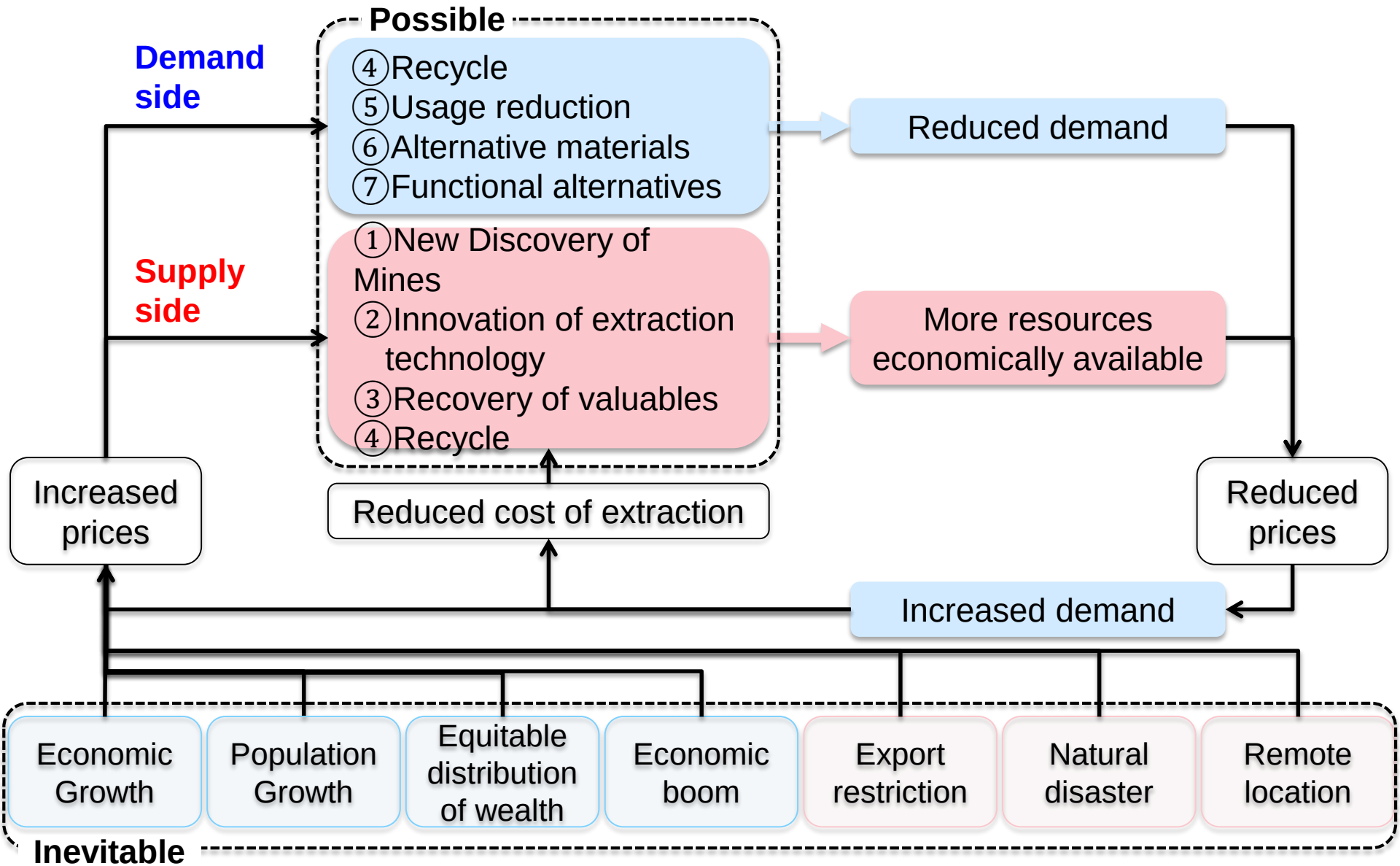




	Demand	Supply
Increasing	・Economic growth(Affluent society) ・Population growth ・Equitable distribution of wealth ・Economic boom	①New discovery of mines ②Innovation of extraction technology ③Recovery of valuables ④Recycle
Decreasing	⑤Usage reduction ⑥Alternative materials ⑦Functional alternatives	・Export restriction ・Natural disaster ・Remote location

Supply curve：Curve showing relationship between price and supply, the higher the price the higher the quantity supplied, and vice versa.
Demand curve： Curve showing relationship between price and demand, the lower the price the higher the quantity demanded, and vice versa.

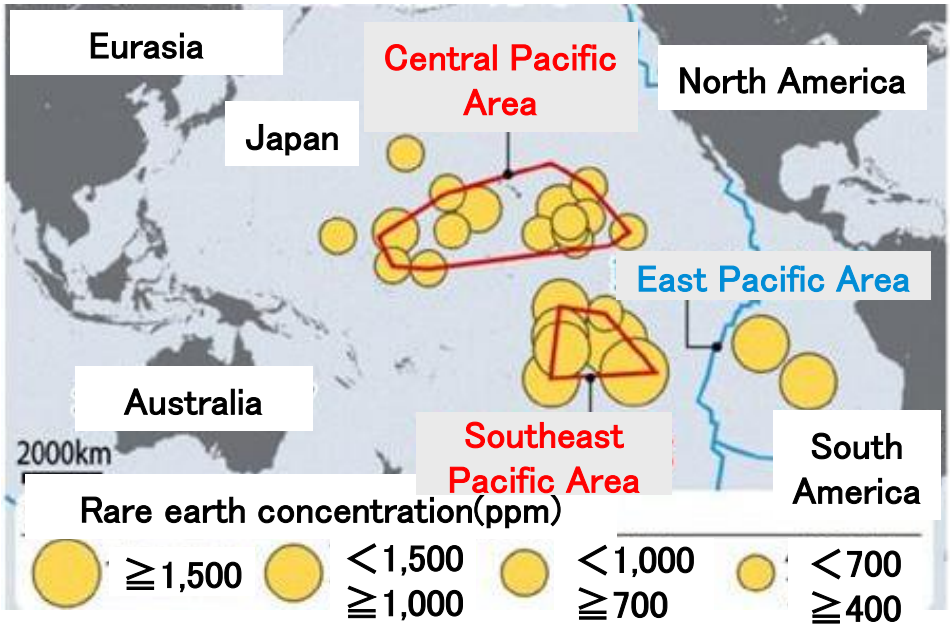
Correlation between/among various factors (in a Causal Loop Diagram)



Case①：New discovery of mines

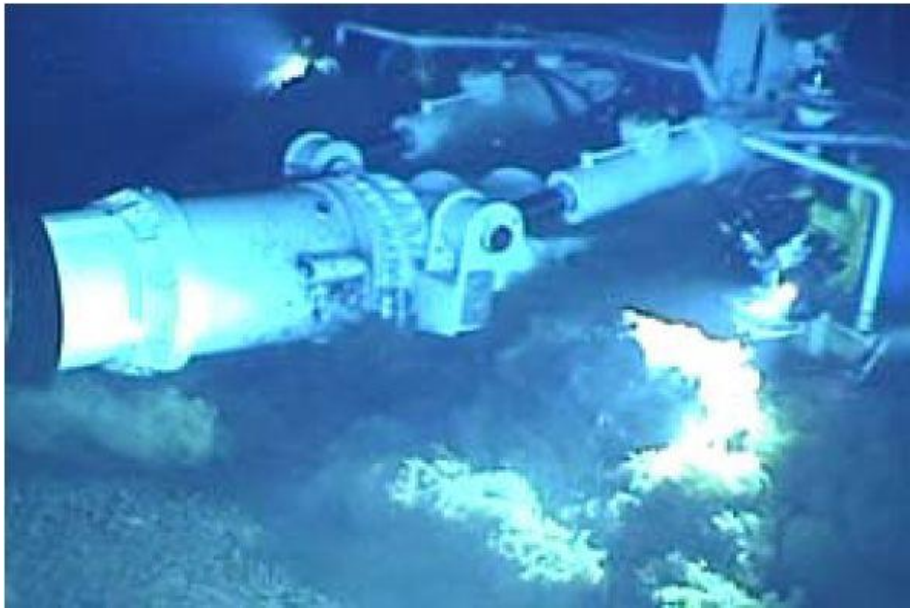
- In response to price hike around August 2011 due to export restriction of rare metals by Chinese government, several projects resumed, and increased production in North America, Australia, Asia and etc. Yet China still accounts for 88% of world rare earth production.
- Development of deep sea hydrothermal deposits, in which highly concentrated deposits of rare earth elements were confirmed, is one of the directions. Though it needs thorough study on impact on marine environment as well as innovation.

Distribution of rare earth containing deposits



Source：太平洋の海底にレアアース含有「夢の泥」発見、産経ニュース、2011.7.4

Deep sea mining test



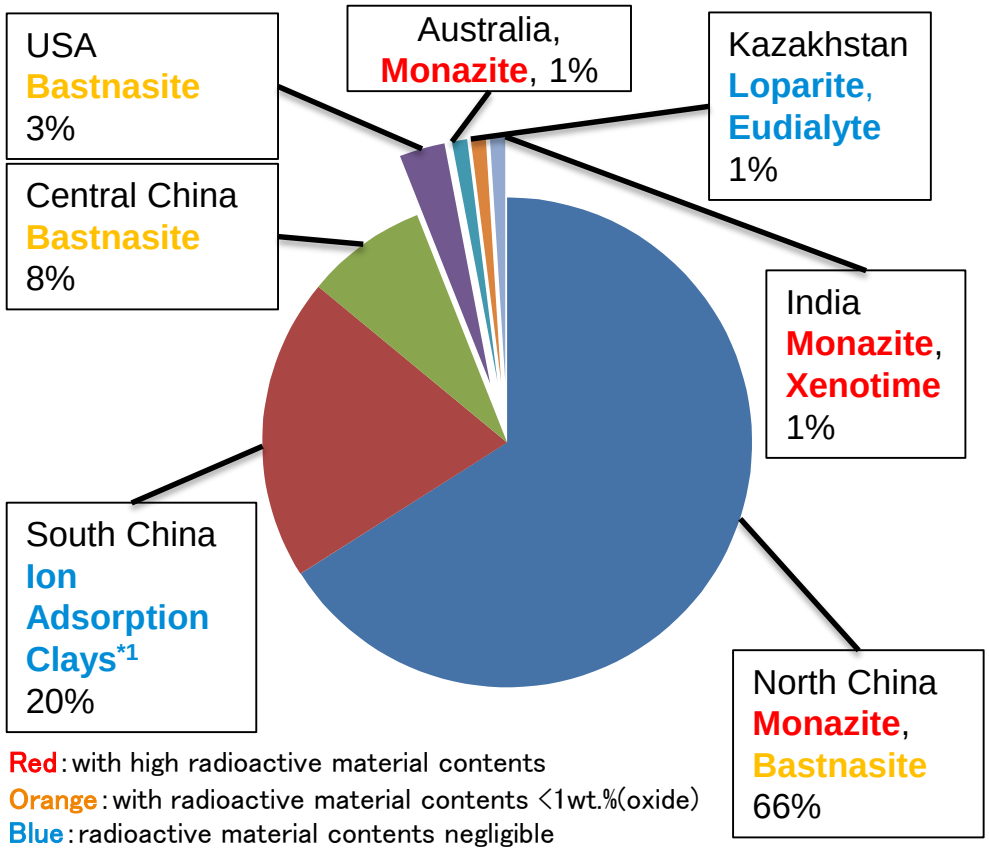
Source：海底採掘要素試験機による海底熱水鉱床の採掘試験に成功、JOGMEC、2012.9.25

Case②：Innovation of extraction technology

○Most of the major rare earth deposits accompany radioactive materials.

○Automation of mining deposits containing radioactive materials is one of the directions.
Once volume reduction technology is established, management costs will be reduced.

World: Production of rare earths by country and ore type, 2014



Red：with high radioactive material contents
Orange：with radioactive material contents <1wt.%(oxide)
Blue：radioactive material contents negligible

*1：radioactive materials eluded by weathering from rare earth rich crust such as Monazite, Xenotime etc.

Source：Rare Earths: Market Outlook to 2020, 15th edition, 2015, Roskill, 2015.03, The Principal Rare Earth Element Deposits of the United States, USGS, 2010.11

Mining automation

Source：Rio Tinto Launches Automated Mine of the Future, sourceable, 2013103.21

(Reference) Major ores containing rare earths

Ores	Chemical Formula
Monazite	$(Ce, La, Nd, Th)PO_4$
Bastnasite	$(Ce, La)(CO_3)F$
Xenotime	YPO_4
Loparite	$(Ce, Na, Ca)(Ti, Nb)O_3$
Eudialyte	$Na_4(Ca, Ce)\ (Fe^{2+}, Mn^{2+}, Y)$ $ZrSi\ O\ (OH,Cl)$

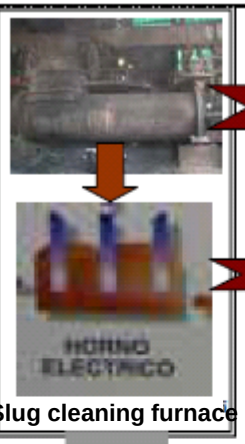
Source：The Principal Rare Earth Element Deposits of the United States, USGS, 2010.11

Case③：Recovery of valuables

○Smelting waste (sludge) contain valuables, such as gold or Indium etc.. Economically sound recovery of these metals can reduce net production cost.

Recovery of valuables from smelting waste(sludge)

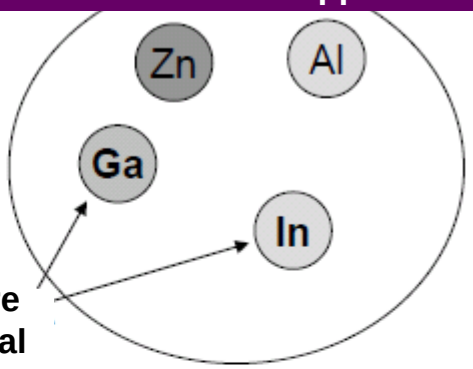
Dry Smelting (Copper Sulfide Ore)



Slug cleaning furnace

Electrolysis (after smelting)

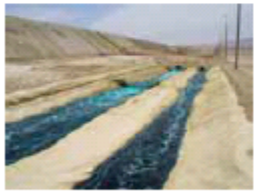
Other major valuable metals other than copper



Rare metal

Sludge

Recovery of rare metals from sludge



Wet Smelting (Copper Oxide Ore)

Sulfuric acid leaching (SX process)

Electrowinning(EW)

Smelting process → Occurrence of sludge(containing rare metals)

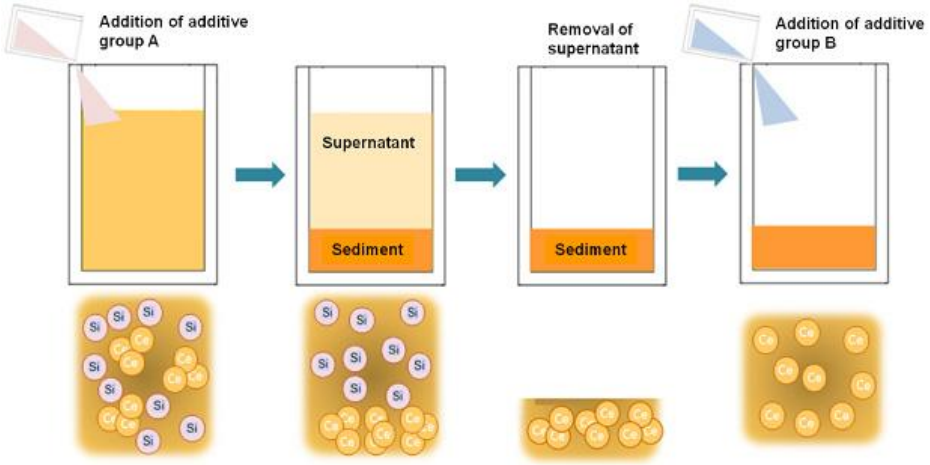
Source：レアメタル高度分離・製錬技術調査、JOGMEC、2008.08.26

Case④：Recycle（Urban mining）

○In Japan, the demand for cerium oxide, which is used as glass polishing powders for hard disk substrates and lenses etc., is reduced by recycle and by substitution to zirconium oxide.

Typical use of Polishing powders（Cerium Oxide)
(Left：Hard disk, Right：lens for automotive light)

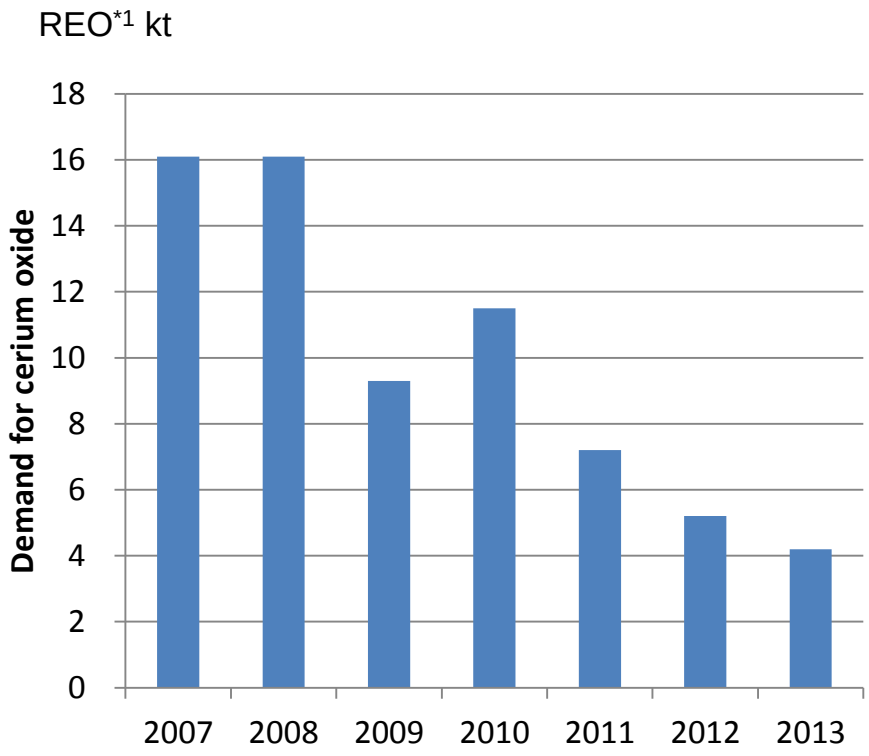
Recycle process for polishing powders(Cerium Oxide)



Separate silicate glass from mixture after polishing hard disk substrates or lenses for automotive light, thus extract cerium oxide and reuse.

Source：Recycling Cerium Oxide Polishing Material, Konica Minolta HP

Demand for cerium oxide in Japan 2007-2013



Demand decreased by recycle and substitution to zirconium oxide.

*1：Rare Earth Oxide、weight rare earth oxide equivalent

Source：レアアース問題の整理ー供給リスクは減少？ー、JOGMEC、2014.09

Possible innovation for usage reduction

○Materials usage reduction, alternative materials and functional alternatives began to affect rare metal market through usage reduction.

function/ product / Measures	Strength	hardness	magnetic	heat resistance	catalyst	Phosphor
	aircraft	Machining tool, Polisher	Motor /generator for HEV and wind turbine	Super alloy	Automotive catalyst, Ni-MH battery	Fluorescent lamp, Cathode Ray Tube
Usage Reduction			○case⑤		○	
Alternative Materials	○Case⑥	△	△	○		
Functional alternatives		△	×		○Case⑦	○

○：payable as business

△：commercialized ,but not economically viable or in development

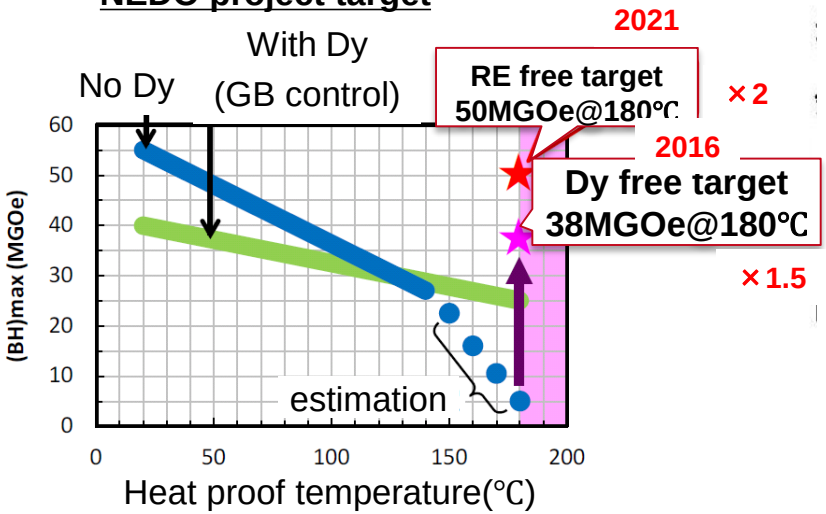
×：no prospects for commercialization

Case⑤：Usage reduction

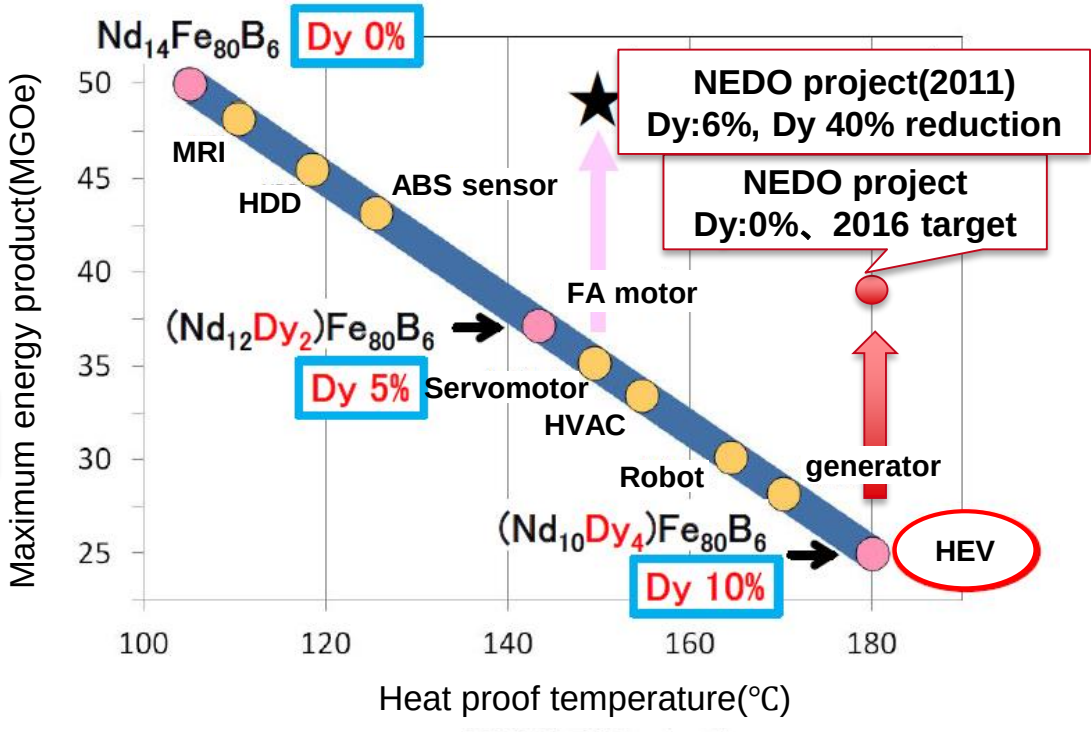
○Dysprosium(Dy), which is added to strong rare earth(RE) magnets(neodymium-iron-boron) to raise thermal stability, is largely dependent on Chinese production. Efforts are underway to overcome this situation.

Nissan LEAF(with -40%Dy RE magnet motor)

NEDO project target



Heatproof temperature versus dysprosium content by application



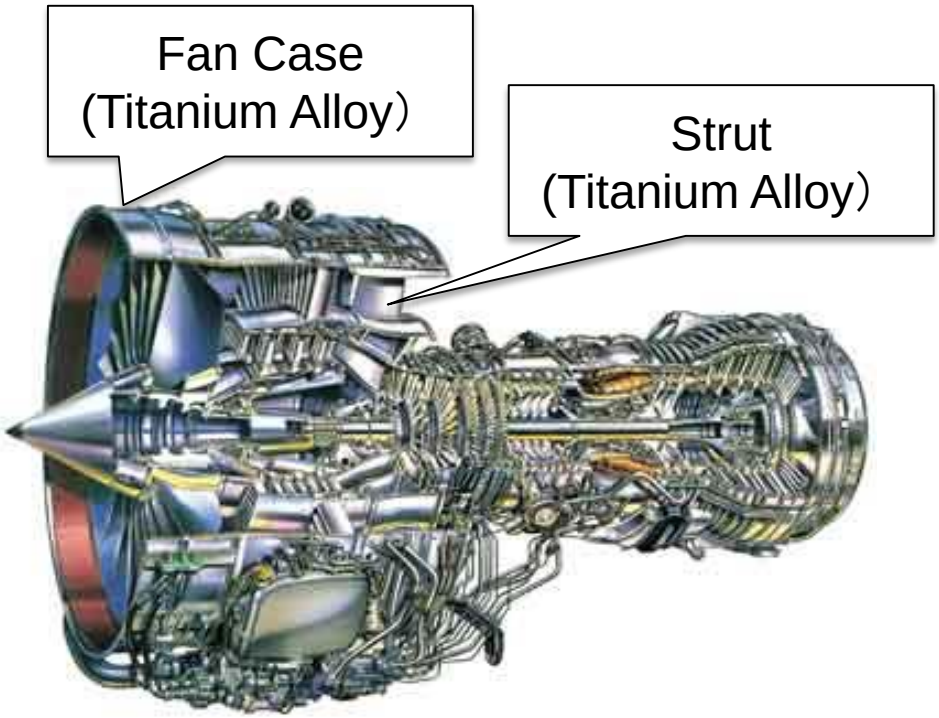
Use of dysprosium achieved 40% reduction by grain boundary(GB) control, and R&D is now targeting toward zero dysprosium magnets.

Source：日産リーフがレアアース削減モーター搭載！電費も向上！、クリッカー、2012.11.21

Source：「次世代自動車向け高効率モーター用磁性材料開発」（中間評価）、NEDO、2014.11.12

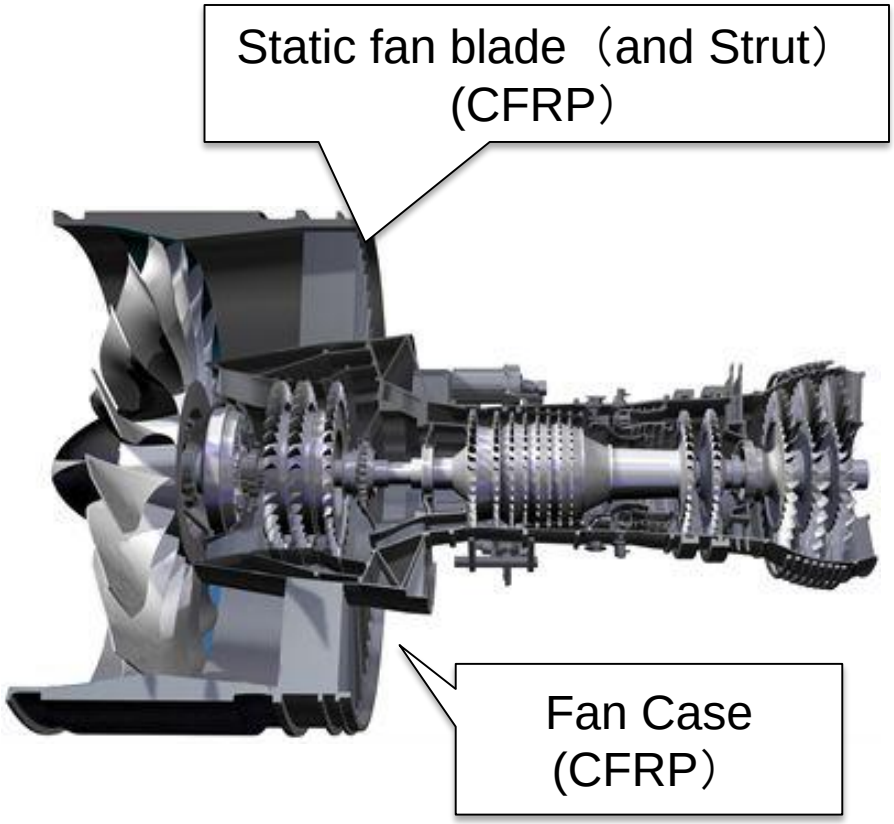
Case⑥：Alternative materials

○ Titanium is being substituted to Carbon Fiber Reinforced Polymer (CFRP) in aircraft engines.



V2500(enter service：1999)

Source：Japanese Aero Engines Corporation



PW1100G-JM(enter service：2015(plan))

Source：Japanese Aero Engines Corporation

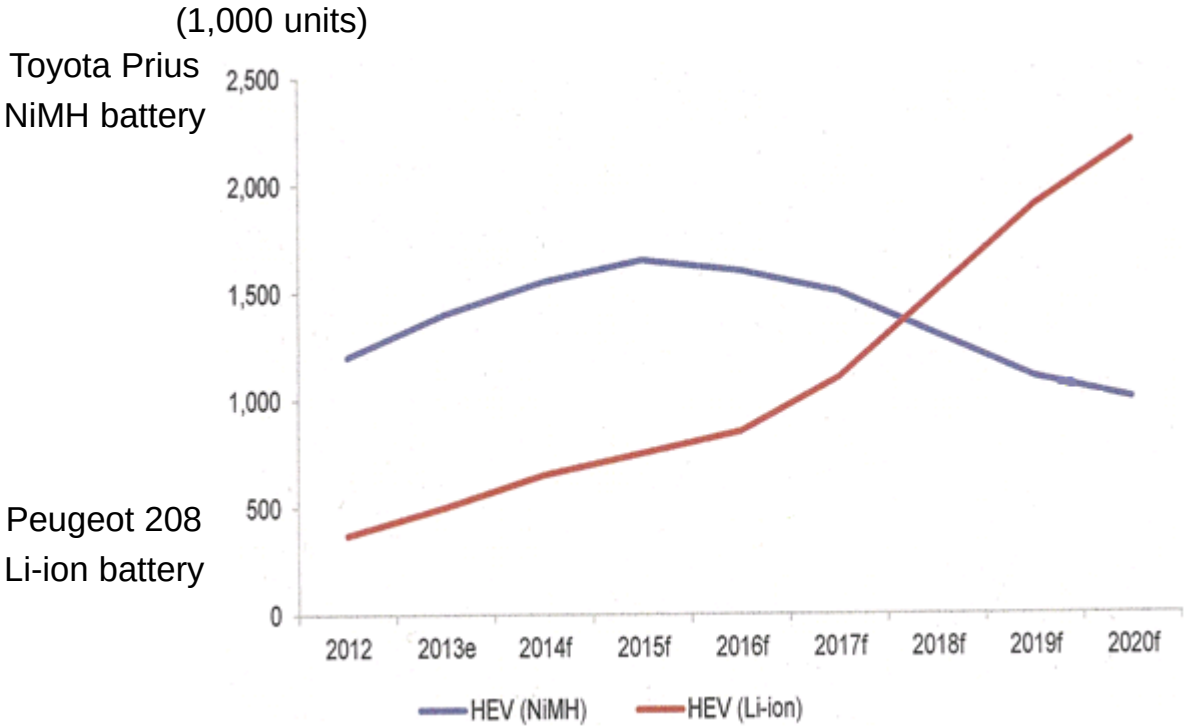
Case⑦：Functional alternatives

- Demand for mischmetal (mixed rare earth composites) for battery use is forecasted to decrease owing to the shift from Ni-MH*1 batteries to Li-ion batteries.
- But it may create strong pressure on Li resource.

Toyota Prius
NiMH battery

Peugeot 208
Li-ion battery

World: Forecast production of HEVs by battery type, 2012 to 2020



*1：Nickel Mischmetal Hydride

Source：Toyota HP、PSA HP

Source：Rare Earths: Market Outlook to 2020, 15th edition, 2015, Roskill, 2015.03

【Reference】 Cases for alternative materials other than rare metals（aircraft）

○Structural materials used for aircraft have been shifting from aluminum alloys to CFRP. And this move triggers evolution of third generation aluminum-lithium alloys.

○Thus it is important to monitor rapidly evolving supply and demand scene(that is, minerals intelligence).

Airbus A340(enter service:1993)
Composite ratio：18%

Airbus A350 XWB(enter service:2015)
Composite ratio：52%
(Aluminum Lithium :20%)

Boeing 767(enter service:1982)
Composite ratio：3%

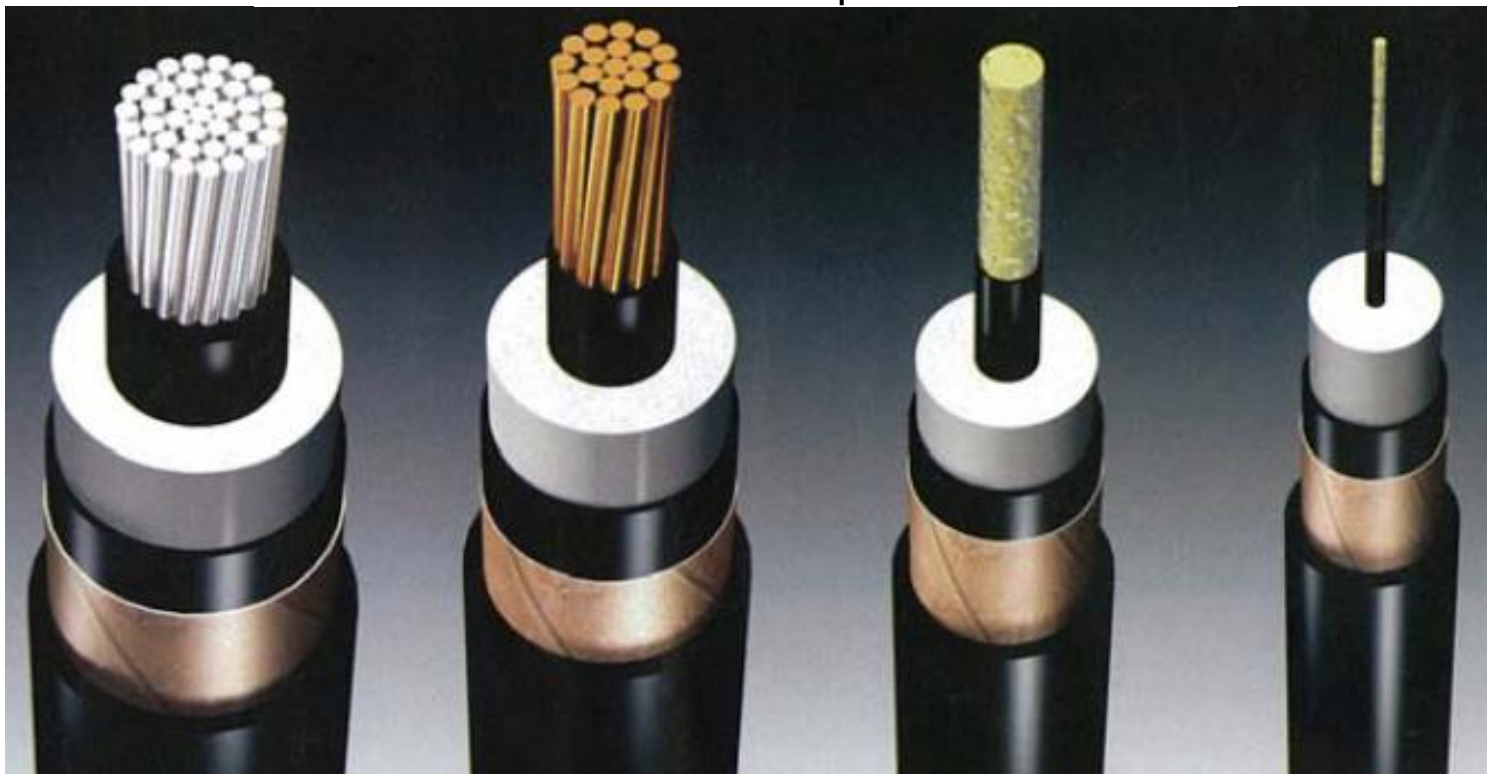
Boeing 787(enter service:2011)
Composite ratio：50%

Source：Airbus HP、航空機におけるアルミニウム合金の利用の概況と今後、JFA、2014.01

【Reference】Cases for alternative materials other than rare metals（wire）

○Power cables shift from copper to aluminum and now carbon nano tube in sight.

Power cables with the same permissible current



Aluminum | **Copper** | **Carbon Nano Tube** | **Carbon Nano Tube（in the future）**

Source：石油開発におけるナノテク、JOGMEC、2011.11.24

QUESTIONS

- **Where is the viable solution(s) ?**

- **What can we do to tackle the challenge(s) ?**

Conclusions

- **Innovation across the whole supply chain, from developing better understanding of ore forming process and 3D/4D geological data sets, to identify deep-seated, concealed ore deposits; to lean mining, ore processing and metallurgical technologies; through international collaboration and technology exchanges are essential to cope with the rare raw material issues,**

And

- **Sustainable mining practices and advanced mining technology should be shared by the operators worldwide through "global open innovation network“ to overcome the problems resulting from different technology levels and environmental regulations between countries and regions.**