Contributions and Problems of Rare Erath Elements for Zero-carbon and Higher Resource Efficiency Society

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PARIS2015

UN CLIMATE CHANGE CONFERENCE

COP21·CMP11

20151202
http://ec.europa.eu/environment/circular-economy/index_en.htm

Circular Economy Strategy

Closing the loop - An EU action plan for the Circular Economy

The European Commission adopted an ambitious **Circular Economy Package, which includes revised legislative proposals on waste** to stimulate Europe's transition towards a circular economy which will boost global competitiveness, foster sustainable economic growth and generate new jobs.

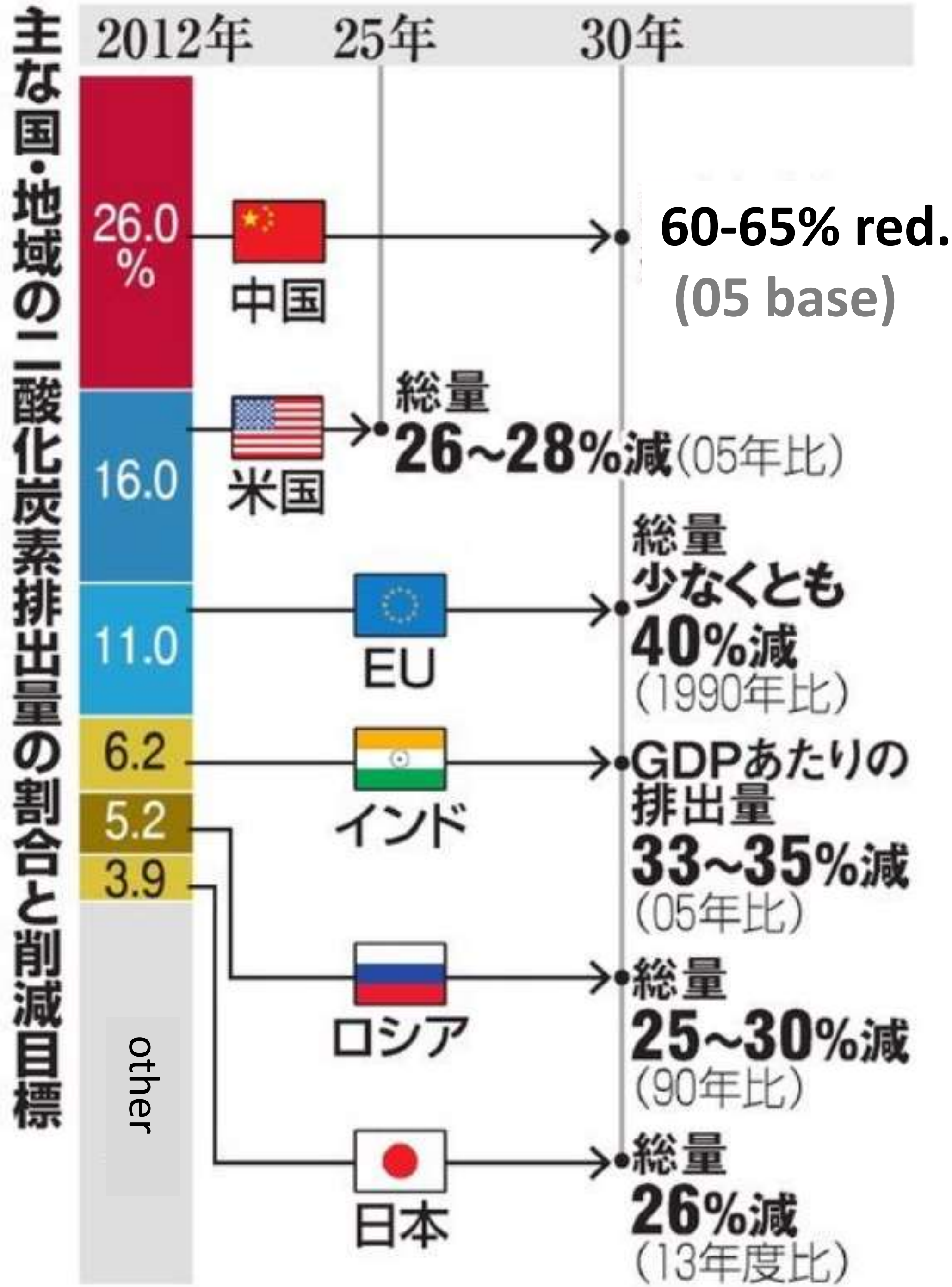
The Circular Economy Package consists of an EU Action Plan for the Circular Economy that establishes a concrete and ambitious programme of action, with measures covering the whole cycle: from production and consumption to waste management and the market for secondary raw materials. The annex to the action plan sets out the timeline when the actions will be completed.

The proposed actions will contribute to **"closing the loop" of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy.**

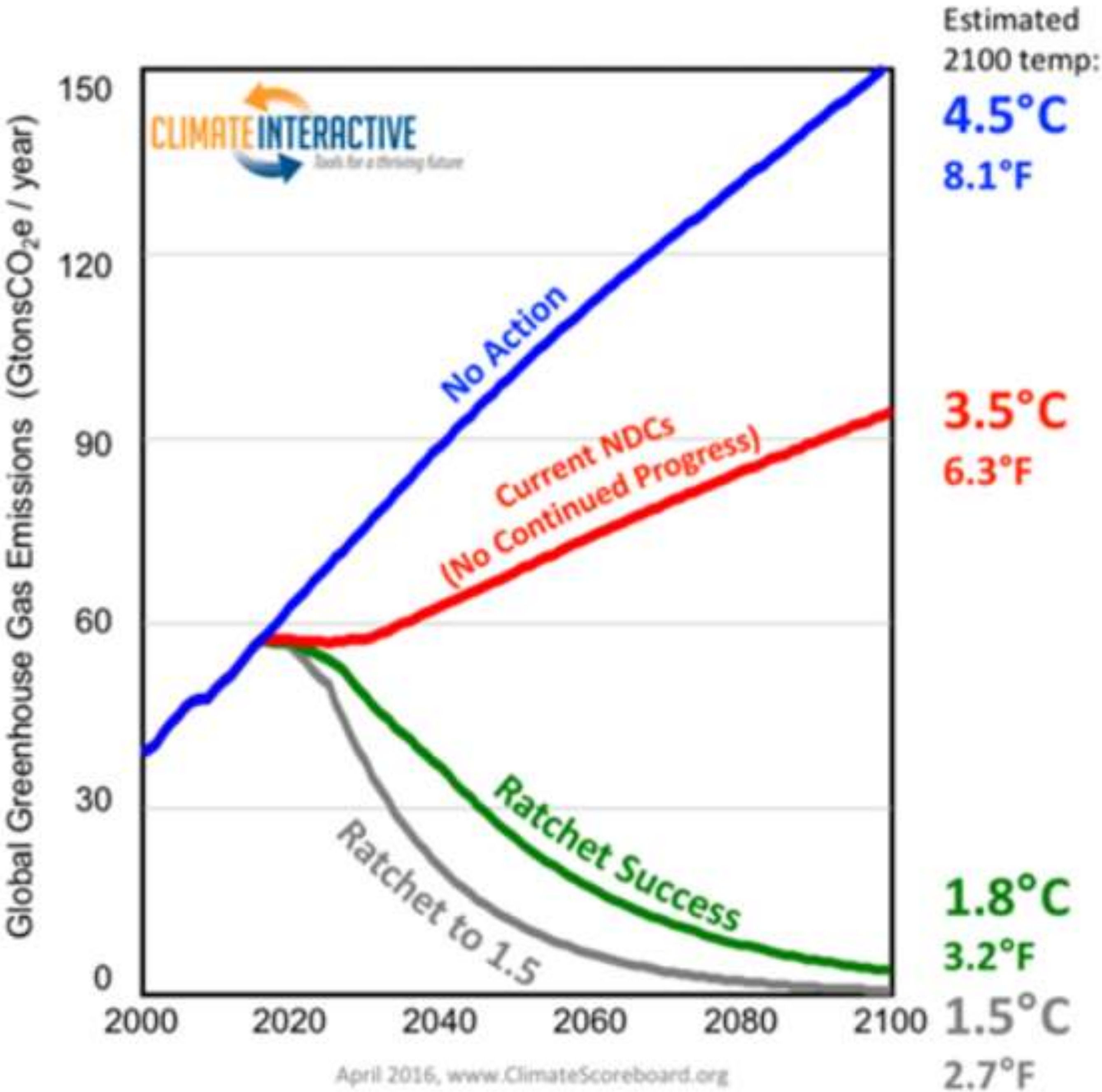
The **revised legislative proposals on waste** set clear targets for reduction of waste and establish an ambitious and credible long-term path for waste management and recycling. Key elements of the revised waste proposal include:

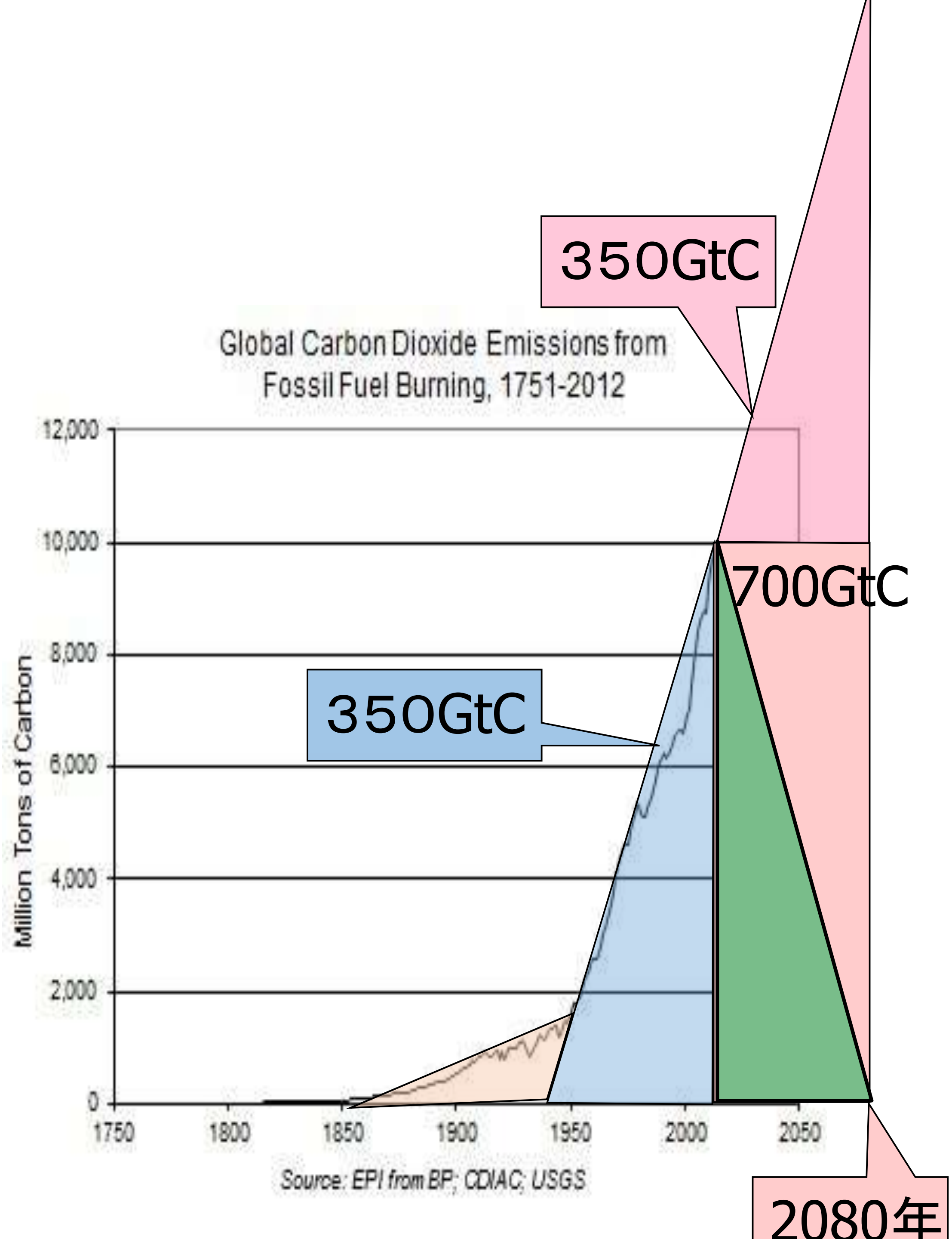
- A common EU target for recycling 65% of municipal waste by 2030;
- A common EU target for recycling 75% of packaging waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of all waste by 2030;
- A ban on landfilling of separately collected waste;
- Promotion of economic instruments to discourage landfilling ;
- Simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU;
- Concrete measures to promote re-use and stimulate industrial symbiosis - turning one industry's by-product into another industry's raw material;
- Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (eg for packaging, batteries, electric and electronic equipments, vehicles).

クライアント領域(C) Shift+Alt+F12



主な国・地域の二酸化炭素排出量の割合と削減目標
2012年
25年
30年
26.0 %
中国
60-65% red.
(05 base)
16.0
米国
総量
26~28%減(05年比)
11.0
EU
総量
少なくとも
40%減
(1990年比)
6.2
インド
GDPあたりの
排出量
33~35%減
(05年比)
5.2
ロシア
総量
25~30%減
(90年比)
3.9
日本
総量
26%減
(13年度比)
other


Estimated
2100 temp:
4.5°C
8.1°F
3.5°C
6.3°F
1.8°C
3.2°F
1.5°C
2.7°F
CLIMATE INTERACTIVE
Global Greenhouse Gas Emissions (GtonsCO2e / year)
150
120
90
60
30
0
2000
2020
2040
2060
2080
2100
No Action
Current NDCs
(No Continued Progress)
Ratchet Success
Ratchet to 1.5
April 2016, www.ClimateScoreboard.org


350GtC
Global Carbon Dioxide Emissions from
Fossil Fuel Burning, 1751-2012
12,000
10,000
8,000
6,000
4,000
2,000
0
Million Tons of Carbon
700GtC
350GtC
1750
1800
1850
1900
1950
2000
2050
Source: EPI from BP; CDIAC; USGS
2080年

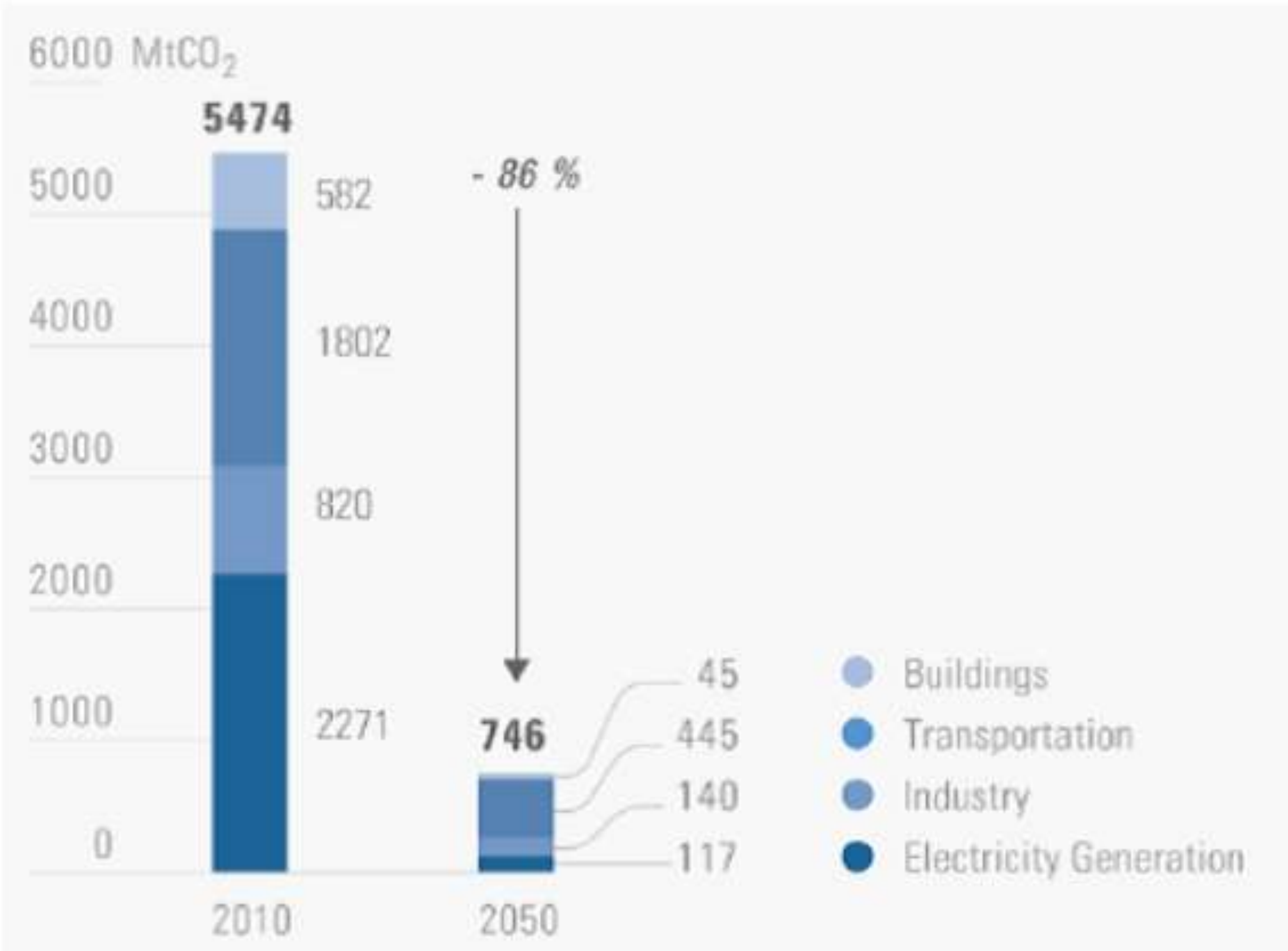
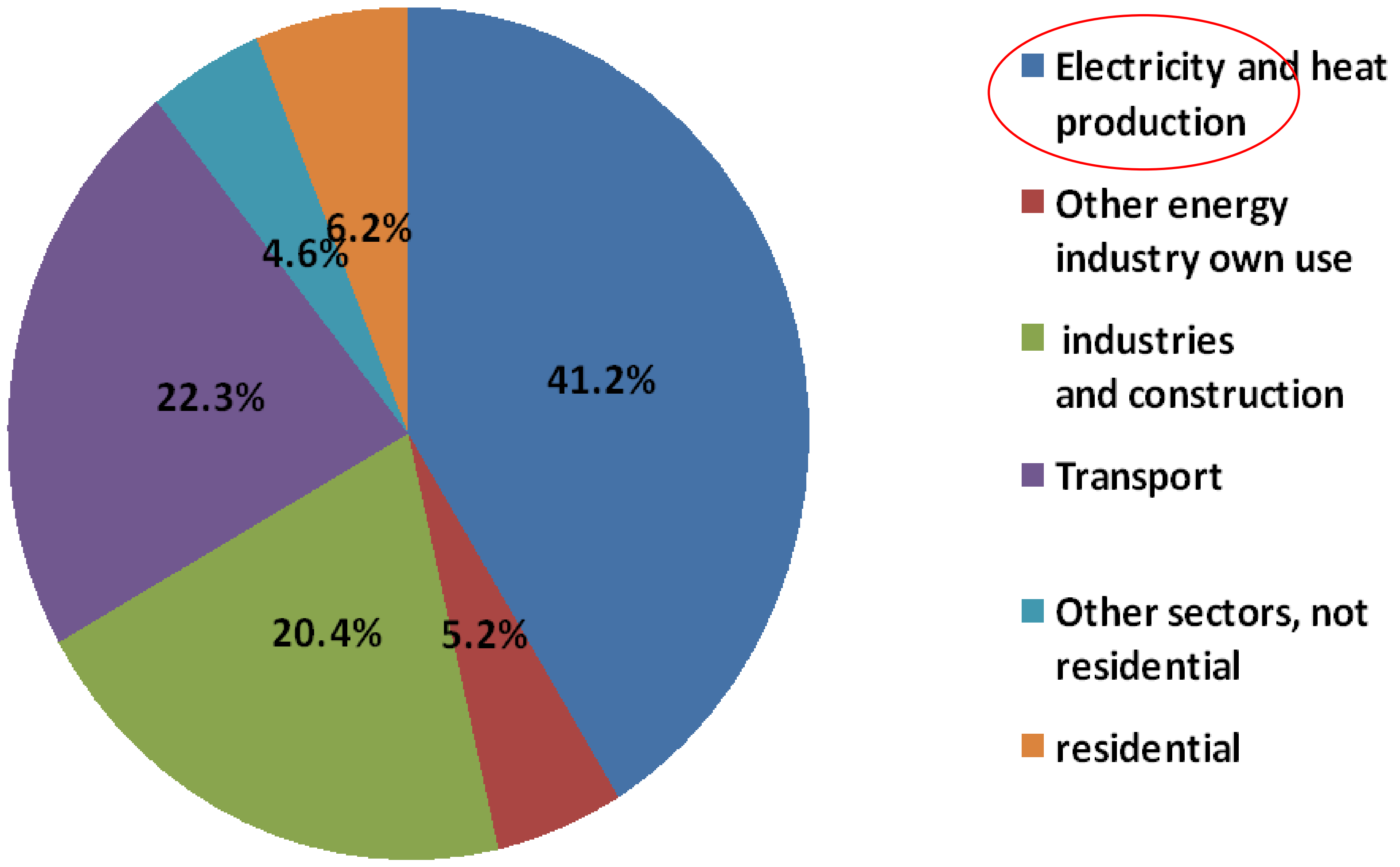
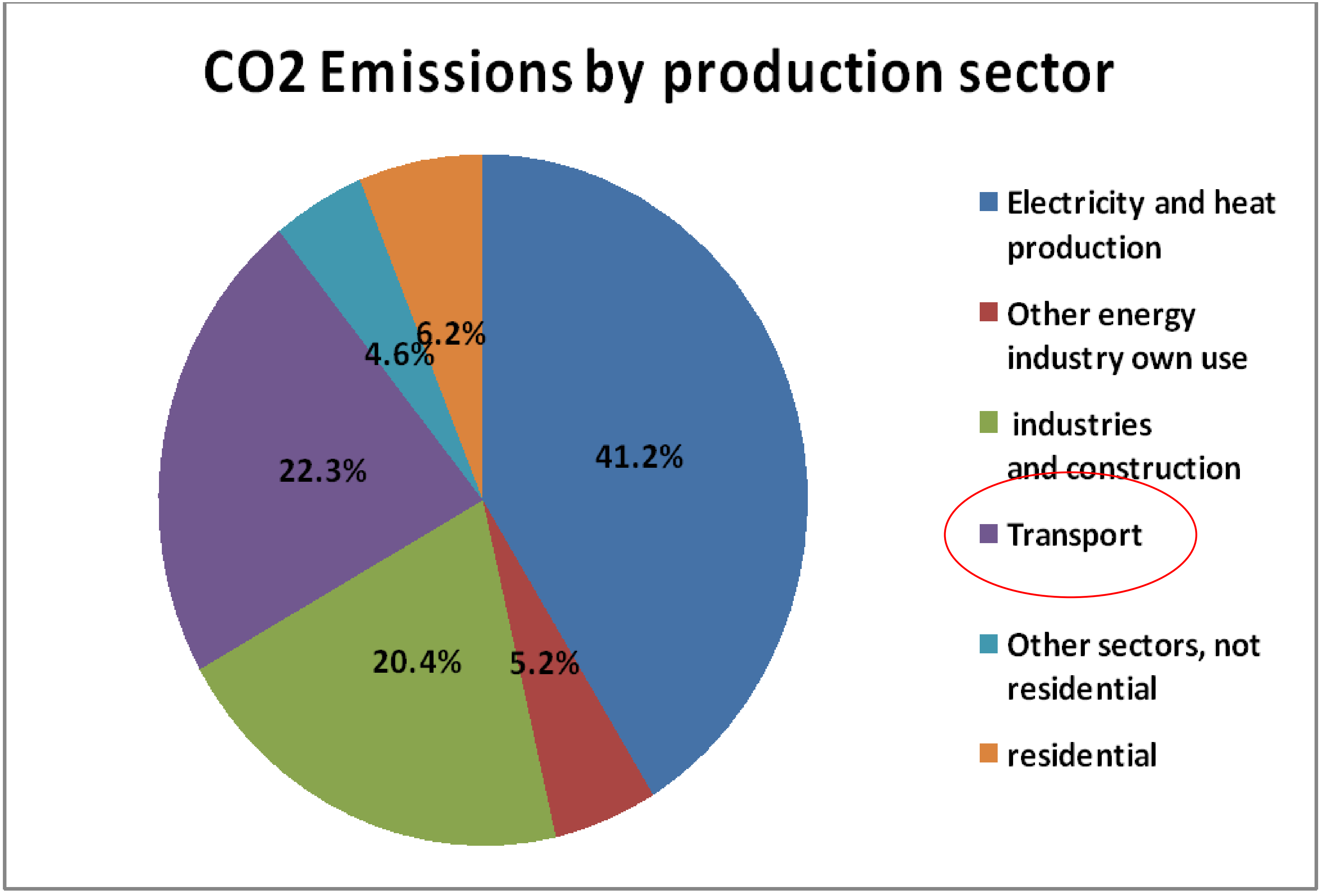


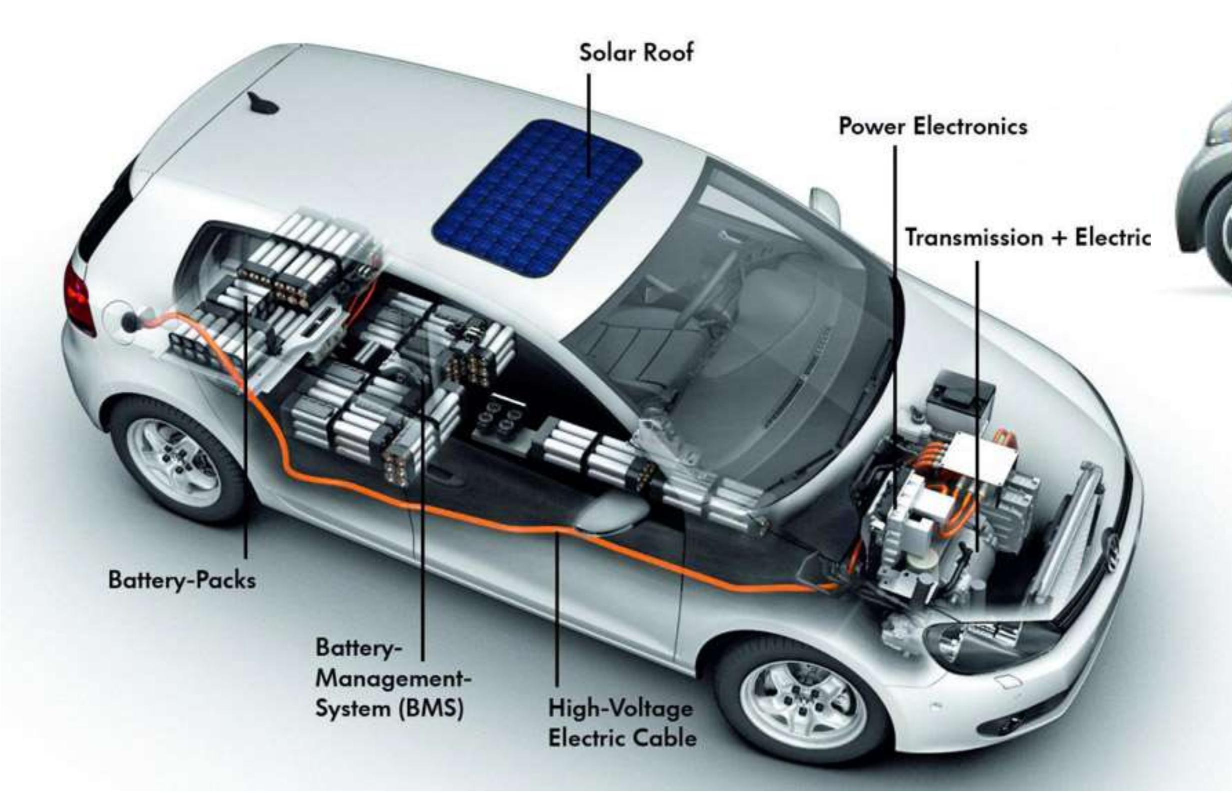
Figure 1: USA Energy-Related CO_2 Emissions Pathway by Sector, 2010-2050

CO2 Emissions by production sector

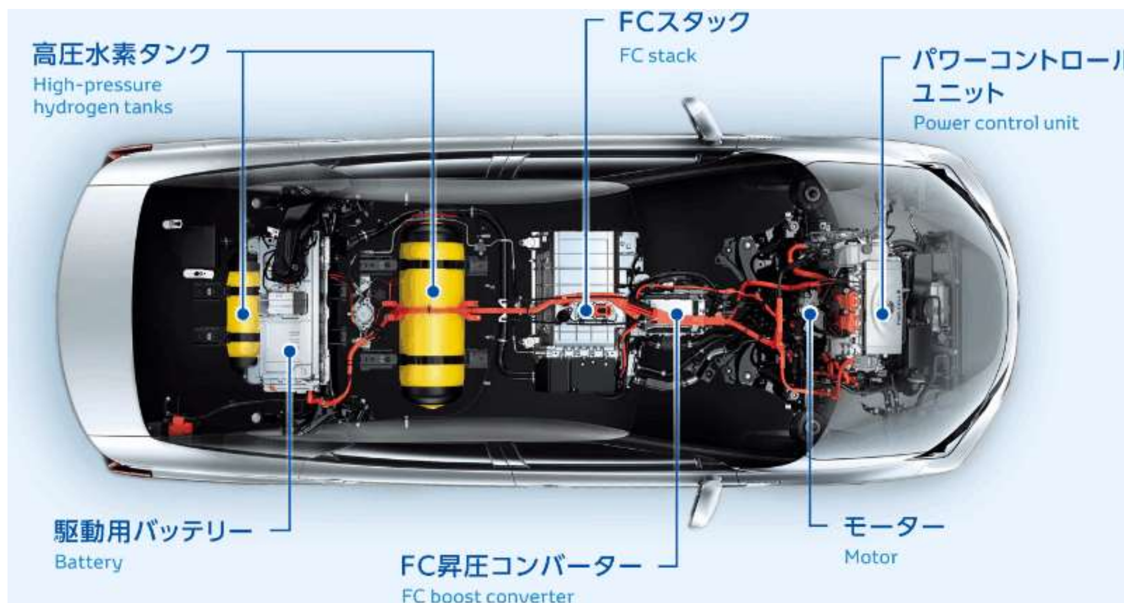


300W AC24V/12V Rare Earth WIND TURBINE GENERATOR PERMANENT MAGNET ALTERNATOR


CO2 Emissions by production sector
6.2%
4.6%
41.2%
22.3%
20.4%
5.2%
Electricity and heat production
Other energy industry own use
industries and construction
Transport
Other sectors, not residential
residential


Solar Roof
Power Electronics
Transmission + Electric
Battery-Packs
Battery-
Management-
System (BMS)
High-Voltage
Electric Cable


Hydrogen Station


高圧水素タンク
High-pressure
hydrogen tanks
FCスタック
FC stack
パワーコントロール
ユニット
Power control unit
駆動用バッテリー
Battery
FC昇圧コンバーター
FC boost converter
モーター
Motor

Environmental white paper, Japan

表5-3-1　60Wタイプ白熱電球をLED電球に置換した場合の比較

	白熱電球60W型	LED電球	比較
写真（注1）			
消費電力	54W	6.4W	約1／8に減（CO2排出量も約1／8に）
寿命	1,000時間	40,000時間	40倍
価格（注2）	100円	2,880円	約29倍
40,000時間利用時の電気代（注1）	47,520円	5,632円	41,888円の減
1年間のコスト（注3）	2,576円	426円	約1.3年で価格差を回収可能

注1：製品画像及び電力料金目安単価は、東芝ライテック社資料から引用

2：LED電球の価格は環境省調べ

3：年間2000時間使用した場合の年間電気代及び購入コスト。価格を寿命（時間）で割り、1時間当たりの電気代に上乗せして算出。

資料：環境省

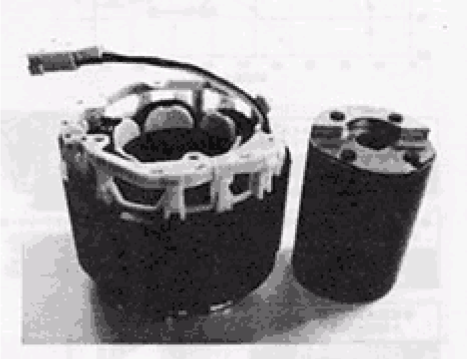
LED

神奈川県「EVシェアリングモデル事業」

写真提供：神奈川県

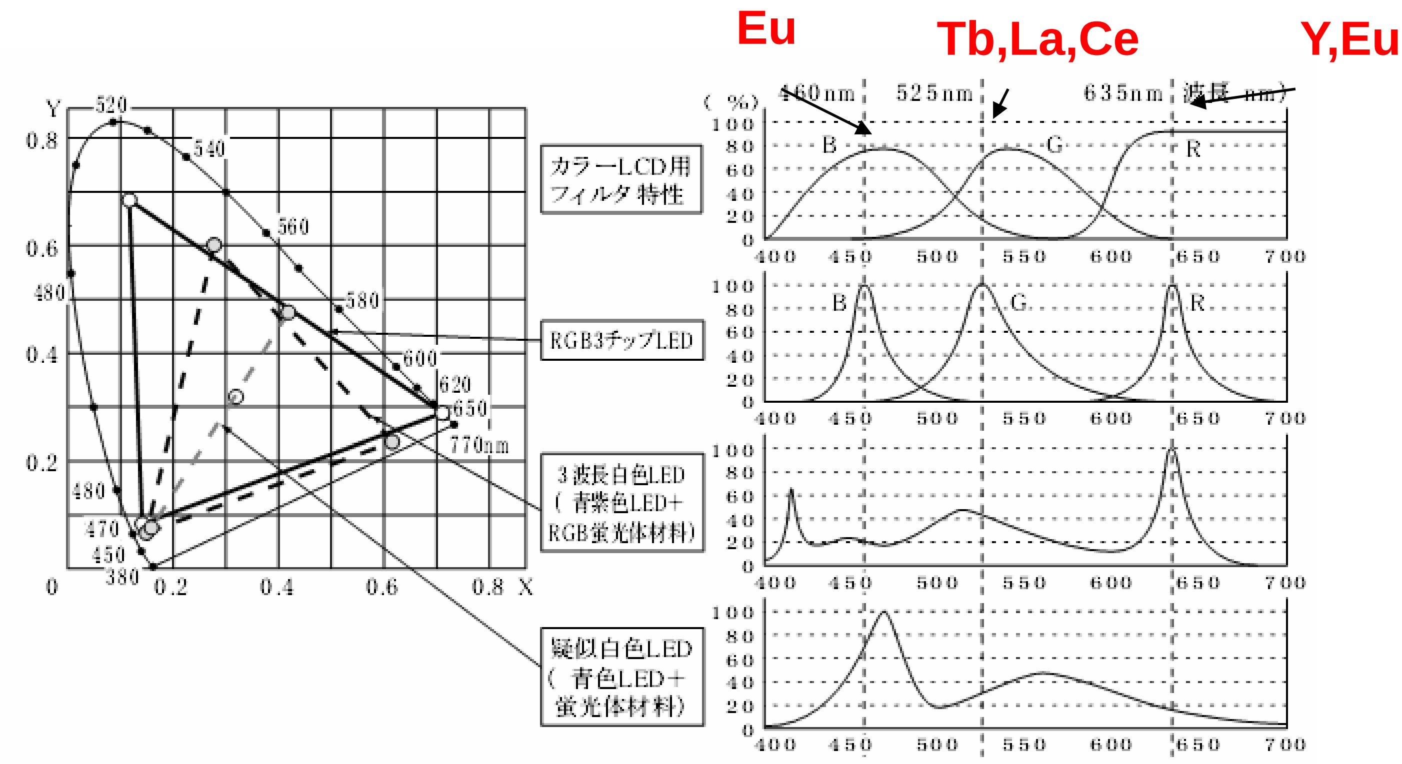
ネオジム磁石

Nd magnet

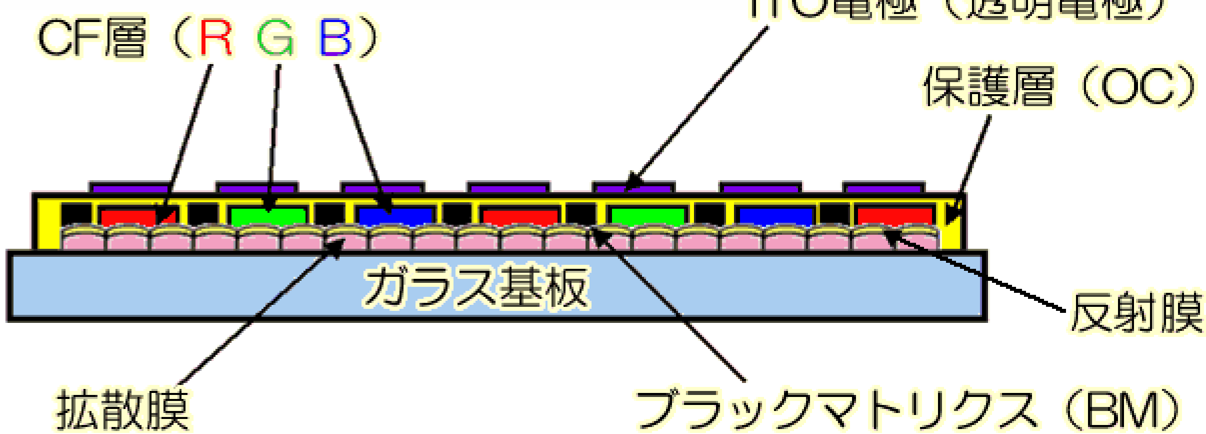


エアコン用DCモータ（東芝）

LED



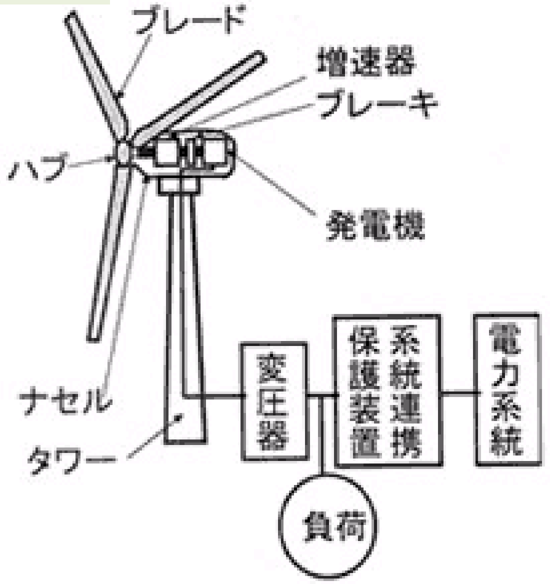
〈図1-A〉 色度図とLEDのタイプ別スペクトル特性



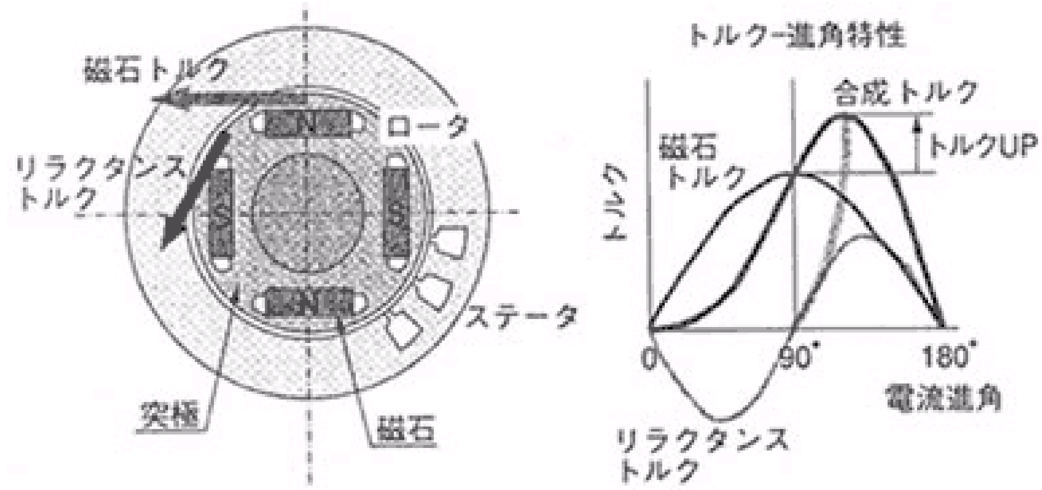
www.aisinc.co.jp/about_colorfilter_3.html

モーター

Ne, B, Dy, Sm, Co, Ni

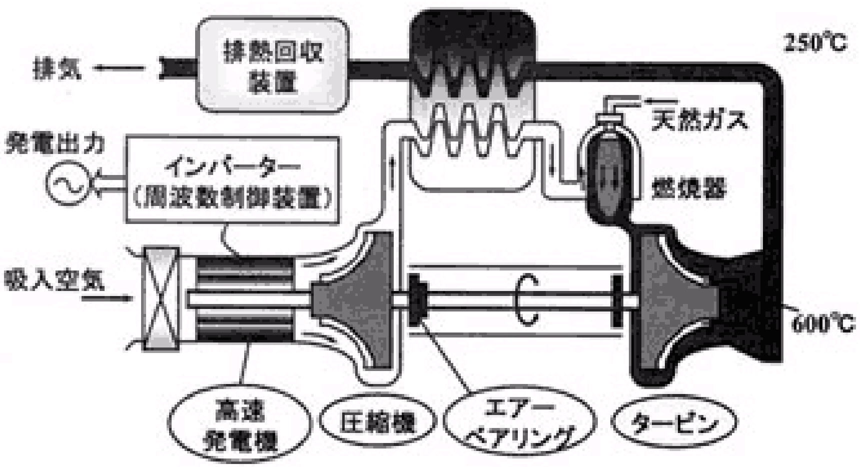


永久磁石発電機を使った風力発電



HEV

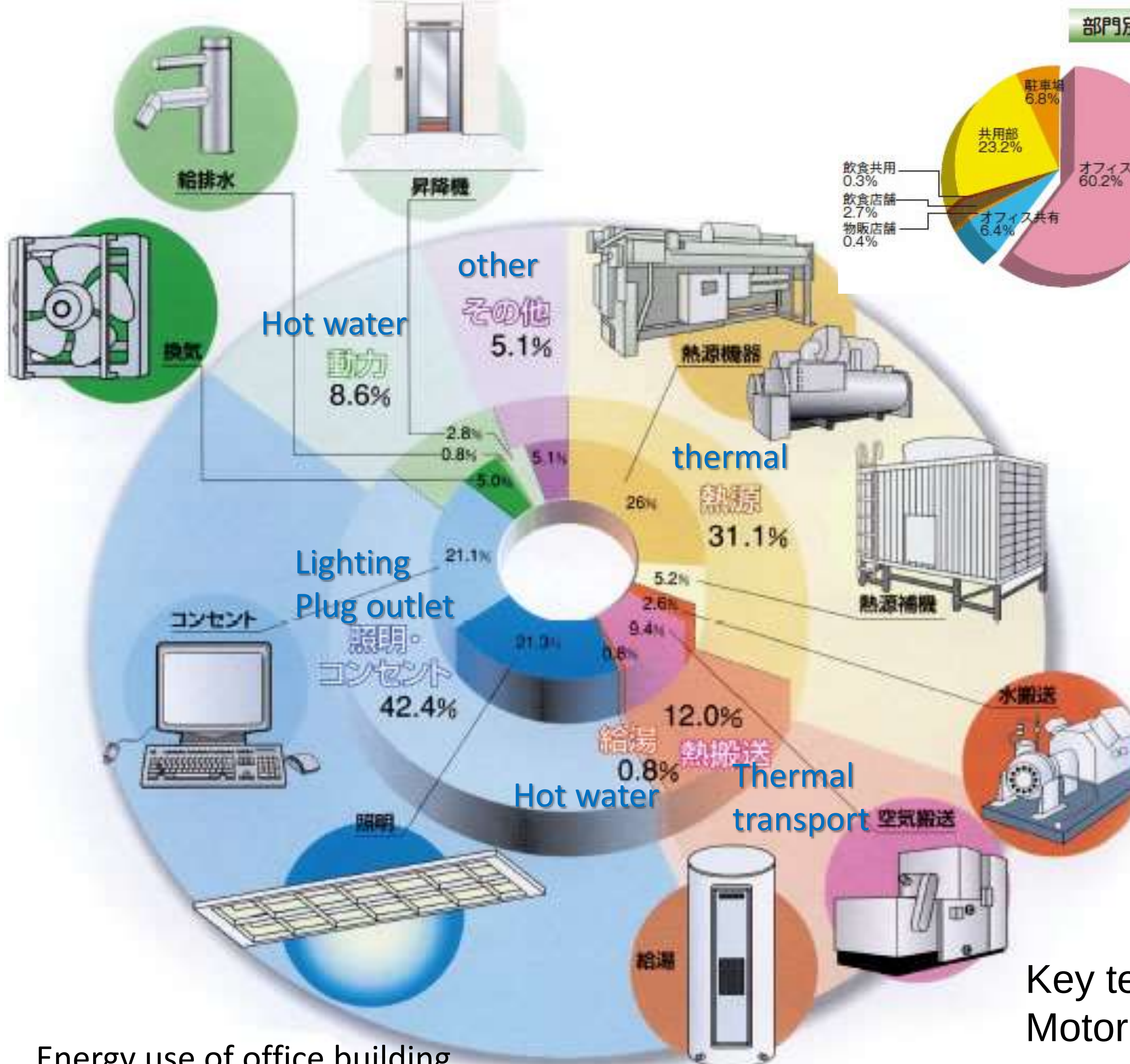
磁石トルクとリラクタンストルクを併用したプリウス用モータ

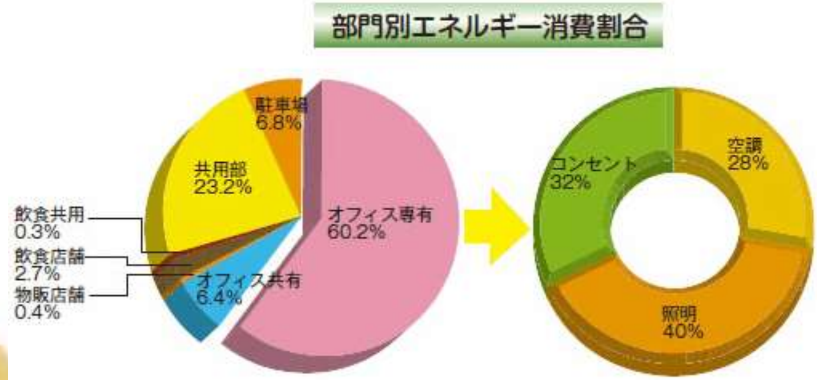


永久磁石発電機を使ったコジェネ発電システム

エアコン用DCモータ（東芝）

http://www.neomag.jp/magnet_history/history_28.html

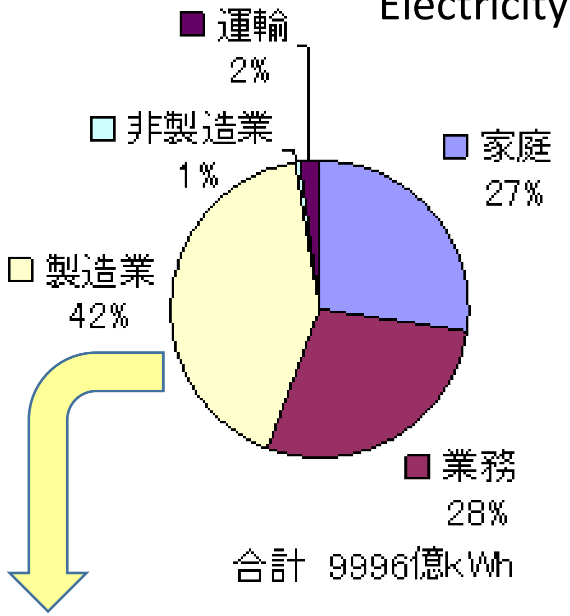




Key technologies are Motor and Lighting

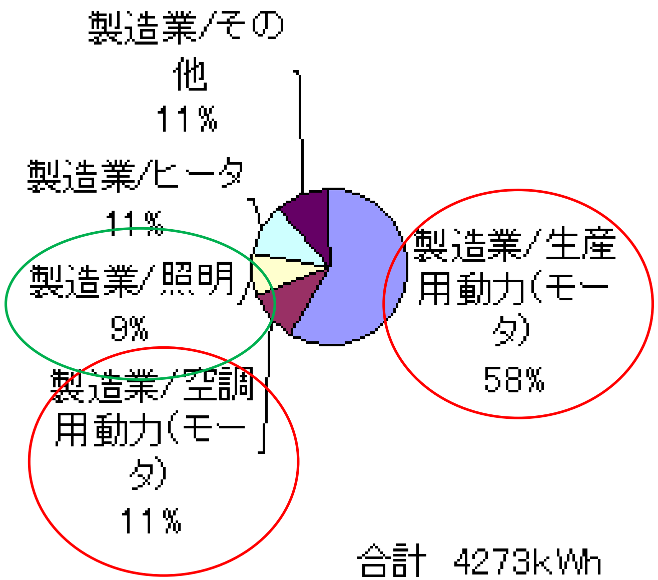
Energy use of office building

Electricity consumption in Japan



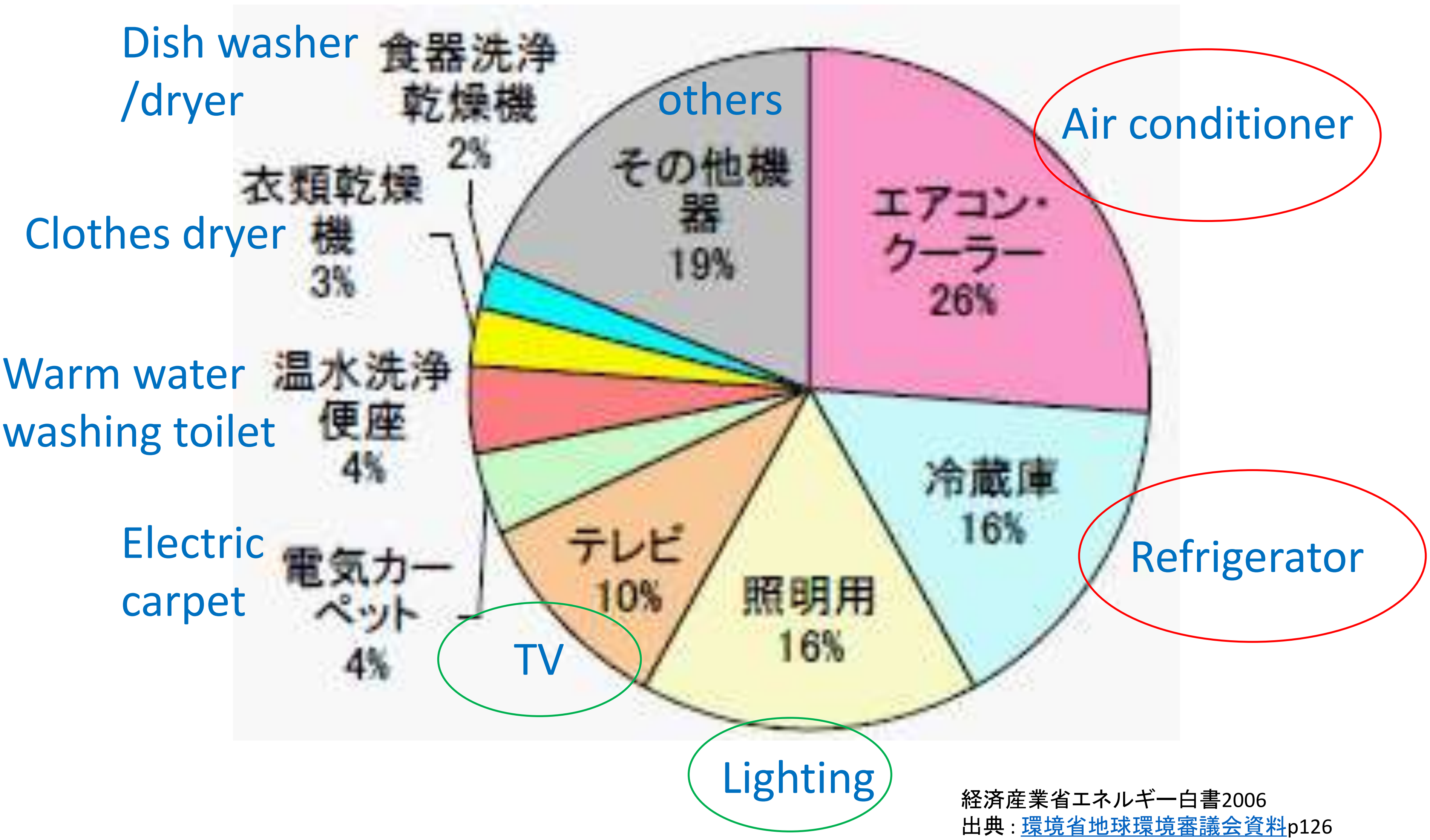
家庭	Residence
業務	Office
製造業	Manufacturing industry
非製造業	Nonmanufacturing industry
運輸	transportation

Electricity consumption of industry in Japan



製造業/生産用動力(モータ)	Motivity for production (motor)
製造業/空調用動力(モータ)	Motivity for air-conditioner (motor)
製造業/照明	Lighting
製造業/ヒータ	Heater
製造業/その他	others

Electricity consumption of residence in Japan

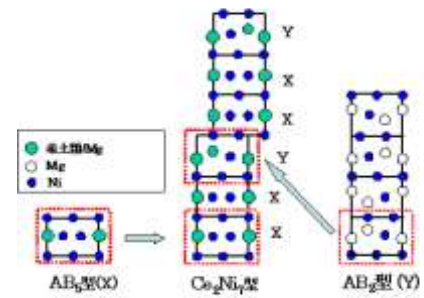


経済産業省エネルギー白書2006
出典：環境省地球環境審議会資料p126

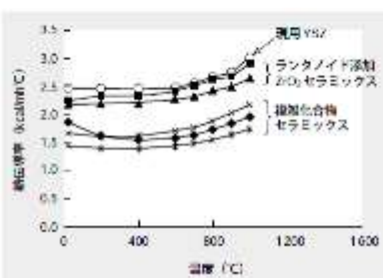
Material for Power Generation and Storage

Nd,Dy

La,Ce,Pr



La, Ce



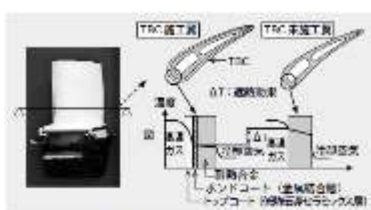


図12 TBCの遮熱効果

Y,La,Gd

Ce,Gd

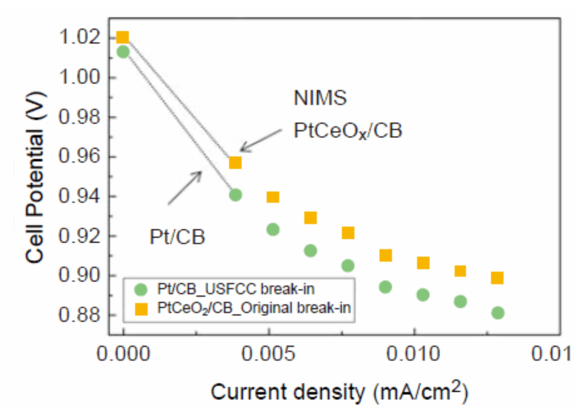
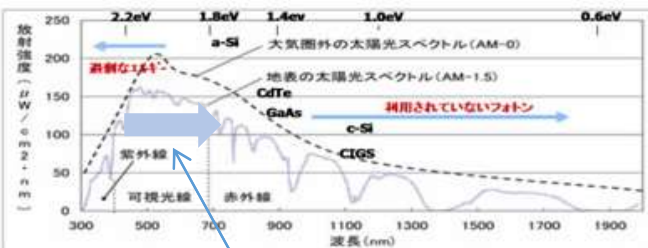
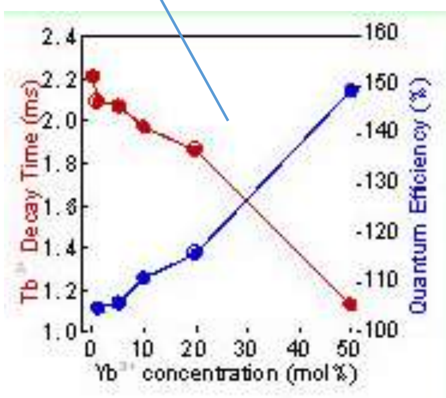
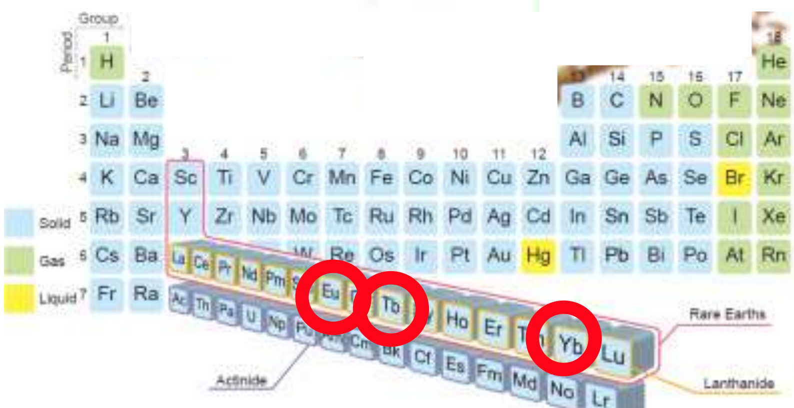


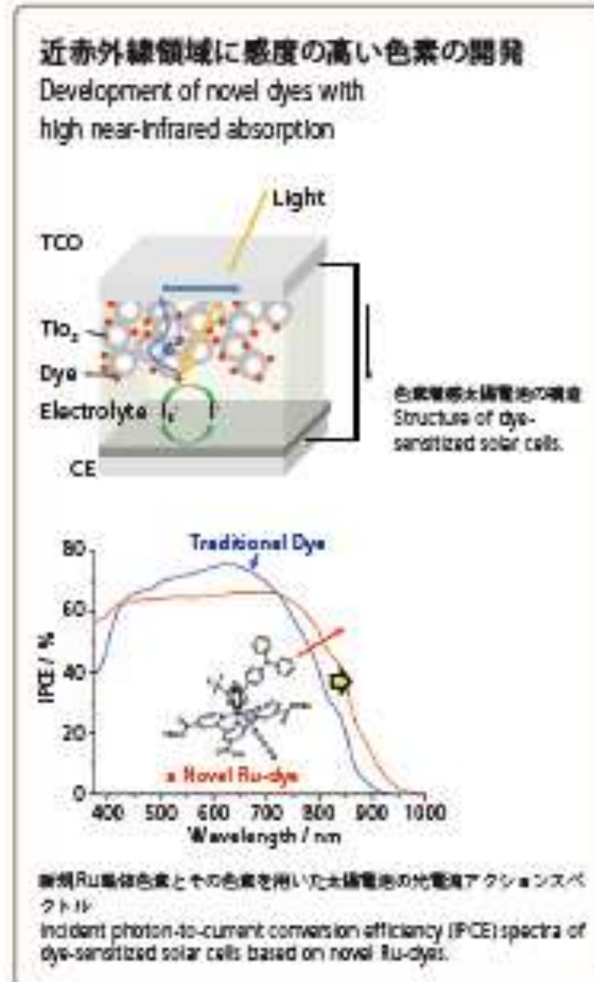
Fig.1 Comparison of generating performance using a NIMS-developed Pt-ceria cathode and an commercial Pt cathode.

Next generation photovoltaics

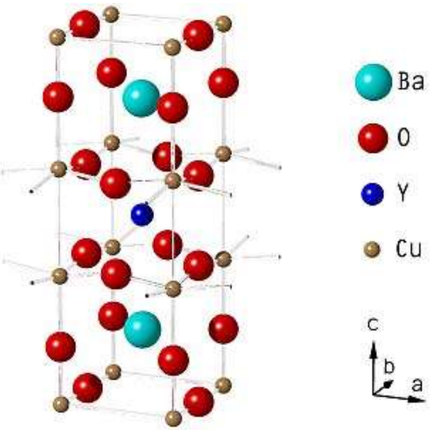


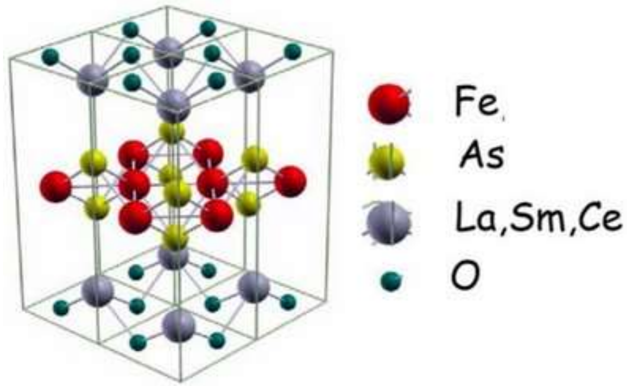


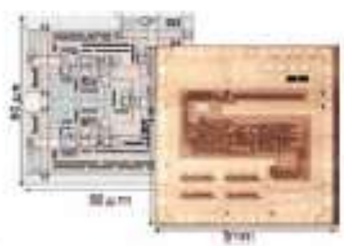


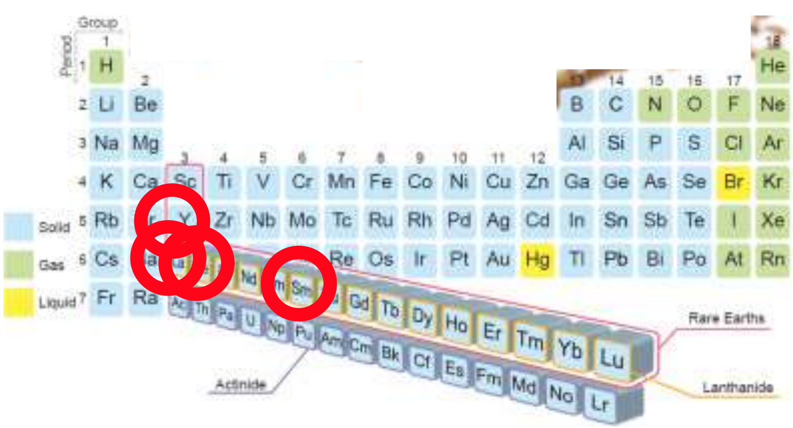


Basic Research on Superconductive towards energy saving









Next-Generation Refrigeration “Magnetic Refrigeration”

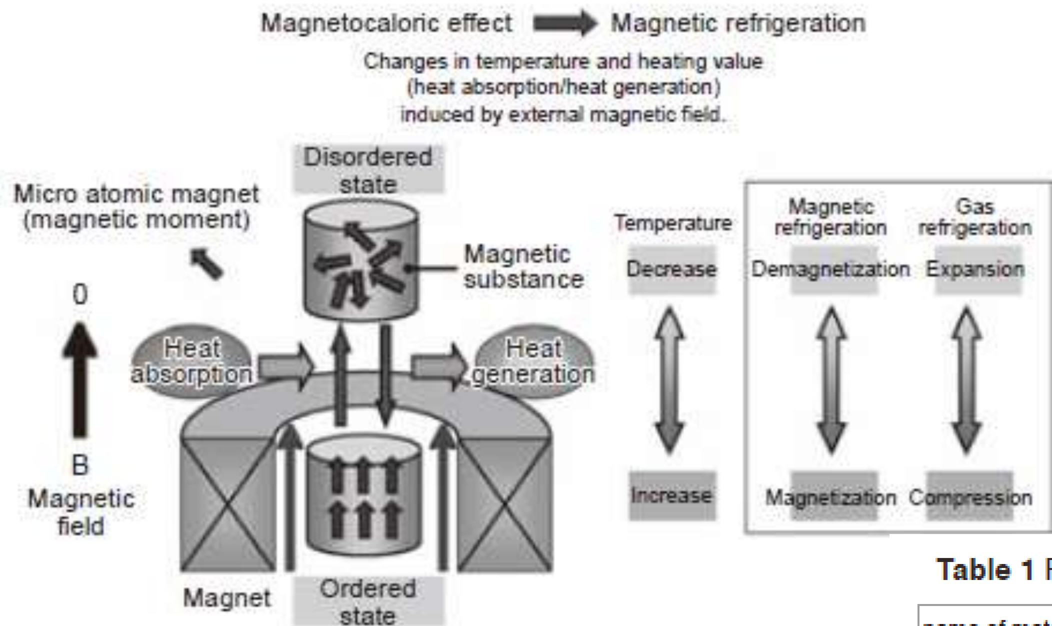


Fig.1 Principle of the magnetocaloric effect

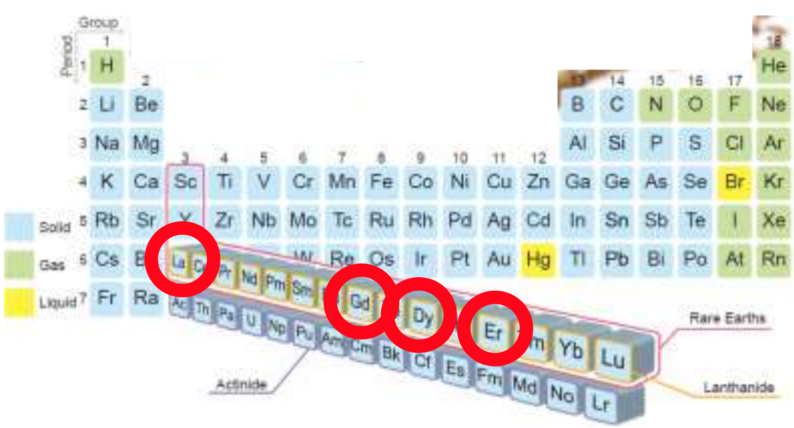
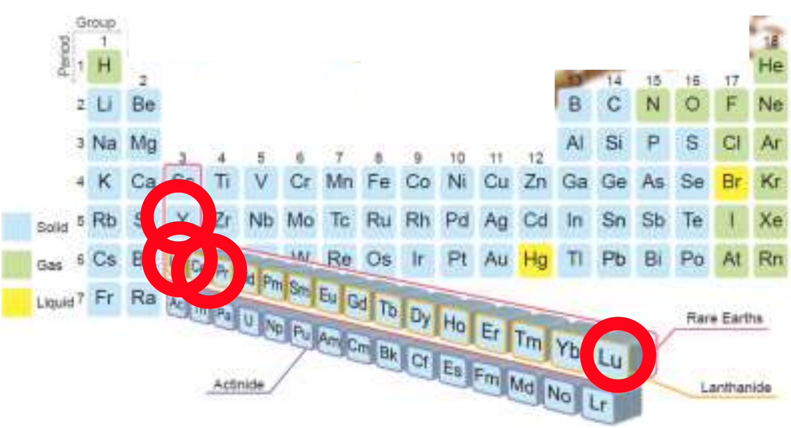


Table 1 Representative examples of magnetic refrigeration materials.

name of material (= Abbreviation)	Magnetic transition temperature	Refrigeration cycle
$CrK(SO_4)_2 \cdot 12H_2O$ = CPA	0.009	Carnot
$FeNH_4(SO_4)_2 \cdot 12H_2O$ = FAA	0.026	Carnot
$Gd_3Ga_5O_{12}$ = GGG	0.85*	Carnot
$Dy_3Al_5O_{12}$ = DAG	2.4	Carnot
$ErAl_2$	12	AMR
GdPd	38	AMR
$DyAl_2$	63	AMR
$GdNi_2$	71	AMR
$Gd_5Si_{0.9}Ge_{3.1}$	120	AMR
$Gd_5Si_2Ge_2$	260	AMR
Gd	293	AMR
$La(Fe_xSi_{01-x})_{13}H_y$	280	AMR
MnAs	315	AMR

New materials enable more efficient use of thermal energy

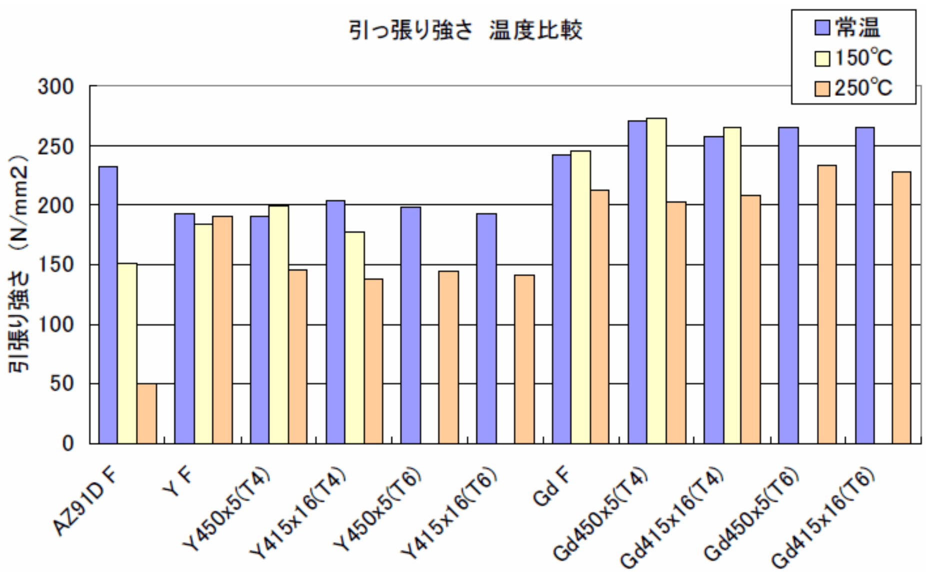
Outokumpu steel name	International steel No EN	International steel No ASTM/UNS	Typical chemical composition % C max	N	Cr	Ni	Si	Others	Maximum service temperature in dry air, °C
4948	1.4948	304H	0.05	–	18.1	8.3	–	–	800
4878	1.4878	321H	0.05	–	17.3	9.1	–	Ti	800
153 MA™	1.4818	S30415	0.05	0.15	18.5	9.5	1.3	Ce	1000
4828	1.4828	–	0.04	–	20	12	2	–	1000
4833	1.4833	309S	0.06	–	22.3	12.6	–	–	1000
253 MA®	1.4835	S30815	0.09	0.17	21	11	1.6	Ce	1100
4841	1.4841	314	0.07	–	25	20	1.7	–	1100
4845	1.4845	310S	0.05	–	25	20	–	–	1125
353 MA®	1.4854	S35315	0.05	0.17	25	35	1.3	Ce	1150



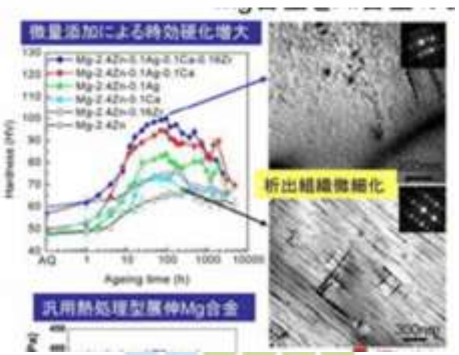
航空機用ジェットエンジン
Jet engine

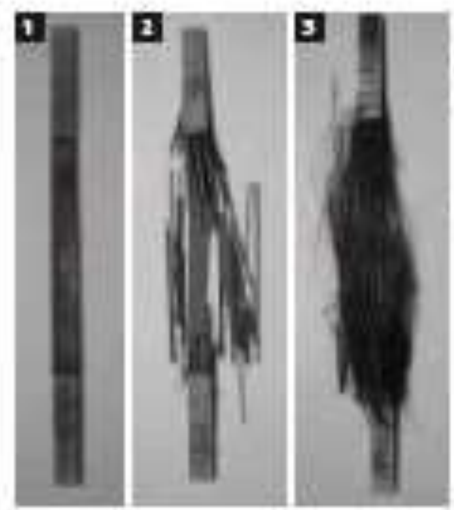
発電プラント
Power Plant

Light-weight high-performance hybrid materials



新しいコンセプトに基づく高信頼性自動車
New concept for high reliable automobiles





1 破壊前
before testing
2 破壊後（従来）
after testing
(conventional hybrid)
3 破壊後（開発品）
after testing
(developed hybrid)

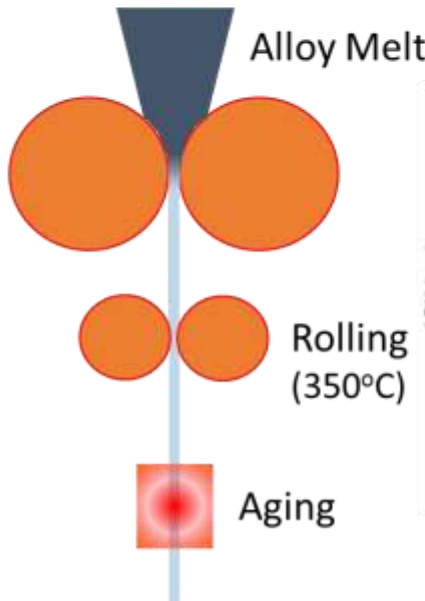
界面性状制御により、破壊（衝撃）エネルギー吸収能力の高い複合材料を実現
Composite materials with high fracture (impact) energy absorbing will be developed by the interface (strength/shape, etc.) control.

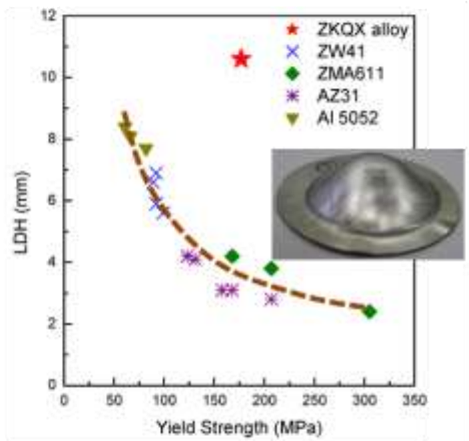
Substitution Gd

Breakthrough in RE-free Wrought Mg Alloy

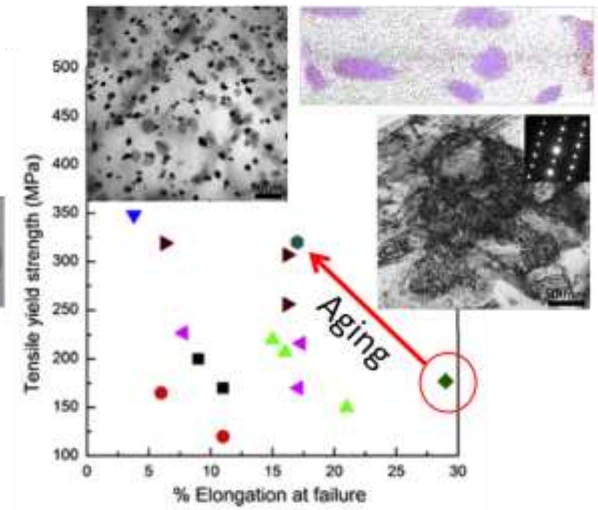
Strip Casting for Cost Reduction

RE-free Low Cost Mg-Zn-Ca-Ag-Zr alloy





Excellent formability in Strip cast & rolled sheet



Achieving high strength by aging

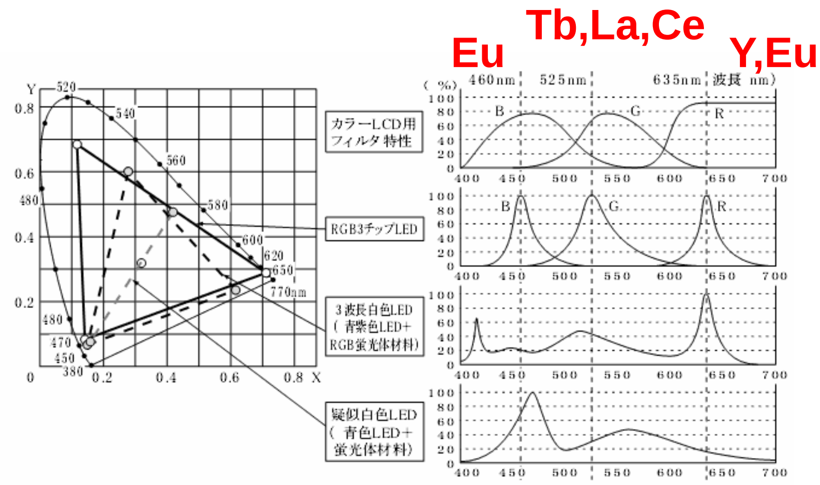
Development of Industrially Viable Wrought Mg alloy

- ***Excellent room temperature formability* like Al alloys**
- ***High strength achievable* by nanostructure modification.**

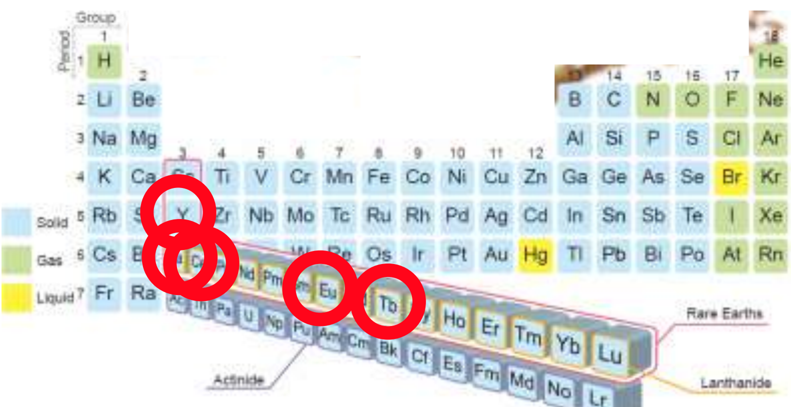
Research Achievement

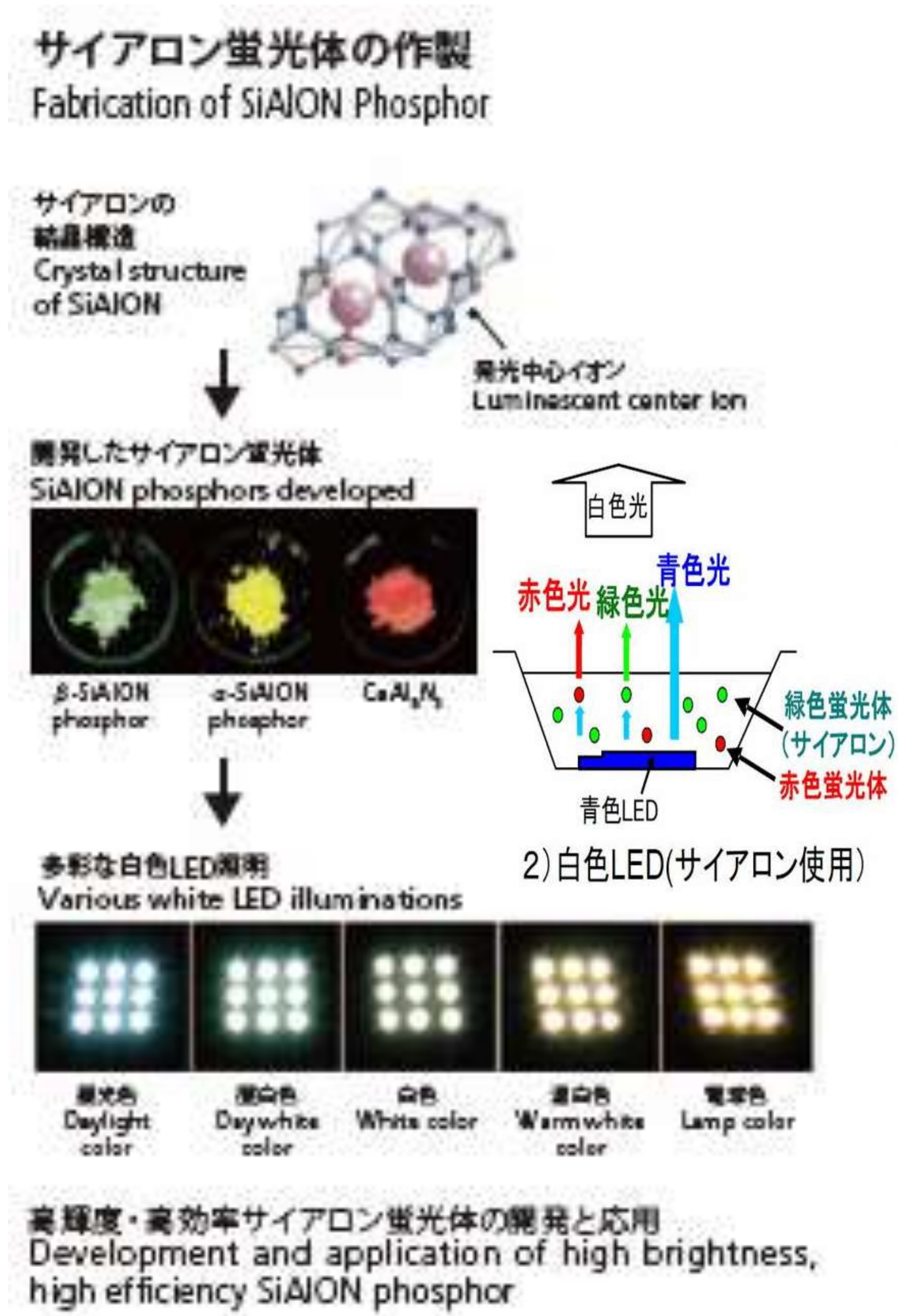
C. L. Mendis et al., Scripta Mater. 64 (2011) 335-338.

Wide-band-gap materials for optics and electronics



〈図1-A〉色度図とLEDのタイプ別スペクトル特性





Sialon Fluorescent Material
with High Brightness and High Efficiency

Research impact

Durable phosphors have been developed by introducing the luminescent ions such as Eu into the crystal of SiAlONs.

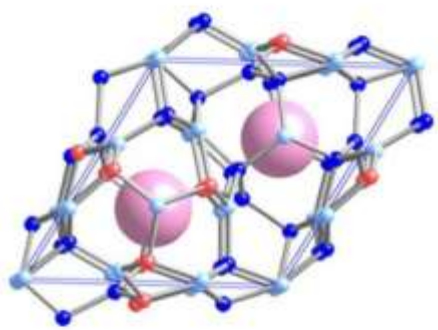


Fig.1 SiAlON crystals

Fig.2 SiAlON Phosphor

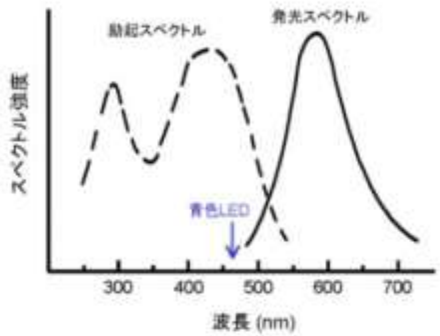


Fig. 3 Luminescence property

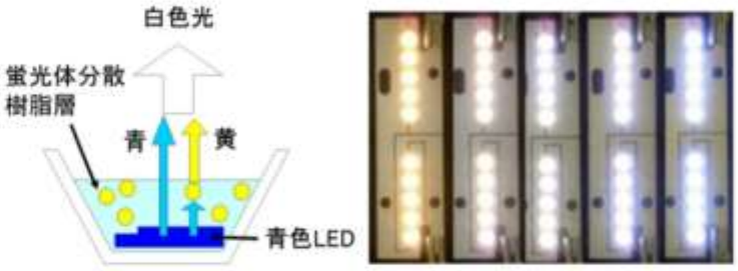
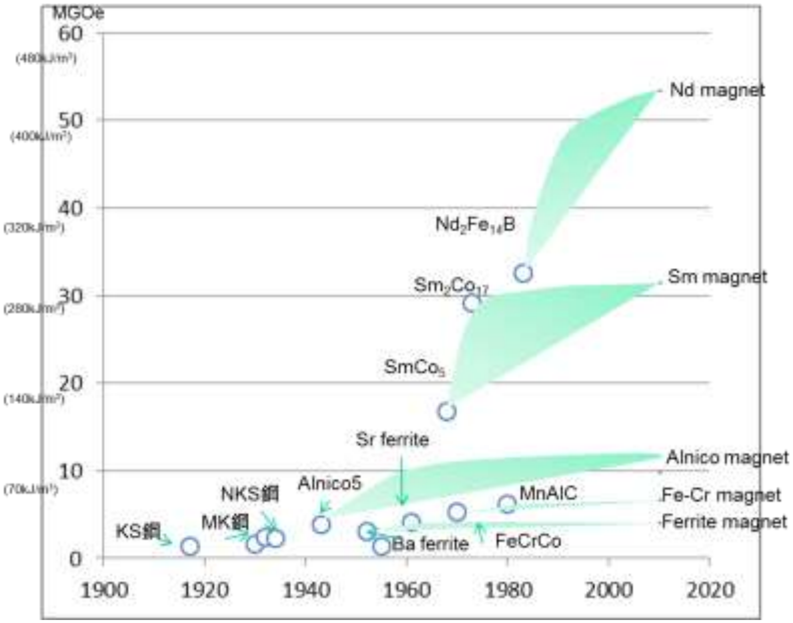


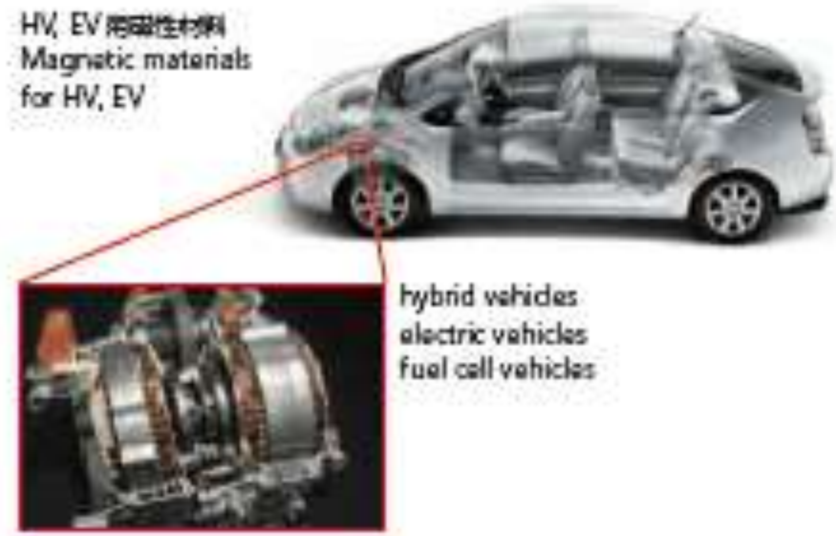
Fig.4 Principle of white LED

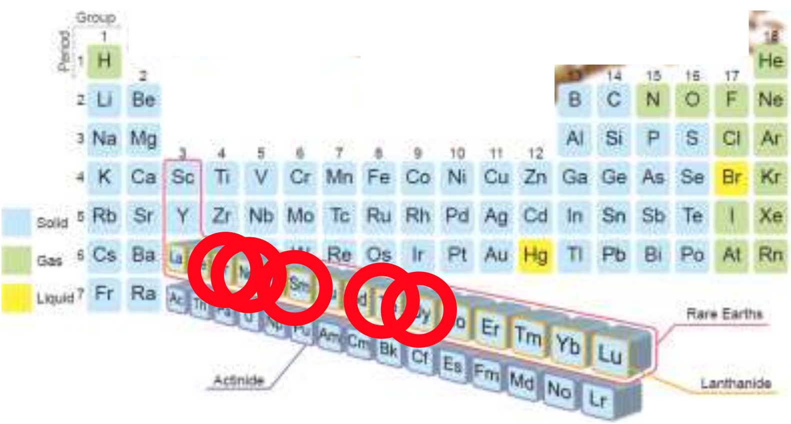
- **Superior to durability and high temperature stability**
- **Excitation by blue LED**

Efficent use of REE

Energy efficient Magnetic Material





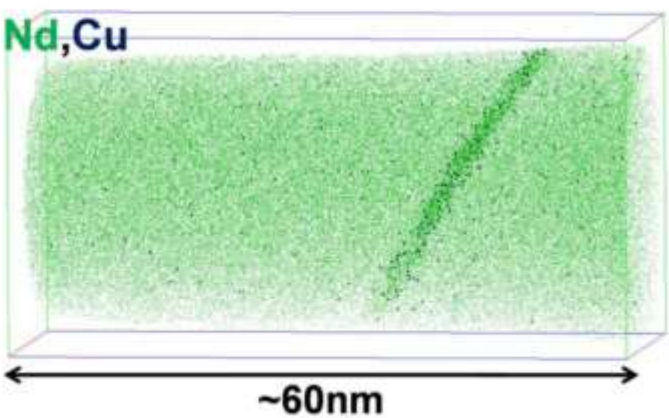


HDD

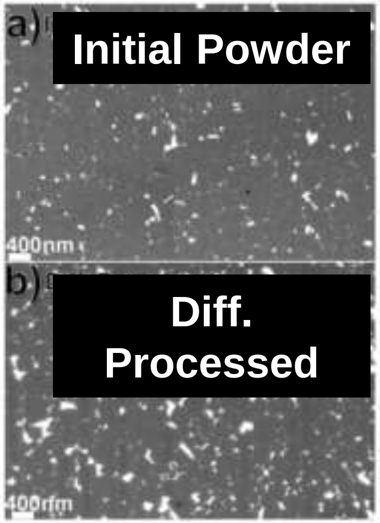
Neodymium Magnet without Dysprosium

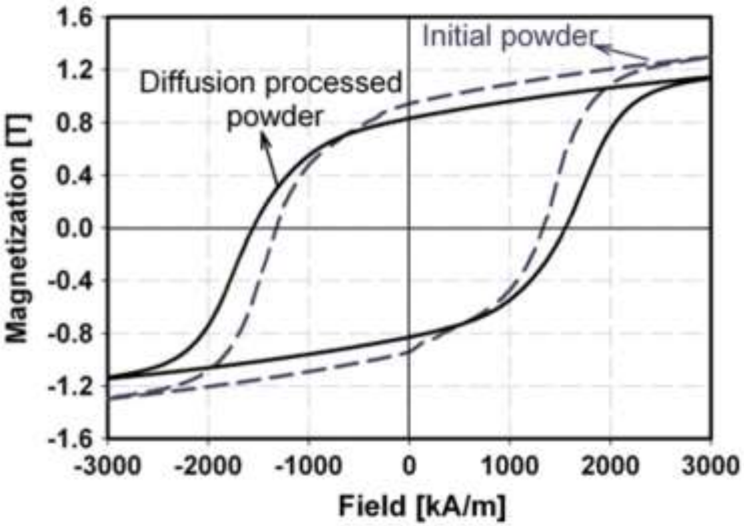
Research impact

- A method for increasing the coercivity of neodymium magnet powder without using dysprosium
- Thickening of the Nd-rich grain boundary phase could be attributed to the coercivity enhancement.



3DAP map of Nd and Cu of the diffusion processed sample





- The systematic nanostructure analysis of existing neodymium magnets using 3D Atom Probe reveals that the coercivity can be improved by decoupling the ferromagnetic interactions between the crystal grains.

REE free

Scripta Materialia, 63, 1124 (2010)

Resource Efficiency and the 3Rs

Achieving the sustainable management and efficient use of resources is addressed in the 2030 Agenda and is crucial for the protection of the environment, climate and planet. Having in mind the importance of sustainable materials management and material cycle societies, we endorse the *Toyama Framework on Material Cycles*. This new framework provides a common vision and a guide for future actions to deepen our efforts on resource efficiency and the 3Rs (Reduce, Reuse, Recycle). We will continue to cooperate through the G7 Alliance on Resource Efficiency. We will work with business and other stakeholders to improve resource efficiency with the aim of also fostering innovation, competitiveness, economic growth and job creation. We encourage all countries to join us in these efforts.

We reaffirm our commitment to address marine litter, recognizing that our efforts on resource efficiency and the 3Rs also contribute to the prevention and reduction of marine litter, particularly plastic, from land-based sources. Furthermore, we support scientific work to enhance global ocean observation and assessment for the science-based management, conservation and sustainable use of marine resources.

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NATURE | COMMENT

The circular economy

Walter R. Stahel

23 March 2016

A new relationship with our goods and materials would save resources and energy and create local jobs, explains Walter R. Stahel.

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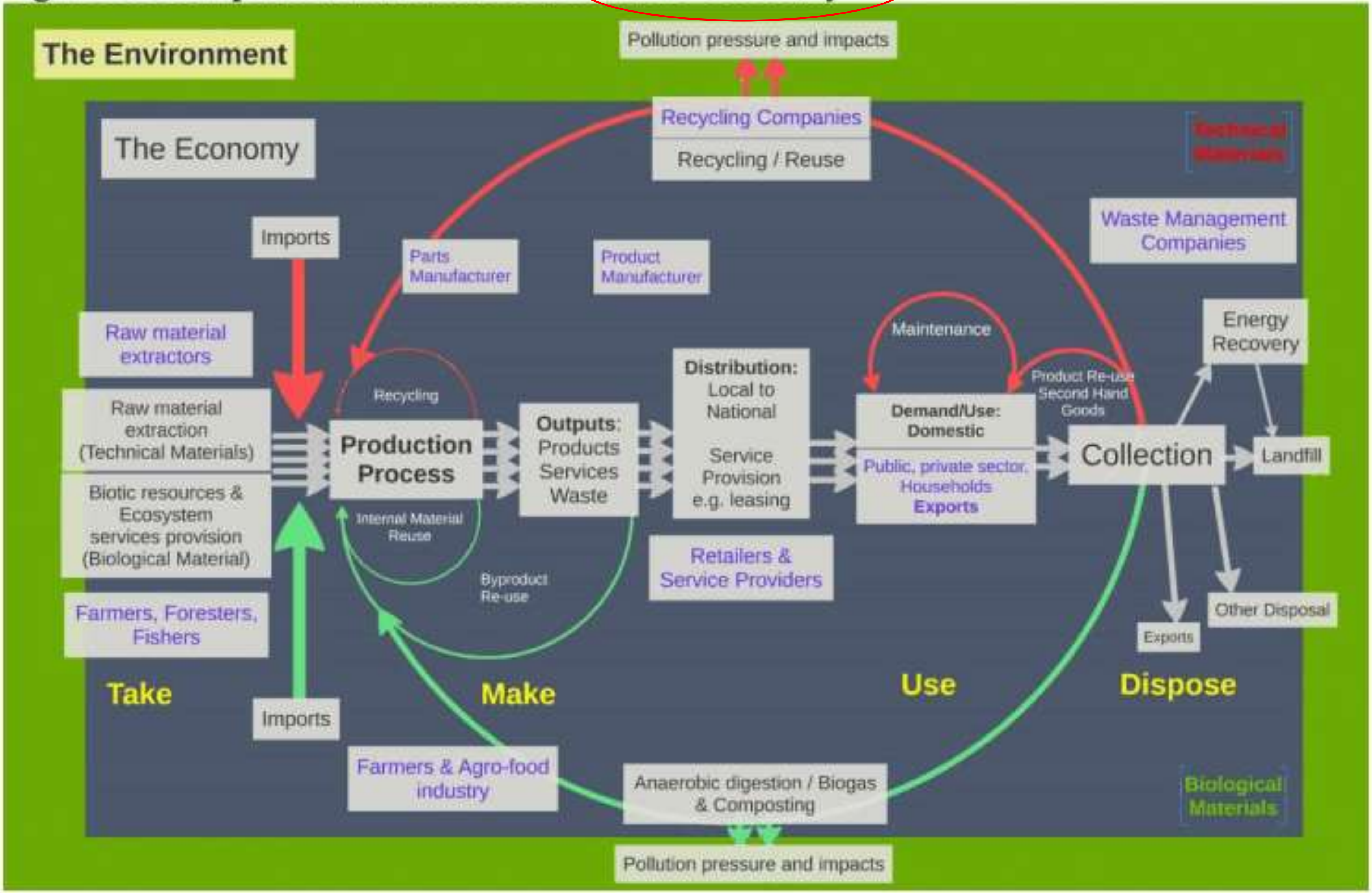
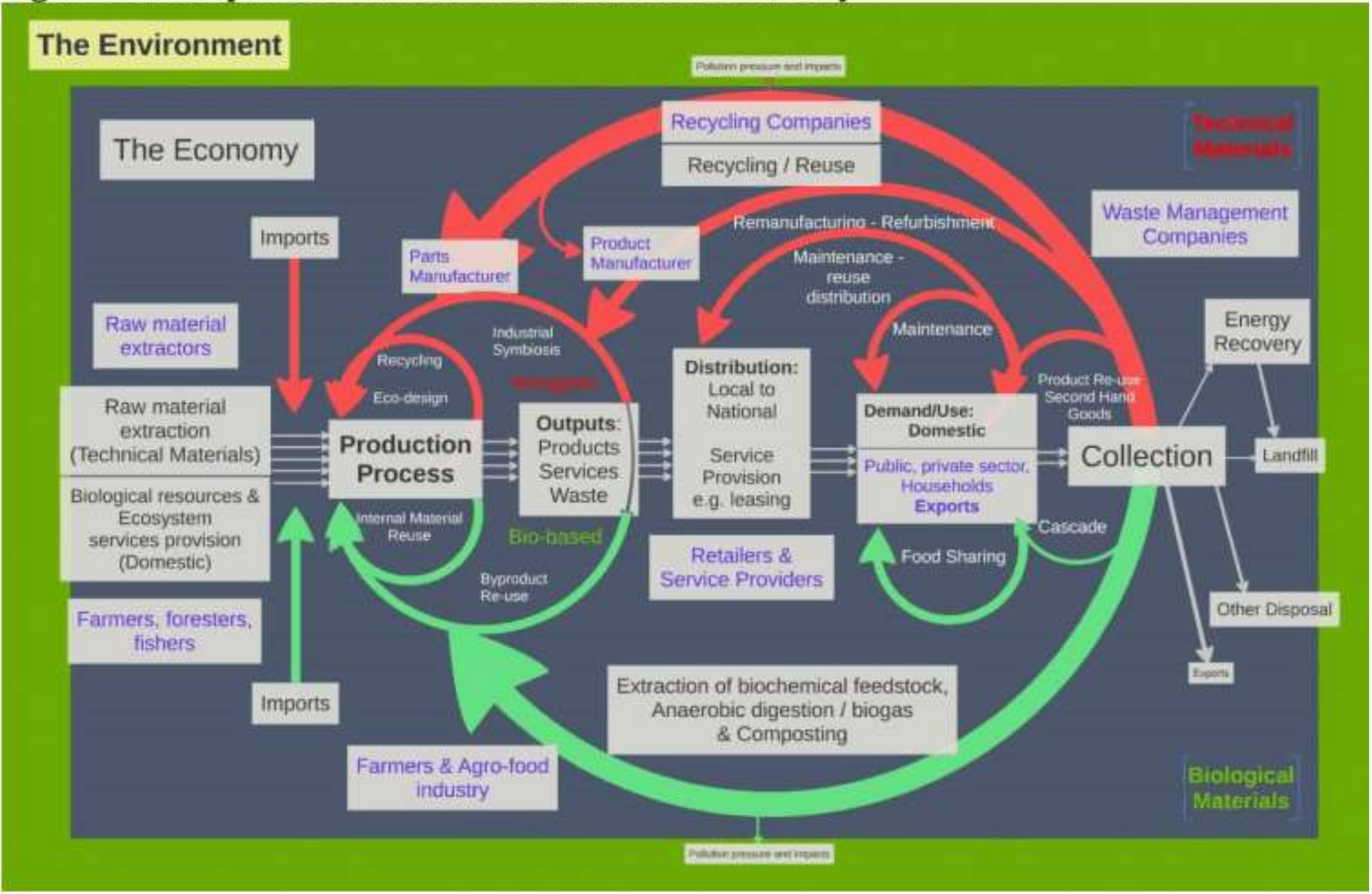
Subject terms: Economics · Society · Materials science · Policy

Figure E1: Simplified illustration of a linear economy

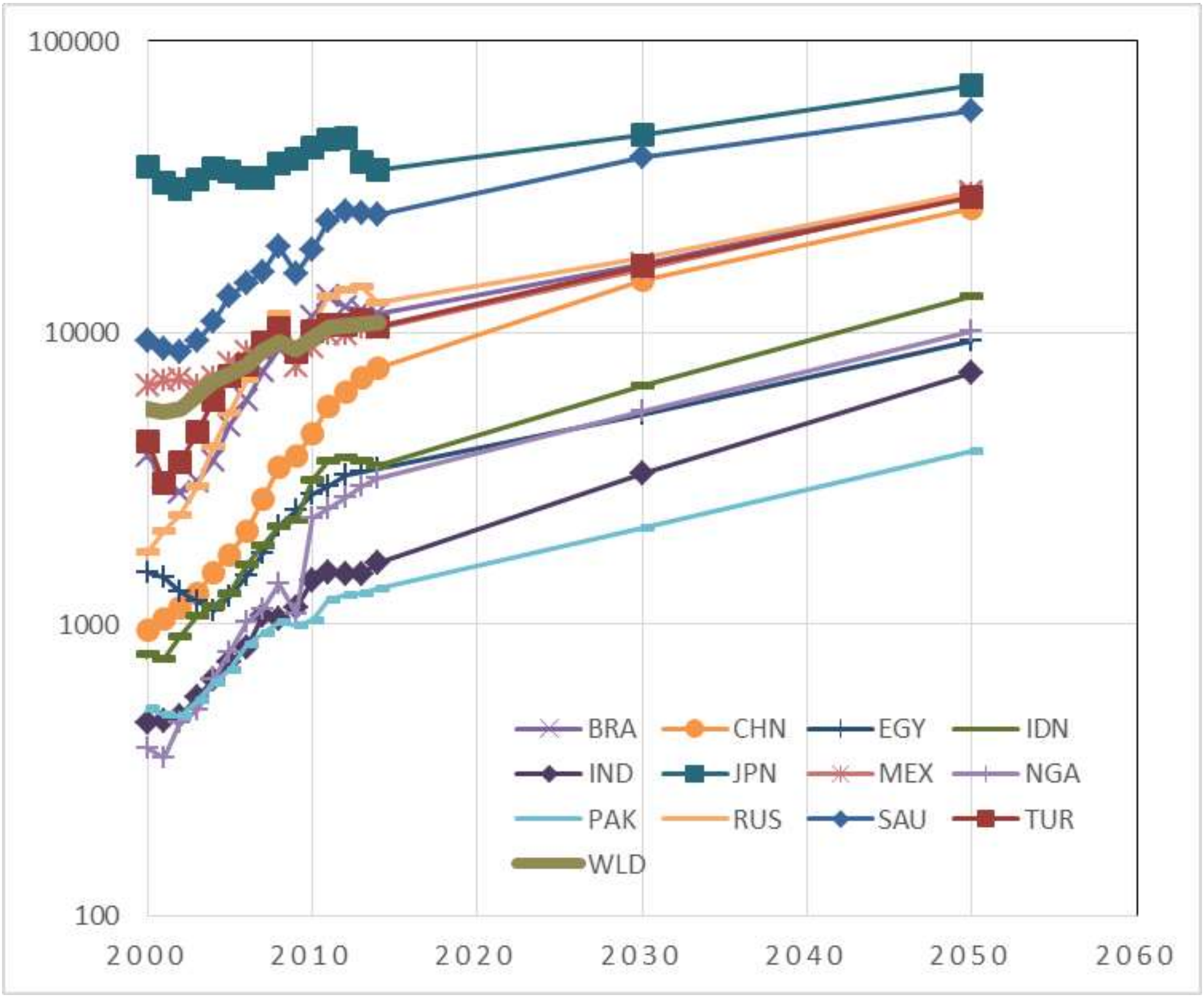


Source: Own representation, P ten Brink, P Razzini, S. Withana and E. van Dijl (IEEP), 2014

Figure E2: Simplified illustration of a circular economy



Source: Own representation, P ten Brink, P Razzini, S. Withana and E. van Dijl (IEEP), 2014


100000
10000
1000
100
2000
2010
2020
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2040
2050
2060
BRA
CHN
EGY
IDN
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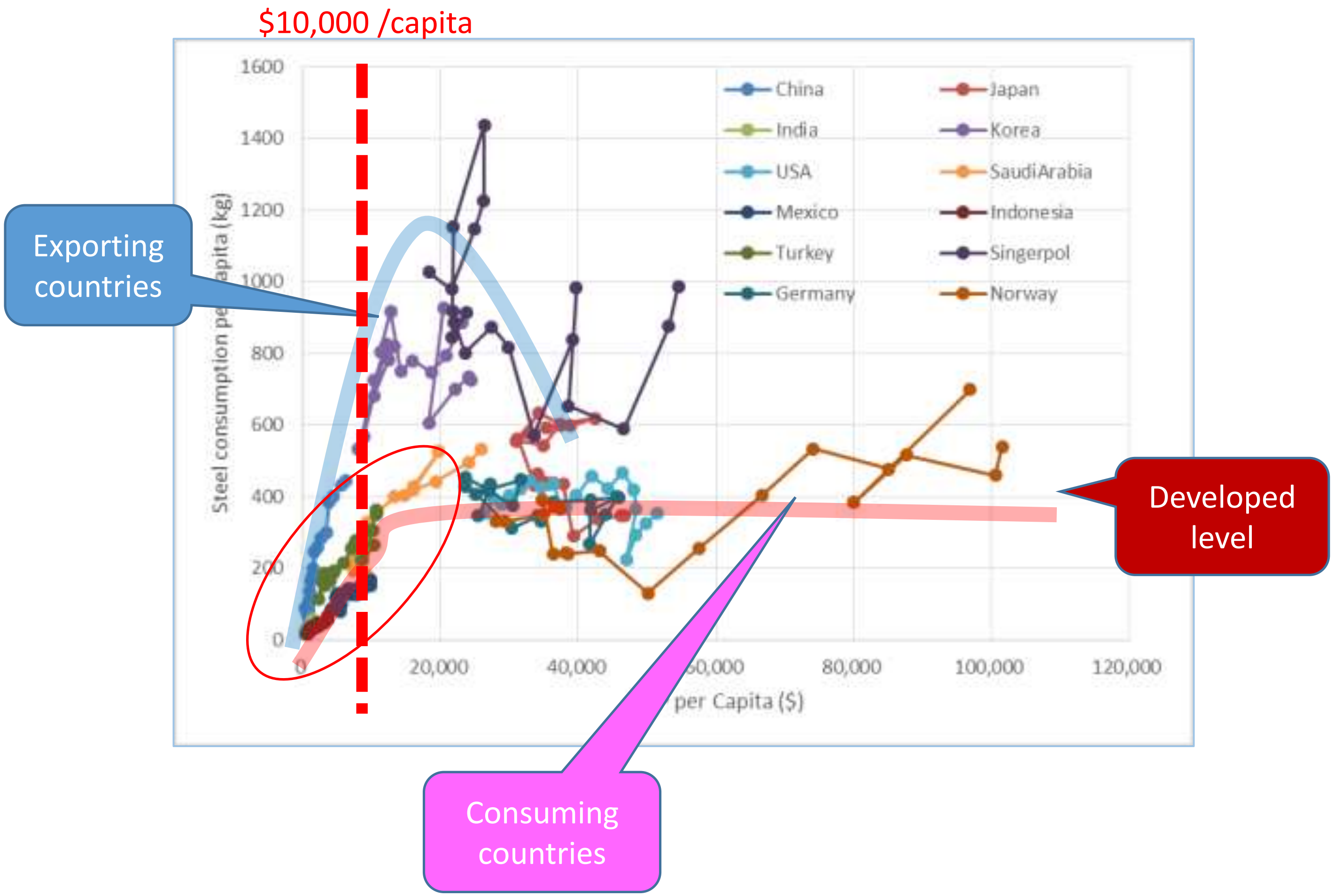
JPN
MEX
NGA
PAK
RUS
SAU
TUR
WLD

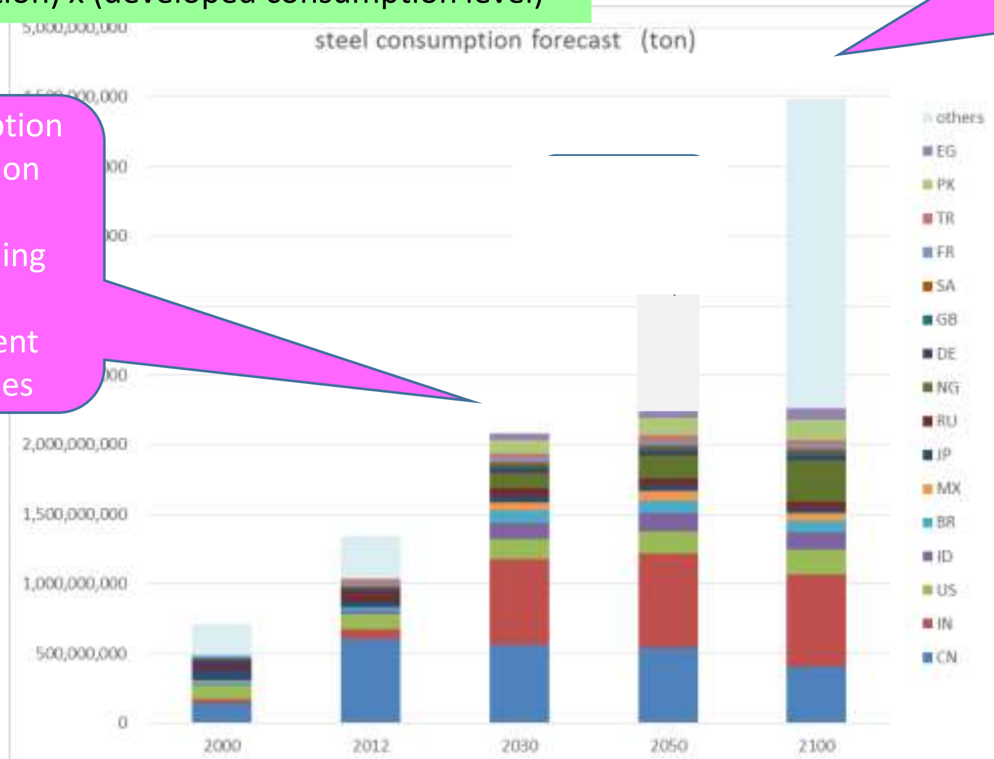
Fe consumption / capita v.s. GDP/ capita from 1994 to 2014



Rough forecast gets to be simpler,
(population) x (developed consumption level)

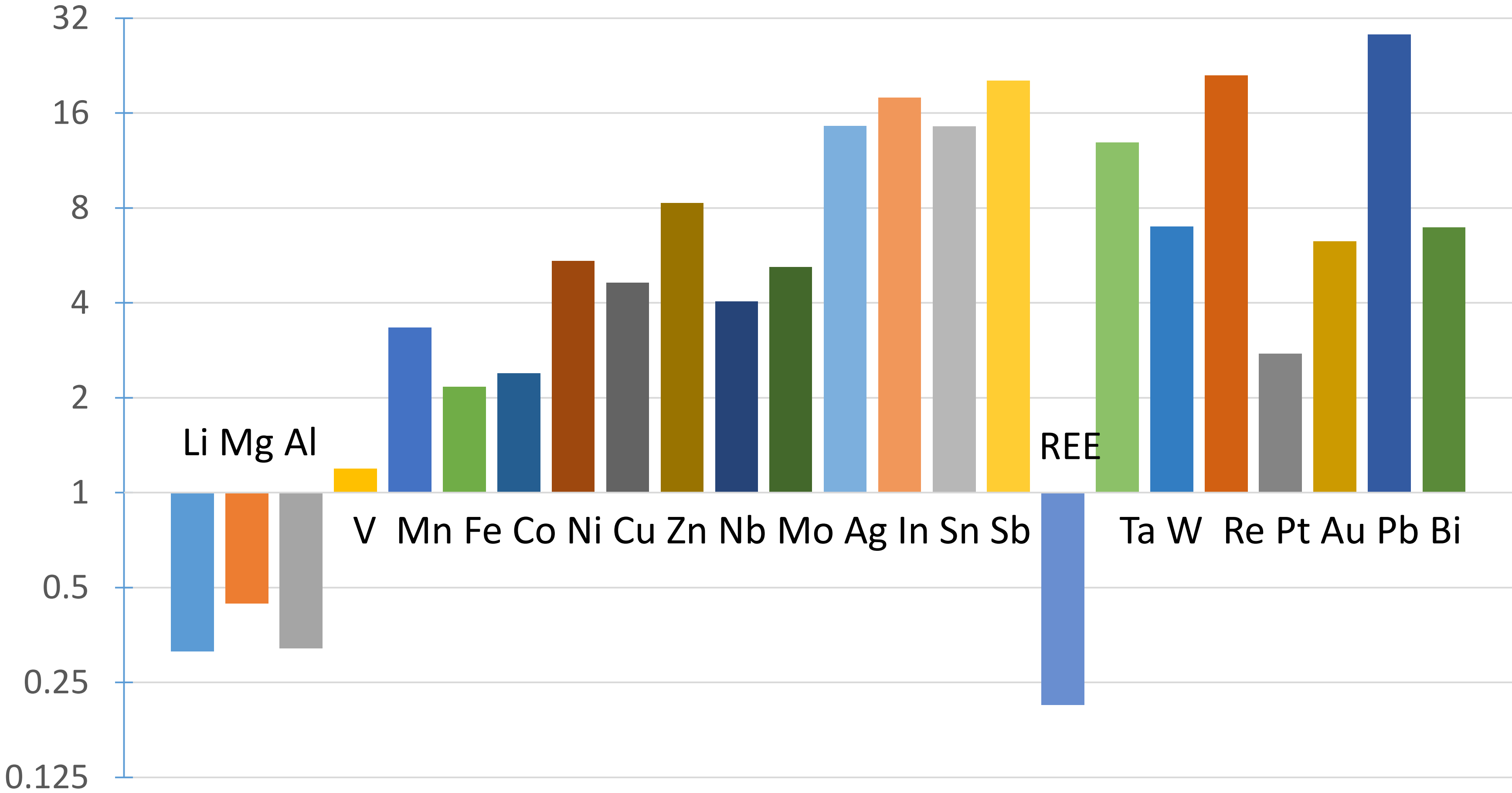
Every country reaches developed level of consumption per capita

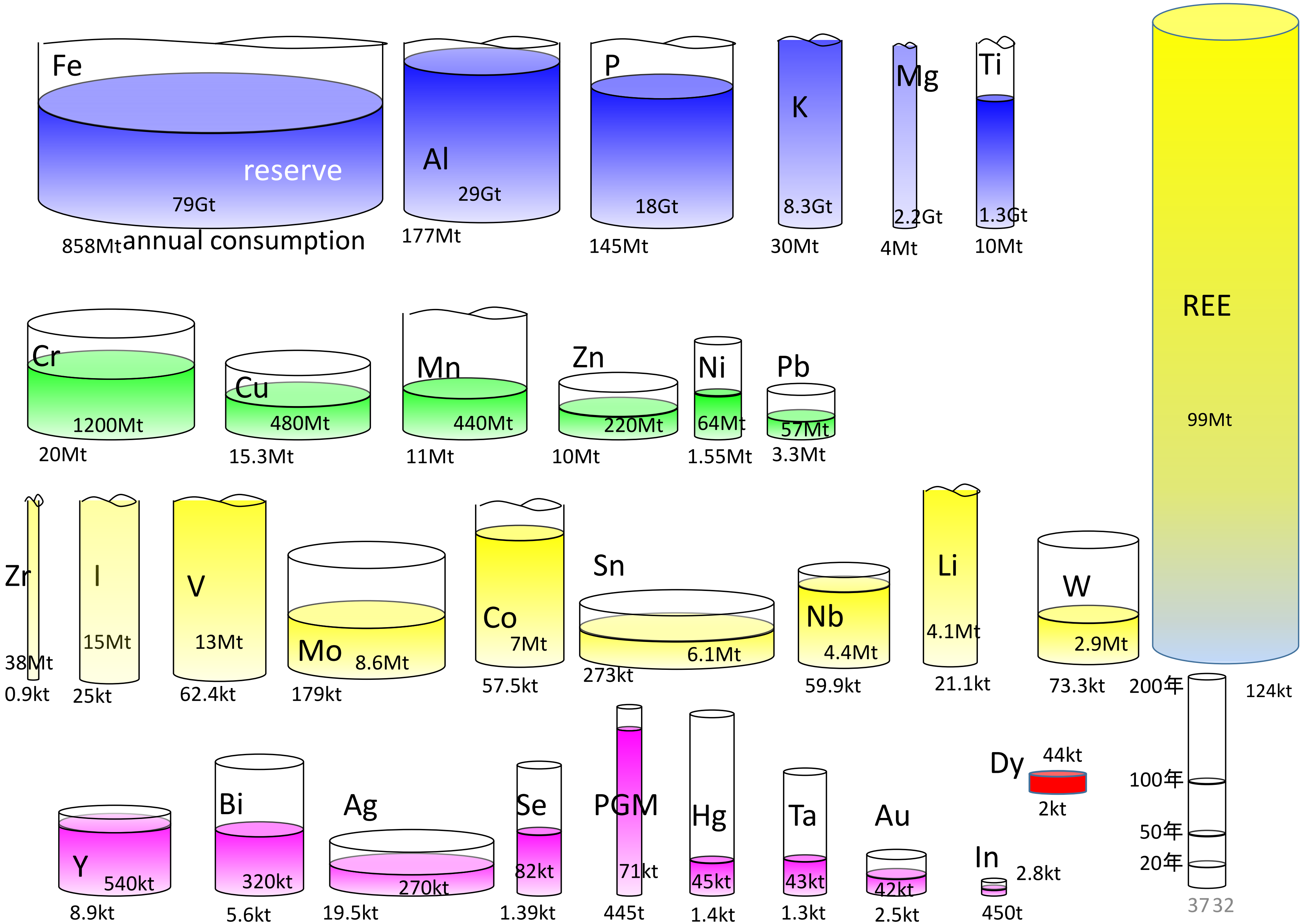
Consumption prediction with concerning only prepotent countries



metal	Fe
Consumption/year at 10Gperson world	4.5Gton/year
Reserve	87Gton

Estimated demand up to 2100 v.s. current reserve amount




Fe
reserve
79Gt
858Mt annual consumption
Al
29Gt
177Mt
P
18Gt
145Mt
K
8.3Gt
30Mt
Mg
2.2Gt
4Mt
Ti
1.3Gt
10Mt
REE
99Mt
124kt
Cr
1200Mt
20Mt
Cu
480Mt
15.3Mt
Mn
440Mt
11Mt
Zn
220Mt
10Mt
Ni
64Mt
1.55Mt
Pb
57Mt
3.3Mt
Zr
38Mt
0.9kt
I
15Mt
25kt
V
13Mt
62.4kt
Mo
8.6Mt
179kt
Co
7Mt
57.5kt
Sn
6.1Mt
273kt
Nb
4.4Mt
59.9kt
Li
4.1Mt
21.1kt
W
2.9Mt
73.3kt
200年
100年
50年
20年
Y
540kt
8.9kt
Bi
320kt
5.6kt
Ag
270kt
19.5kt
Se
82kt
1.39kt
PGM
71kt
445t
Hg
45kt
1.4kt
Ta
43kt
1.3kt
Au
42kt
2.5kt
Dy
44kt
2kt
In
2.8kt
450t

32


Mashijing馬石径
坲上
Mashijing 馬石径
24
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24° 58'14.42" N 115° 03'12.45" E 標高 378 m
高度 2.13 km

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ISRN Metallurgy
Volume 2014, Article ID 907536, 10 pages
http://dx.doi.org/10.1155/2014/907536

Research Article

Life Cycle Impact of Rare Earth Elements

Hindawi

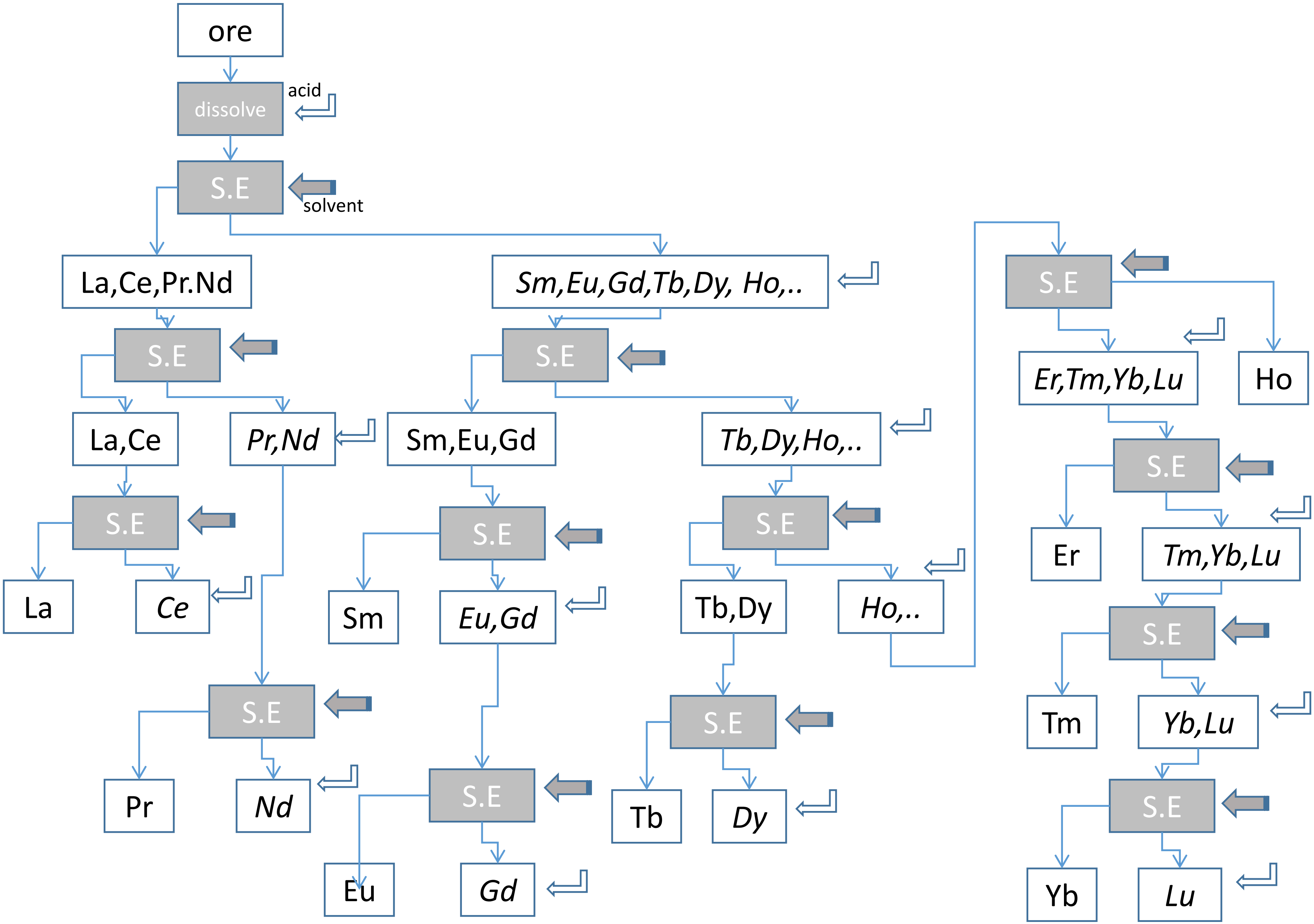
P. Koltun[1] and A. Tharumarajah[2]

Table 4: Life cycle inventory and impact for the production of 1 kg RE oxides using price-based allocation.

RE oxide	Classification	Energy consumption		Water consumption, kL	Environmental impact	
		Electricity, MJ	Heat, MJ		GHG emissions, kg CO_2 eq.	Resources depletion, MJ surplus
La_2O_3	Light	26.13	34.39	12.82	11.16	12.52
CeO_2	Light	24.12	31.74	11.83	10.30	11.56
Pr_6O_{11}	Light	190.97	251.28	93.69	81.53	91.52
Nd_2O_3	Light	154.78	203.67	75.94	66.09	74.18
Pm_2O_3	Medium	0.00	0.00	0.00	0.00	0.00
Sm_2O_3	Medium	37.95	62.16	22.74	17.73	20.59
Eu_2O_3	Medium	3472.18	5686.98	2080.32	1622.04	1883.96
Gd_2O_3	Heavy	121.12	198.38	72.57	56.58	65.72
Tb_4O_7	Heavy	2826.83	4628.93	1718.02	1325.42	1538.92
Dy_2O_3	Heavy	1574.95	2578.98	957.18	738.45	857.40
Ho_2O_3	Heavy	0.00	0.00	0.00	0.00	0.00
Er_2O_3	Heavy	124.38	203.67	75.59	58.32	67.71
Tm_2O_3	Heavy	0.00	0.00	0.00	0.00	0.00
Yb_2O_3	Heavy	111.65	182.83	67.86	52.35	60.78
Lu_2O_3	Heavy	0.00	0.00	0.00	0.00	0.00
Sc_2O_3	Heavy	11630.4	19044.8	7068.42	5453.15	6331.55
Y_2O_3	Heavy	80.77	132.26	49.09	37.87	43.97

2.1.2 Roasting by vitriol

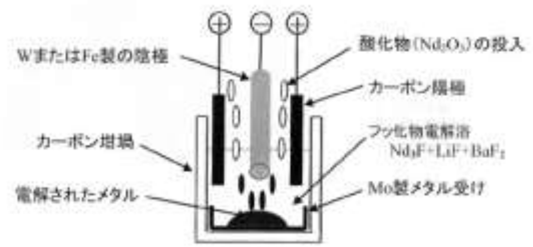
- Advantages:
  - ✓ easy to be produced in a large scale;
  - ✓ low cost;
  - ✓ high recovery rates of REs
- Disadvantages: [7]
  - ✓ radioactive contamination caused by Th;
  - ✓ unrecoverable of Th which lies in slag;
  - ✓ hard to recovery the exhaust gas and slag contained Fl
- Treatment on solution of RE sulphates:
  - ✓ extraction and stripping by P204;
    - ➢ High recovery rate and production quality; but high investment
  - ✓ deposition by ammonium carbonate; (widely used)
    - ➢ Low investment; but high running cost and pollution


ore
dissolve
acid
S.E
solvent
La,Ce,Pr.Nd
Sm,Eu,Gd,Tb,Dy, Ho,..
S.E
Ho
Er,Tm,Yb,Lu
La,Ce
Pr,Nd
Sm,Eu,Gd
Tb,Dy,Ho,..
Er
Tm,Yb,Lu
La
Ce
Sm
Eu,Gd
Tb,Dy
Ho,..
Tm
Yb,Lu
Pr
Nd
Eu
Gd
Tb
Dy
Yb
Lu

2.4 RE metals and alloy

- The main prepareing techniques of RE metals and alloy:
  - ✓ molten salt electrolysis
  - ✓ metallothermic reduction
  - ✓ fire refining

Ndの溶融塩電解



電解条件： 約10V、数千A、950〜1000℃

(1) Molten salt electrolysis:

14kWh/kg-REE

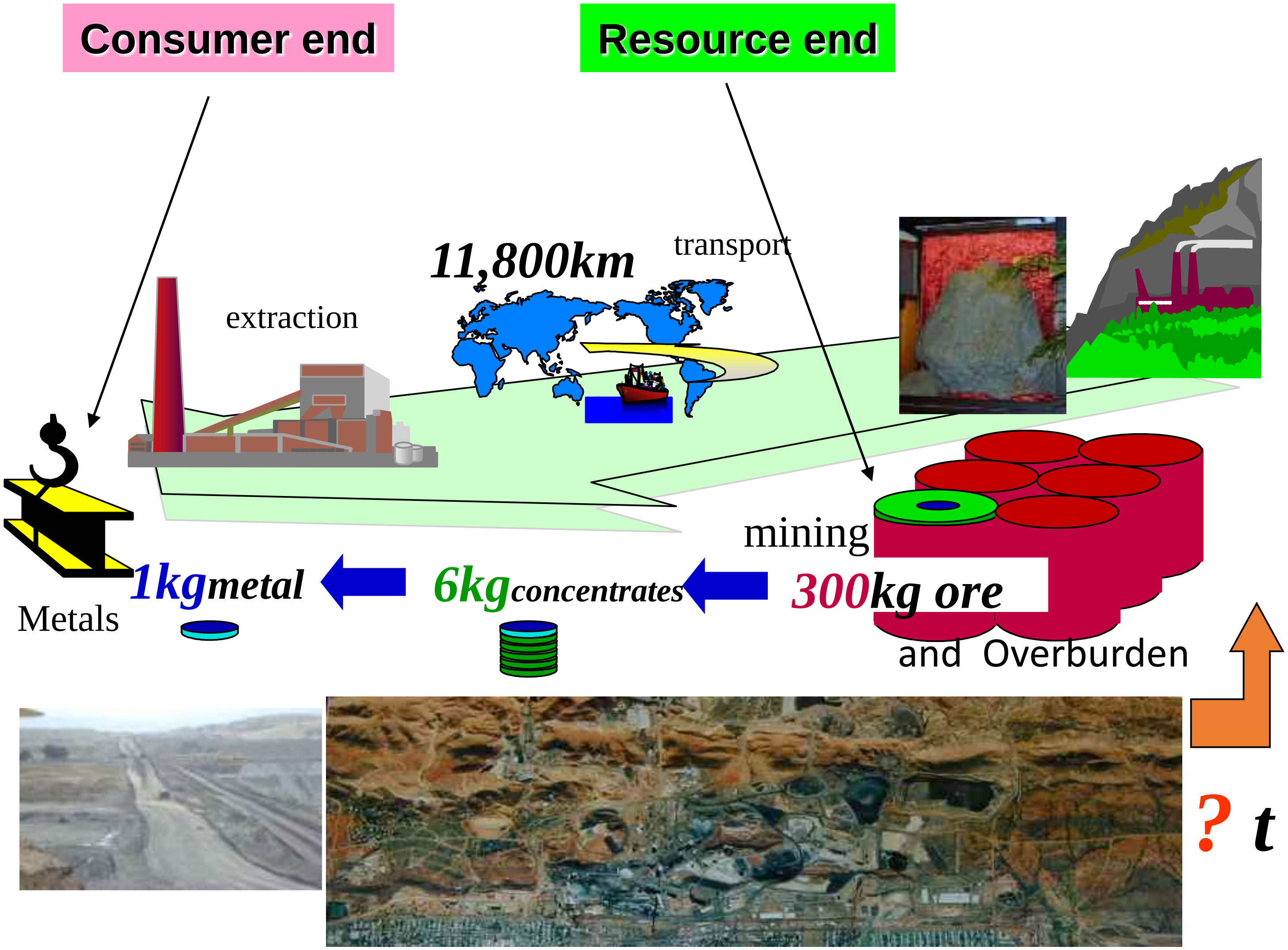
a) Oxide electrolysis:

- ➢ Taking RF_3-LiF as molten salt, graphite as anode and tungsten (W) bar as cathode, RE oxides were electrolyzed at 980~1050℃ to obtain liquid RE metals.
- ➢ This method was widely utilized to prepare La, Ce, Pr, Nd, PrNd, DyFe and GdFe.

b) Chloride molten salt electrolysis:

- ➢ Taking RCl_3-KCl as molten salt, graphitic cell as anode and tungsten (W) bar or molybdenum (Mo) bar as cathode, RE oxides were electrolyzed at 980~1050 ℃ to obtain liquid RE metals.
- ➢ This method was mainly used to prepare RE alloy with low Mg/Fe and high La/Ce.
- ➢ Disadvantage: chlorine pollution

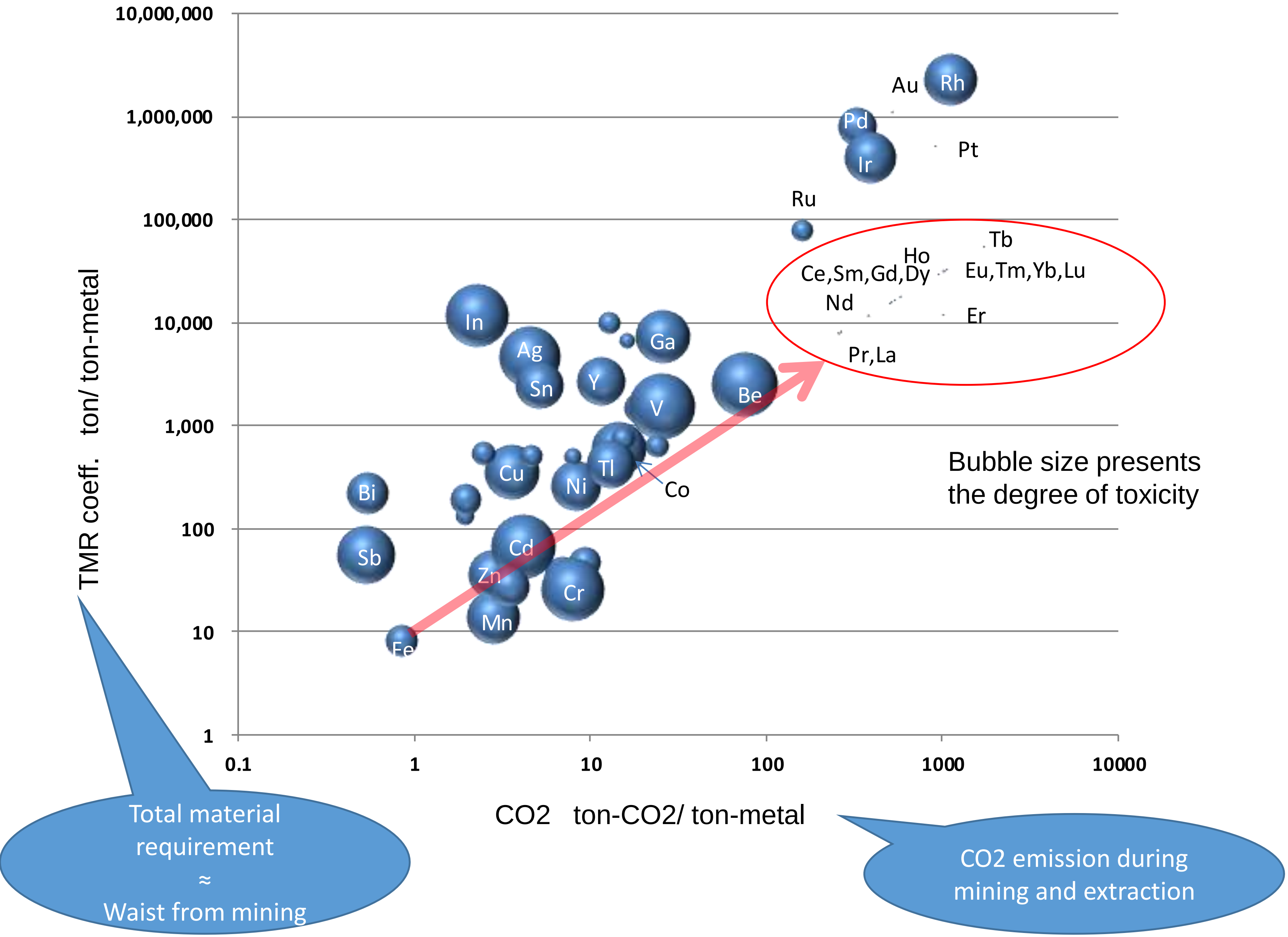
Resource(-end)-view weight



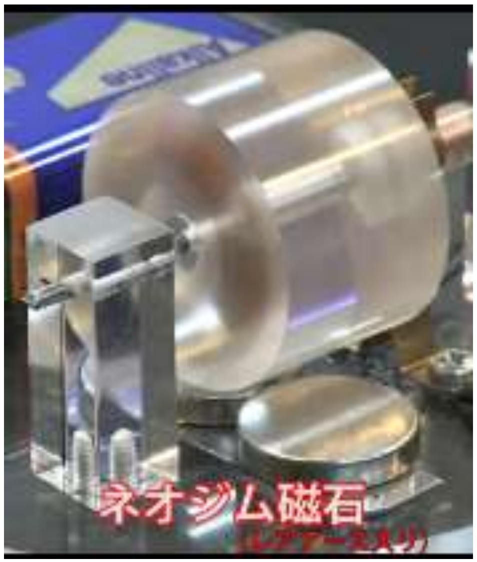
TMR: Total Materials Requirements, or Ecological rucksacks

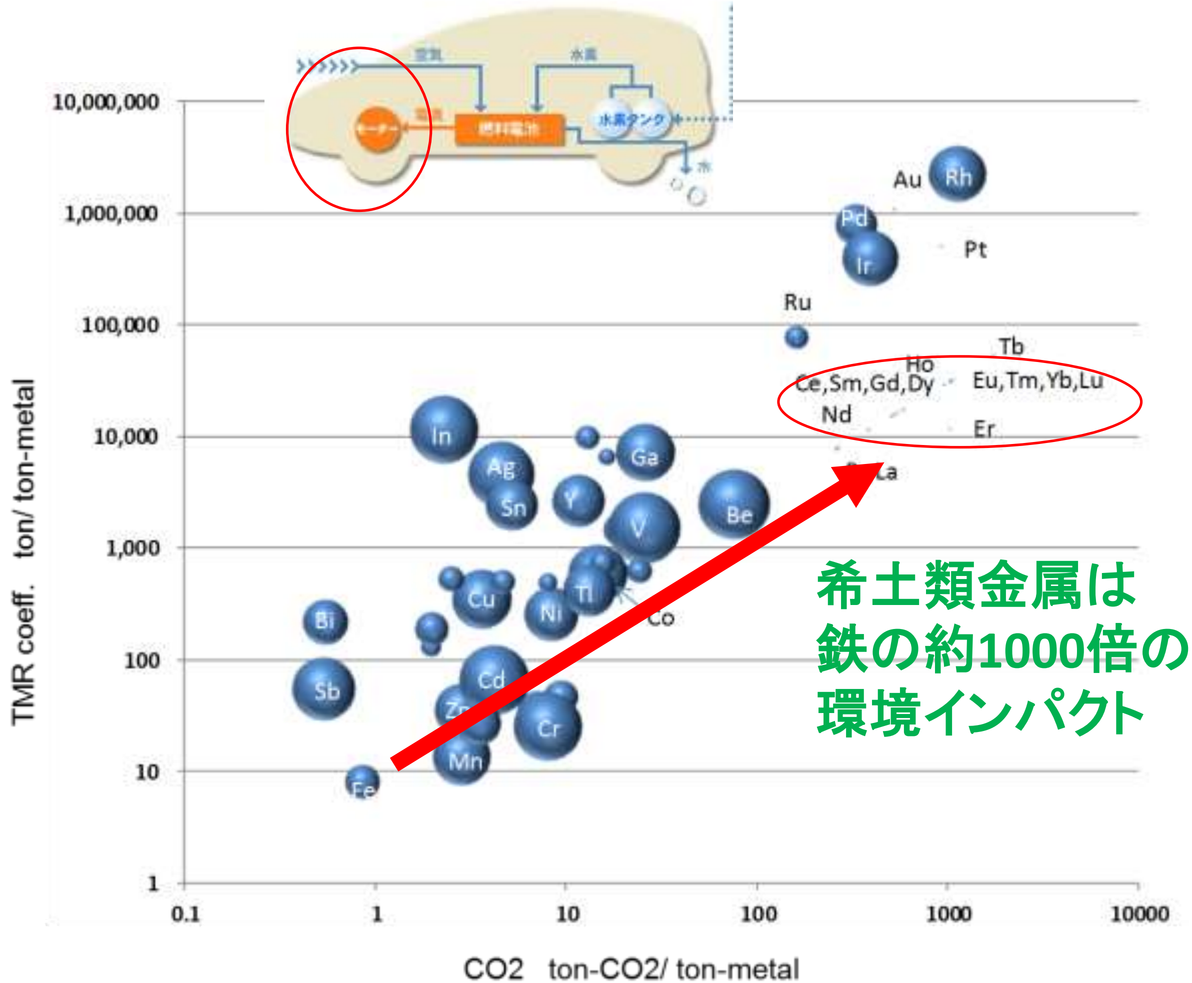
More than 1.5ton ecological rucksack

1kg R.E.E. is nearly equivalent to 1 ton Fe by environmental view

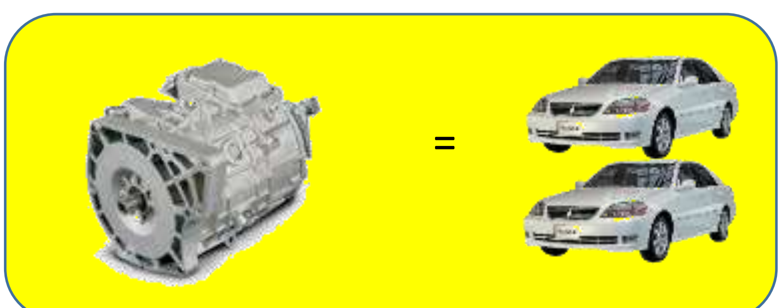


モーター (レアアース)





1.2kg Nd磁石/台



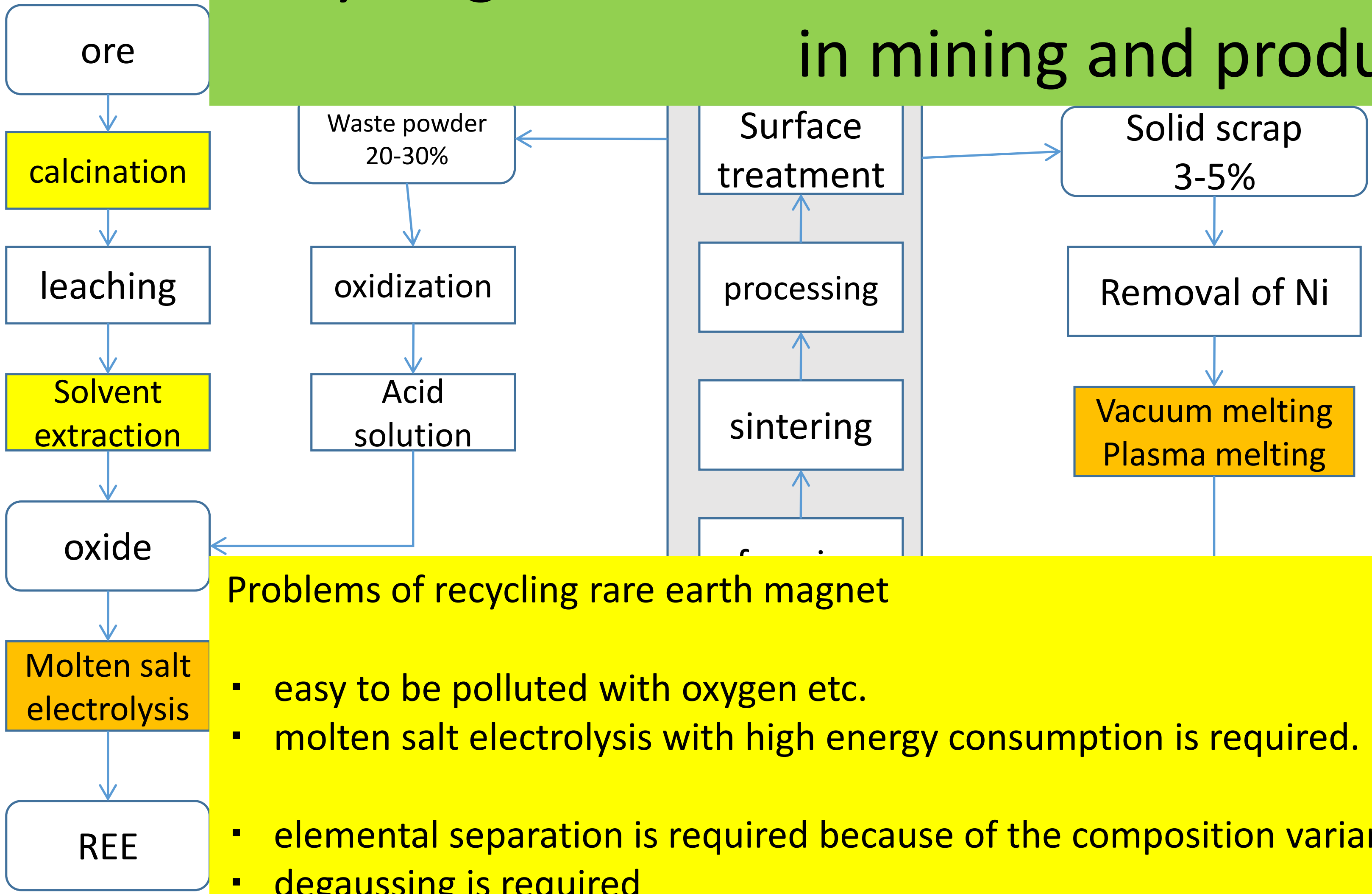
Develop more efficient material with less TMR

TMR comparison of substitution from Sm-Co to Nd-Fe-B

	Fe-Nd-B			Sm-Co	
	Fe	Nd	B	Sm	Co
	14	2	1	2	17
Atomic mass	56	144	11	150	59
mass%	0.72	0.27	0.01	0.23	0.77
TMR coeff. (t/kg)	0.008	12	0.14	16	15
TMR(t/kg)	0.46			15.2	
Max. energy product J/m^3	300			200	
TMR/max.energy product index	0.02			1	

Nd-Fe-B has 50 times better resource efficiency.

Recycling reduces the environmental impact in mining and production



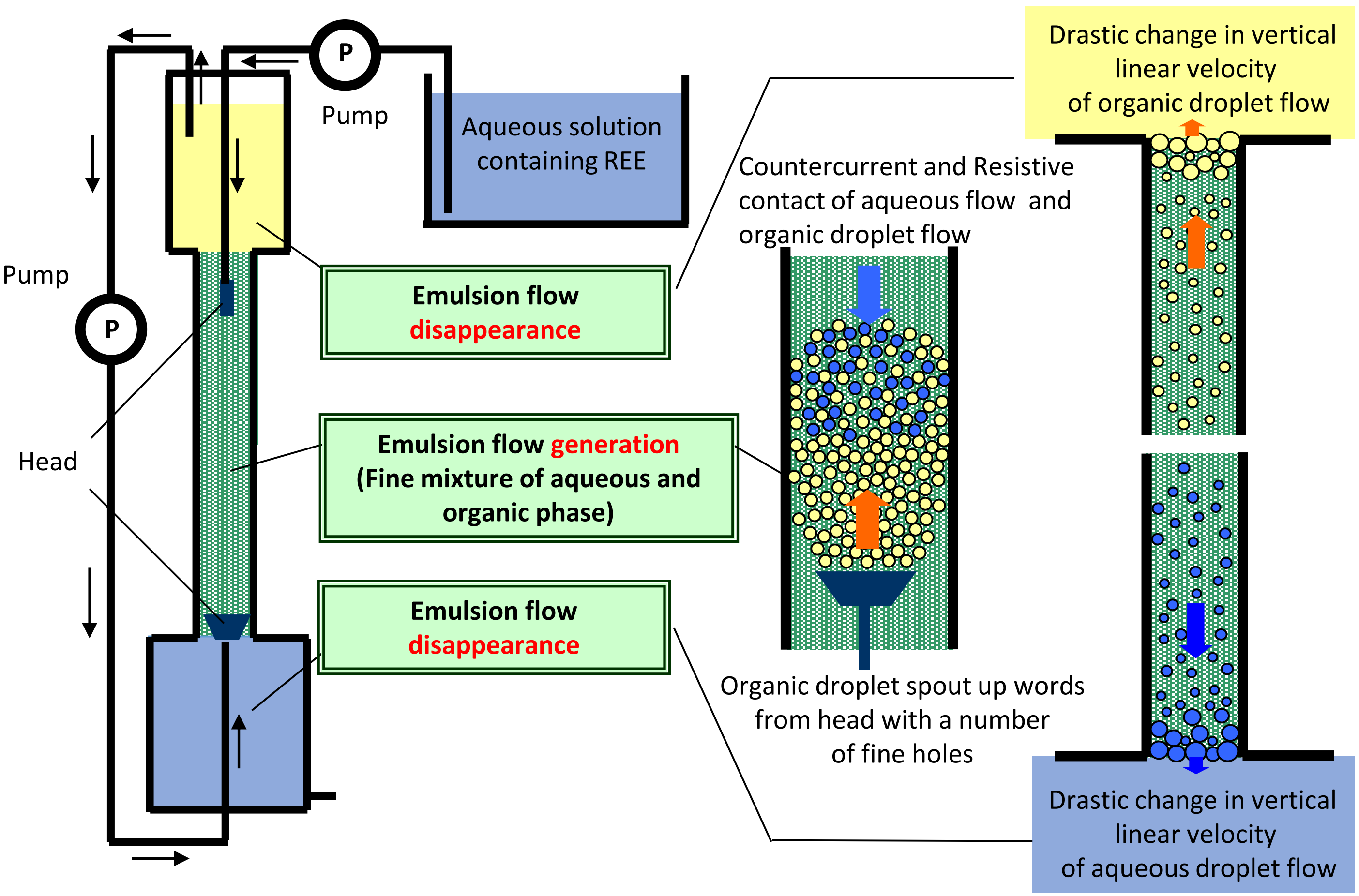
Problems of recycling rare earth magnet

- easy to be polluted with oxygen etc.
- molten salt electrolysis with high energy consumption is required.

- elemental separation is required because of the composition variance of producer
- degaussing is required

Wt%	O	C	N
Initial metal	<0.05	<0.03	<0.01
magnet	0.7	0.04	0.008
Polished powder	1～5	0.5～2	0.5～1

Newly Developed Emulsion Flow Solvent Extraction Technology



NOTE : Emulsion flow solvent extraction technology has been developed by Japan Atomic Energy Agency (JAEA).

Developments of REE (Nd,Dy) Mobile Recycle Plants

Proposal in the first EU-US-Japan trilateral conference on critical materials (2011)

Nd-Dy recovery equipment Model Ⅰ (2011-2013)

Nd-Dy recovery equipment Model Ⅱ (2014-2015)

Nd/Dy separation & purification equipment Model Ⅰ (2014-2015)

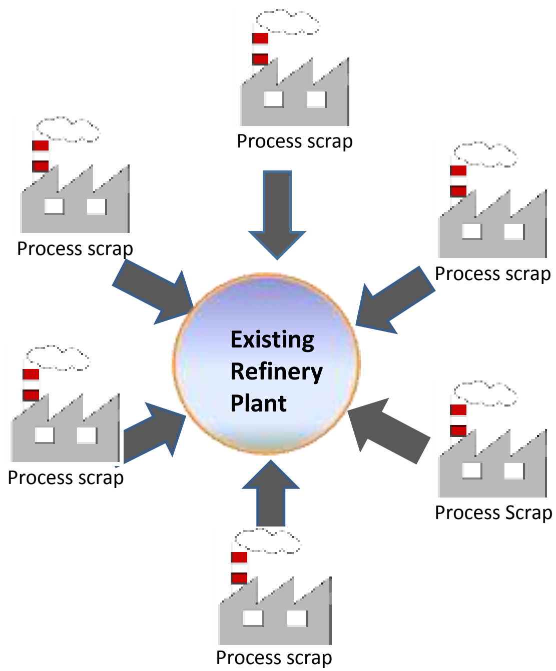
Nd/Dy separation & purification equipment Model Ⅱ (2015-)

20ft International standard container

Note: These development projects have been supported by METI and NEDO from 2011 to 2015

New Concept of Rare Earth Urban Mining with REE Mobile Recycle Plant

【Present State】

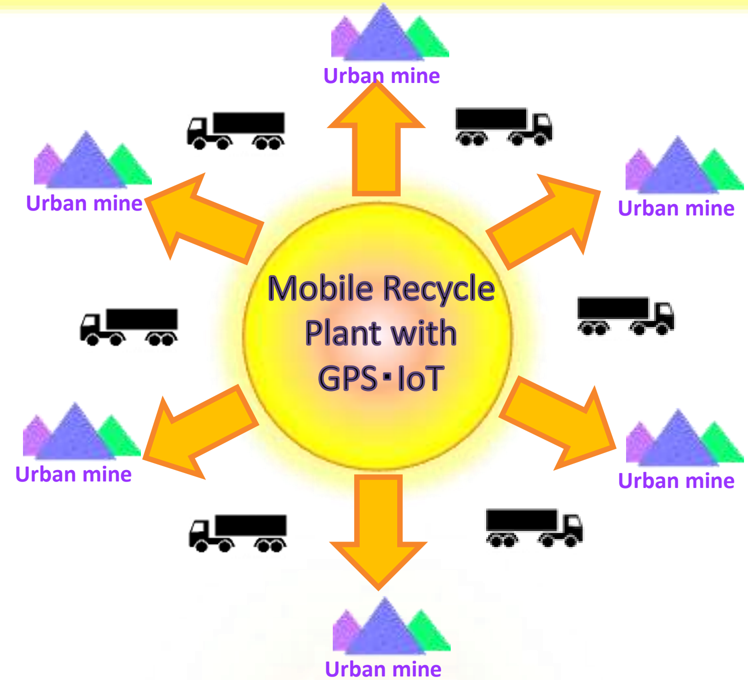


Nd magnet scrap collected from mass production manufacturing plant

Complementary relationship

【New Concept】

Urban mine mapping based on global material flow analysis (MFA) and life cycle assessment (LCA) of Nd magnets will support the new concept of rare earth urban mining.



Mobile recycle plants go to urban mines and recover REE from end-of-life products in a global network
(Remote and real time management utilizing GPS, IoT)

From the view point of Carbon zero society,

REE technology will give a great contributions to it.

From the view point of resource efficiency,

resource view weight REE is considerable quantity.

In order to reduce the environmental impact of production, it is important

to develop higher efficient material with less TMR element and

to enhance recycling.