Sustainability

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Material science & technology is the knowledge and measure to know and change the heaven-born resources to utile materials for human-being’s society.

Therefore, material science and technology takes following two roles for the sustainability, one is realization sustainable systems in society, the other is avoidance of crisis associated with natural resource use.
For the realization of sustainable system, MST is indispensable to materialize any engineering systems for sustainability and to operate with reliability.

Development in following field are expected especially to contribute to the prevention of global climate change.

- Energy conversion
  - M4 power plant, M4 solar cell, M4 fuel cell, M4 hydrogen system, M4 thermo-electric system M4 other energy conversion

- Energy storage and transportation
  - M4 battery, Super-conductor, softmagnetic material

- Energy efficient use
  - M4 illumination, magnet, M4 power IC, light weight material

- CO2 stabilization
For avoidance of resource crisis, MST has a responsibility to develop sustainable utilization of materials as followings,

a) dramatic reduction of material in quantity per unit function,

b) material design of good recyclability

c) substitution technology of material from critical resource to abundant resources
In order to develop above technologies and science which leads them, we need another collaboration on the evaluation of social and environmental impact of MSTs development such as LCA method.

The evaluation method will be powerful to let other entity in society understand the role of MST, and check the confliction between materialization of engineering system and avoidance of resource risk.
Scientific Approach for Resource Risk
–Japanese New Material Research Project
"Science & Technology on Elements Project"–

2009.6.25

Materials’ Scientific NewDeal Center,
National Institute for Materials Science
HALADA Kohmei
The Earth is Burning.

Let’s cool it.
new technologies and new engineering materials are required in order to cool earth.
We’ve stormed into the era of revolution

- Consider → Improve → Achieve
- Percentages of improvement → several fold of shift
  - numerical targets
  - large expectation to innovation
  - participation from very very various entities

We need caution against the Risk of Risk-imputation
Eco-innovation requires new demand of rare & special materials.
Requirement of material rapidly increases year by year

- Steel 100Mt
- Cement 100Mt
- Aluminum 1Mt
- Plastic 10Mt

図3 生産量の変化

As the climate change is getting important, therefore, we need to take care of other risks.

Catastrophe comes from neighboring risks.
Several times amount of resources will be required by 2050.

It will be close to the amount of reserve by 2050: Fe, Mo, W, Co, Pt, Pd

It will require several times amount of reserve by 2050: Ni, Mn, Li, In, Ga

It will run over the amount of reserve base by 2050: Cu, Pb, Zn, Au, Ag, Sn
Four types of the two step line model of metal consumption v.s. GDP per capita

Fe-type: weakly de-coupled
Al, Ni, Mo, Ag, Sb

Zn-type: de-coupled
Cu, Sn, Pb, W, Cr, Mn, Au

Si-type: still coupling
Pt, Co

R.E.-type: further coupling
Li, In, Ga

Fe
y = 0.0064x + 440
R² = 0.4506

Zn
y = -3.13E-05x + 6.74E+00
y = 9.01E-04x

Si
y = 3.91E-05x

R.E.
y = 0.0057x
y = 2.19E-03x
Several times amount of resources will be required by 2050.

- It will be close to the amount of reserve by 2050: Fe, Mo, W, Co, Pt, Pd
- It will require several times amount of reserve by 2050: Ni, Mn, Li, In, Ga
- It will run over the amount of reserve base by 2050: Cu, Pb, Zn, Au, Ag, Sn

Accumulated consumption from 2000 to 2050

- Already mined
- Resources
Four types of the two step line model of metal consumption v.s. GDP per capita: 

- **Fe-type:** weakly de-coupled Al, Ni, Mo, Ag, Sb
- **Zn-type:** de-coupled Cu, Sn, Pb, W, Cr, Mn, Au
- **Si-type:** still coupling Pt, Co
- **R.E.-type:** further coupling Li, In, Ga

Data graphs showing trends in metal consumption per capita (kg) vs. GDP per capita ($).
While materials play an essential role in the development of human society, their negative aspects of environmental burden through the massive production, consumption, and disposal have been pointed out. The demand for materials is now expanding further in order to satisfy growing human needs. It may cause a rapid increase in the resource risk. We, who aim to utilize materials to construct a sustainable society, reconfirm the importance of the following three principles.

Three principles in the area of resource use
- Resource Conservation
- Environmental Protection
- Regional and Generational Equity

Based on these principles, we ask you, consumers of materials, to observe the following four practices. We also pledge ourselves to advance technologies which realize these four practices in material research.

Four practices in the area of resource use
- Use minimum quantity
- Use completely
- Circulate as many times as possible
- Use abundant resources

International Symposium of Sustainable Energy and Material was held at 2007 at Ishigaki Island, Japan to discuss the contribution of materials science and engineering to sustainable use of energy and resource.
6. Elements Science and Technology Project
   “Ubiquitous (abundant) element strategy project”
   “strategic stimulation of elements project”

Planned budget for fiscal 2007: 700 million yen

What is the Elements Science and Technology?

○ Science and technology aimed at revolutionizing the paradigm of material research and development and creating new materials

For substitution, Japan government has launched a new research project on long-term strategic substitution technology

abundant and harmless elements
- Finding **new structured alternatives** to rare or harmful elements

② Advanced use of the effective functions of strategic elements
   - **Drastically reducing** the use of rare or harmful elements
   - **Exploring new functions** based on elements science and technology

③ Practical material design technologies for use the effective use of elements
   - Designing materials with a limited environmental load and composite functions

A new molecular structure composed of lime and aluminum oxide: alternatives to ITO
Through clarification of the role of specific element on a function of material, the function shall realized by substitution of the element or the nano-structure control in order to reduce or substitute the element of rare resources.

**Promoted in Nano--technology & materials strategic field**
**Public offer as a key technology R&D series was subjected.** 7 thema (2007), 5 thema (2008) were accepted.
**Collaboration of METI & MEXT**
**Converging approach among disciplinary**

[Diagram of elements science & technology project]
MEXT
Science & Technology of Elements Project

Wide spectrum of element selection
From fundamental science, aiming for radical substitution or drastic reduction in quantity
Paradigm shift of materials research
¥650M (+ ¥150M at 2009)

NEDO(METI)
Rare metal substitution Project

Elements which need urgent action
(In, Dy, W, PGM, Tb, Eu, Ce)
Practical destination of research, Intensive R&D
¥1,550M (+¥600M at 2009)

Substitution of rare elements into abundant one
Drastic improvement of materials efficiency

Check & Re-built each theme

Scientific bases for next generation, Proposal of application research by 5 years

Numerical target of reduction in quantity, Sample level production by 5 years
- Aluminum galvanized steel plate in order to substitute Zn
- Anodic aluminum amorphous oxide resistive random access memory
- Hydrogen induced new functions in sub-nano lattice structure
- Self-organized nano particle catalyst aspire for precious metal free catalyst
- Ba based piezo material for substitution to Pb
- TiO2 based transparent electrode substitution for ITO(In Sn Oxide)
- Nano composite magnet with less rare earth elements
- Precious metal minimized catalyst by higher dispersion processing
- Precious metal free nano hybrid catalyst
- Molecular catalyst for energy conversion for substitution for precious metal
- Design of advanced function from Si oxide based material
- Strategic development of ubiquitous material
THEMA OF RARE METAL PREOJECT IN NEDO

- Reduction in quantity of In for transparent electrode
- Substitution of In for transparent electrode
- Reduction in quantity of Dy in rare earth magnet
- Reduction in quantity of W for hard tool material
- Substitution of W for hard tool material

Calling for applications

Reduction or substitution of Pt for purification catalyst of automobile
Reduction or substitution of Ce for precise grinding material
Reduction or substitution of Tb and Eu for luminescent material
**Approach of Minimization:**

Material design of higher resource efficiency, namely reduction in quantity per function, is expected as immediate measure. Nano-technology is powerful in this approach.

**Approach of Substitution** to more abundant element:

Material design with nano-technology has the possibility of functional design with other chemicals and elements. Band gap design electron orbit design with nano-technology give us various possibility.

**Approach of Circulation:**

Japan has a great possibility of urban mining. Nano-technologies such as molecular identification expected to provide new tool to selective concentration from waste,
Japan has great possibility of Urban mining

Percentage of estimated amount of urban mining comparison to reserves in the world
Nano-stripping Mechanism For Extraction of Rare Metals from Urban Concentrates

Rare metals
- Rh(III)
- In(III)
- Ru(IV)
- Ir(IV)

(1) Extraction

TPPS Probe

(1) Extraction

(2) In (III) ion-Selectivity

(3) Releasing

[M(TPPS)]^n+

(4) Reuseability

Pure In(III)

(3) Separation

Nanostripper
POSSIBLE CASES FOR MINIMIZATION OF ELEMENTS USE

- **Case 1**
  Get the bottom of minimum function unit in materials nano-scale structure

- **Case 2**
  Apply localized phenomena such as surface localization or boundary localization

- **Case 3**
  Design or find of advanced function by nano-scale composite

- **Case 4**
  Control miner defective structure to eliminate additive elements to render harmless effect.
計算科学で予想されたPd$_{13}$クラスターとTiO$_2$薄膜表面間の触媒機能に影響する相互作用
Our known semiconductors are only a part of them. We have various kinds of unexplored semiconductor in our own backyard.
COMPATIBLE FUNCTION DESIGN FOR SUBSTITUTION OF ELEMENTS

- Case1 compatibility of atomic size, ion size
- Case2 compatibility of electron orbit
- Case3 compatibility of functional carrier
- Case4 compatibility of defect and distortion
- Case5 compatibility of boundary structure
- Case6 actualization of submerged function
- Case7 another nano-scale mechanism for same macroscopic function
Lattice Engineering (= atoms re-arrangement)

**Considering function units not as the kind of elements but its arrangement and consequently generated electron status.**

**Design as lattice’s structure**

**In sub-nano size order**

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- **doping**
  - プラズマ水素ドーピング by Ishigaki, NIMS

- **Substitution of Zn plating to Al or Si**
- **Substitution of Dy to common metal**
- **Substitution of Pt to common metal or organics**

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**Excitation**

**Orbital**

**Dielectric**

**Piezoelectric**

**Thermoelectric**

**Density**

**Thermal conductivity**

**Luminescence**

**Conductivity**

**Photonic**

**Emission**

**Excitation**

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**to enrich the Possibility of Element Selection from common resources, Fe, Si, Al, Ca**
The inverse FFT image is rotated for 45 deg.

The essential is not composition but nano structure.

Functional elements can be observed in nano order.

**TiC nano-carbide in steel**
Nano fabrication realizes specially arranged structure

a) CNT
b) Fullerene nano wisker
c) Oxide nanosheet
d) Carbon nano cage
e) Molecular assembling
Atomic arrangement calculation in the field of photo-catalyst

Various photocatalysts are developed by band-gap design

computer material design is powerful to explore material
Alchemy → Chemistry → Metallurgy

Introduction of elements
Controlling elements

Nano technology → Nano Alchemy

Atom arranging size
material control

From element to atom, electron
“Aufheben” of “elements”

Collaboration among metallurgy, semiconductor, chemistry is required,

Materialallurgy
<table>
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<th>Element</th>
<th>Market Size of Metals</th>
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<tr>
<td>H</td>
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What is the ultimate solution of the sustainable use of energy and resources?

For energy,

Utilization of solar energy from the Father Sun

For resources,

Utilization of soil composition (Si, Fe, Al, Ca, O etc.) from the Mother Earth and C as their children

Toward the solution, we endeavor to realize it.

Before the solution, we manage to supply the demand by available technology.
Scientific New Deal of material is starting Now!!