Sustainable Materials Management: A Holistic Perspective from NASA

Presentation* by

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NASA Environmental Management Division

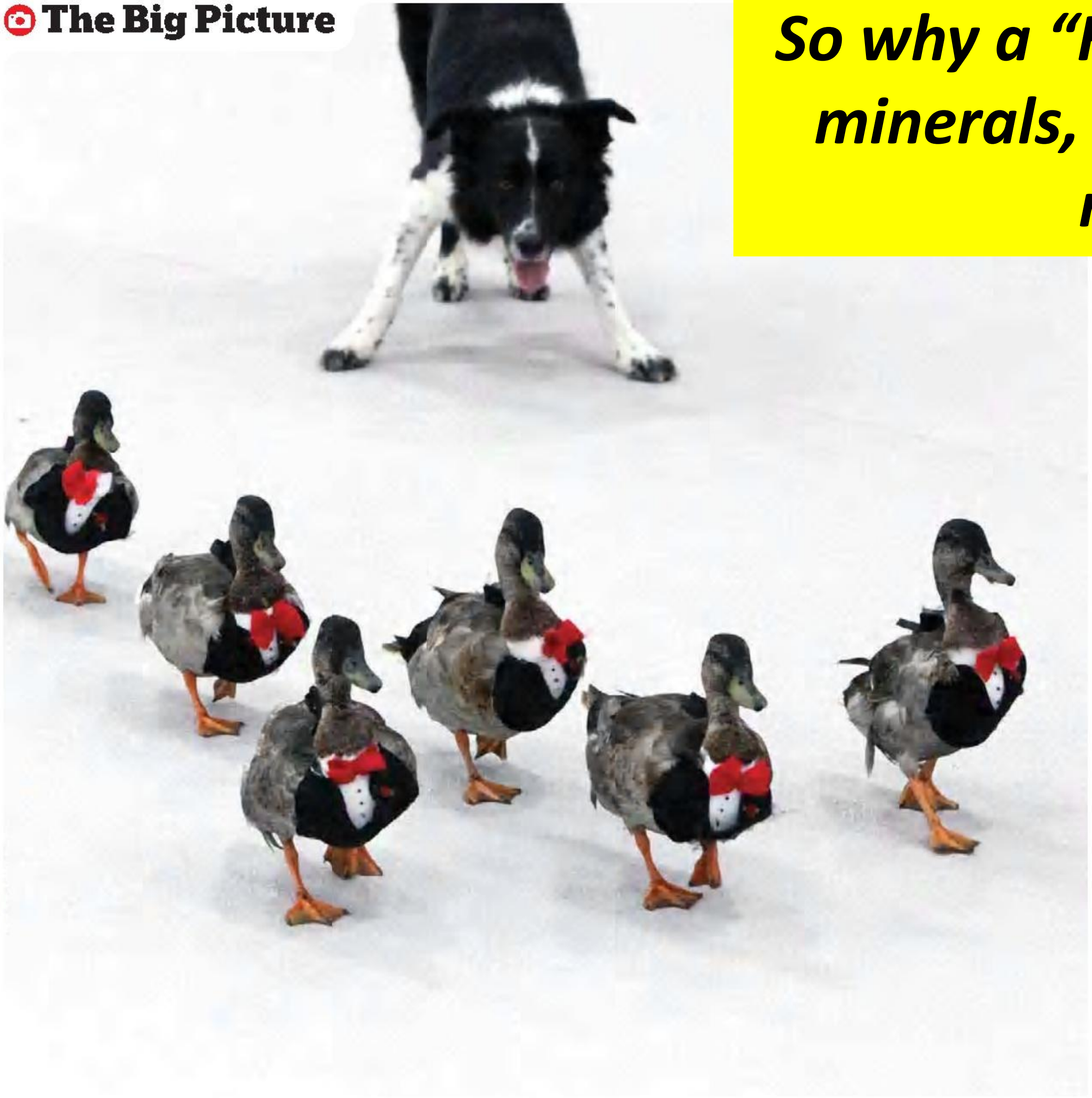
Christina Hudson
SAIC

Session: Defense and Energy Critical Materials Strategies

2011 Technology & Rare Earth Metals Conference: Technology Metals for Energy & Security
Washington, DC
22-23 March 2011

This presentation does not represent the official position of NASA or the United States government. This presentation only reflects only the personal views of the presenters.

So why a "Holistic Approach" to minerals, mineral products & materials?



HILLARY, A BORDER COLLIE, herds guest ducks at the grand opening of the Purina Event Center in Gray Summit, Mo. Six Westminster Kennel Club Dog Show winners walked a red carpet before a poodle cut the ribbon. The dog-show venue features a 45,000-square-foot Great Hall and a 13,500-square-foot Benching and Grooming area. (AP)

Express (Washington Post publication) (20 August 2010) at page 2.


HILLARY, A BORDER COLLIE, herds guest ducks at the grand opening of the Purina Event Center in Gray Summit, Mo. Six Westminster Kennel Club Dog Show winners walked a red carpet before a poodle cut the ribbon. The
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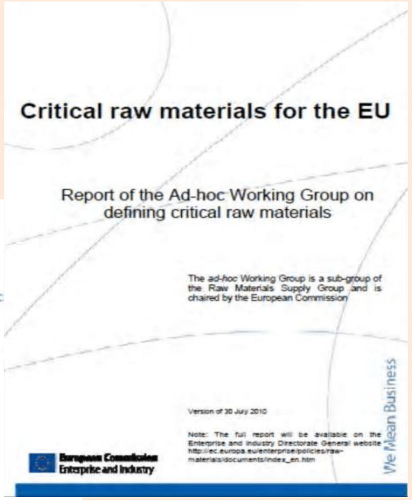

Critical raw materials for the EU

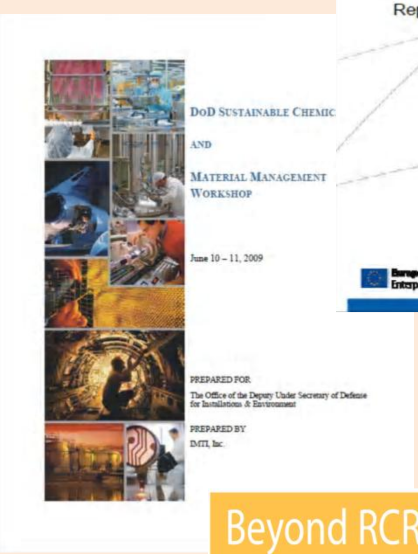
Report of the Ad-hoc Working Group on defining critical raw materials

The ad-hoc Working Group is a sub-group of the Raw Materials Supply Group and is chaired by the European Commission

Version of 30 July 2010

European Commission
Enterprise and Industry

We Mean Business


DoD Sustainable Chemic

and

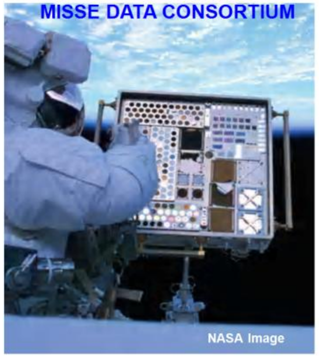
Material Management Workshop

June 10 – 11, 2009

Prepared for
The Office of the Deputy Under Secretary of Defense for Installations & Environment

Prepared by
IMTI, Inc.


Materials Lifecycle
and Envir
Consideration

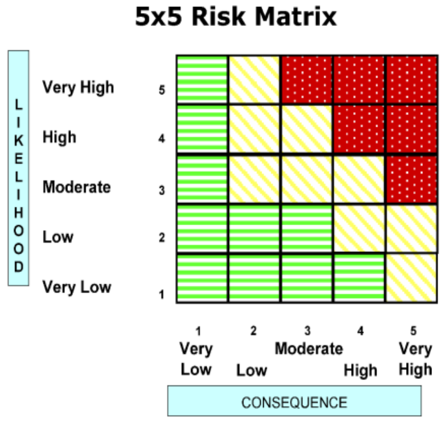



Beyond RCRA

Waste and Materials Management in the Year 2020

Spacecraft Materials Consortium

NASA-HQ Risk Management Framework



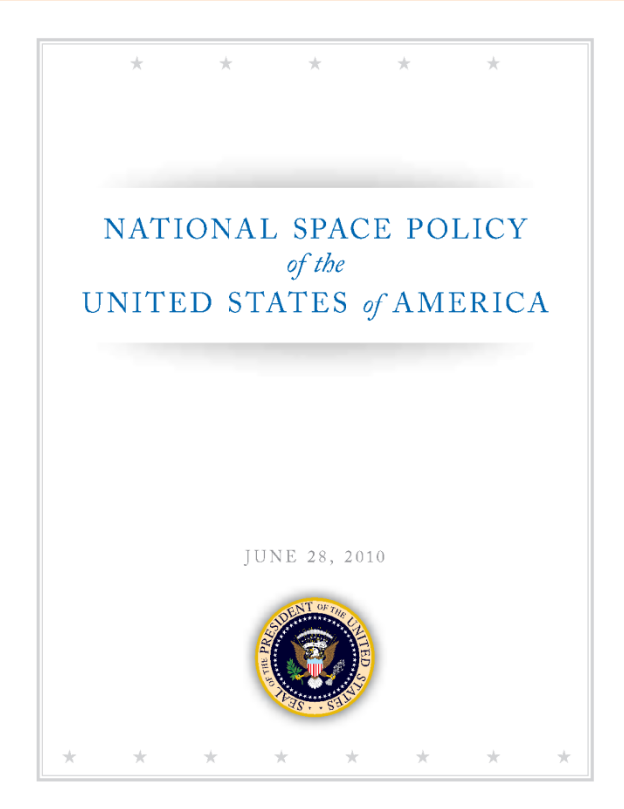
NASA RISK MANAGEMENT STATUS OPTIONS:

1) *Research*
2) *Monitor*
3) *Mitigate*
4) *Accept*

ENTERPRISE RISK MANAGEMENT

ARM #8537 - Risk Statement ***(Condition & Consequence)*****.** ***Given that*** *NASA systems and processes utilize many hazardous and toxic materials (for design, operation, and maintenance) which are required for the life-cycle of the system or process;* ***there is a possibility that*** *some materials and processes will be unavailable due to environmental, safety, and health (ES&H) driven obsolescence and will require efforts to identify and qualify substitutes.*

Context. Long-lived systems and processes required for flight systems (e.g., CEV and STS) and ground support equipment frequently experience the unforeseen unavailability of materials. Environmental, safety, and health (ES&H) regulations can directly and indirectly cause unavailability of required materials. Root Cause – the availability of materials can be affected by a combination of vendor economics, natural disasters, technology advances, safety hazards, and environmental regulations. System architects and designers may not have anticipated extended operational life. The unavailability of a material caused by low quality discontinuation and plant/ company closings are frequently driven by vendor economics.



National Space Policy of the United States of America

28 June 2010

SPACE SYSTEM DEVELOPMENT & PROCUREMENT

(Sustainable Materials Management)

Inter-sector Guidelines

- **Foundational Activities and Capabilities - Improve Space System Development and Procurement. Department and agencies shall:**

***

Engage with **industrial partners** to **improve processes** and effectively manage the **supply chains.**

Memorandum for: OMI/Dept. of Commerce Rare Earth Materials Roundtable Participants

From: David Cammarota
Director, Office of Materials Industries, U.S. Dept. of Commerce

Subject: Summary of December 11, 2009 Rare Earth Materials Roundtable

The roundtable was comprised of 25 stakeholders representing key end-users and suppliers of rare earth materials, as well as interested USG agencies, including DoD, GAO, USTR, and the White House (list of participants is attached). The purpose of the roundtable was to discuss issues related to rare earth metals that may affect existing end-uses, and, in particular, emerging "green technology" end-uses in order to provide policy makers with a snapshot of concerns for U.S. competitiveness in these emerging industries. Roundtable participants expressed the concern that a surge in demand for these products, and subsequently rare earth metals, could put U.S. manufacturers at a competitive disadvantage if timely and cost competitive access to these materials is not ensured. Some participants indicated that a crisis point could be reached as early as the period 2012 to 2014. Participants indicated that this is an issue with broad economic, as well as national security implications, and that the development of a viable industry requires considerable funds and that there are substantial risks involved, a combination that is beyond the capabilities of the few remaining companies in this sector to undertake. Participants agreed that this is an issue that requires government/industry partnerships.

Key Findings

- The U.S. manufacturing/supply chain has too many gaps
  - Total reliance on imports, and only a few suppliers (China)-need to ensure access
  - Lack of U.S. infrastructure – only one rare earth mine in the U.S., only one magnet producer left in the U.S., few component manufacturers
  - Need to re-establish manufacturing capabilities in the U.S.
  - Licensing issues - U.S. reliance on foreign production technologies – could hamper development of U.S. supply chain
- Not enough attention is given to the demand side
  - Insufficient R&D in the U.S. devoted to production processes and new end-uses
  - Lack of innovation in order to keep manufacturing in the U.S.
- There is a shortage of capital, and this is a capital intensive sector
- There is a shortage of materials engineers and other pertinent scientists in the U.S.
- Solving one gap in the supply chain does not fix the problem, need holistic approach
- More consideration needs to be given to recycling of rare earth metals
- China
  - 97% of global rare earth materials production
  - 80% of global, dense rare earth magnets production
  - Restrictive trade policies
    - Creates supply concerns - disadvantages U.S. end-users/manufacturers
    - Draws manufacturing to China
    - Draws R&D to China

Outcomes

- OMI will prepare and disseminate a list of principal points of contact at USG agencies

Office of Materials Industries (OMI), US Department of Commerce "Rare Earth Materials Roundtable"

11 Dec 2009

Some Selected Key Points

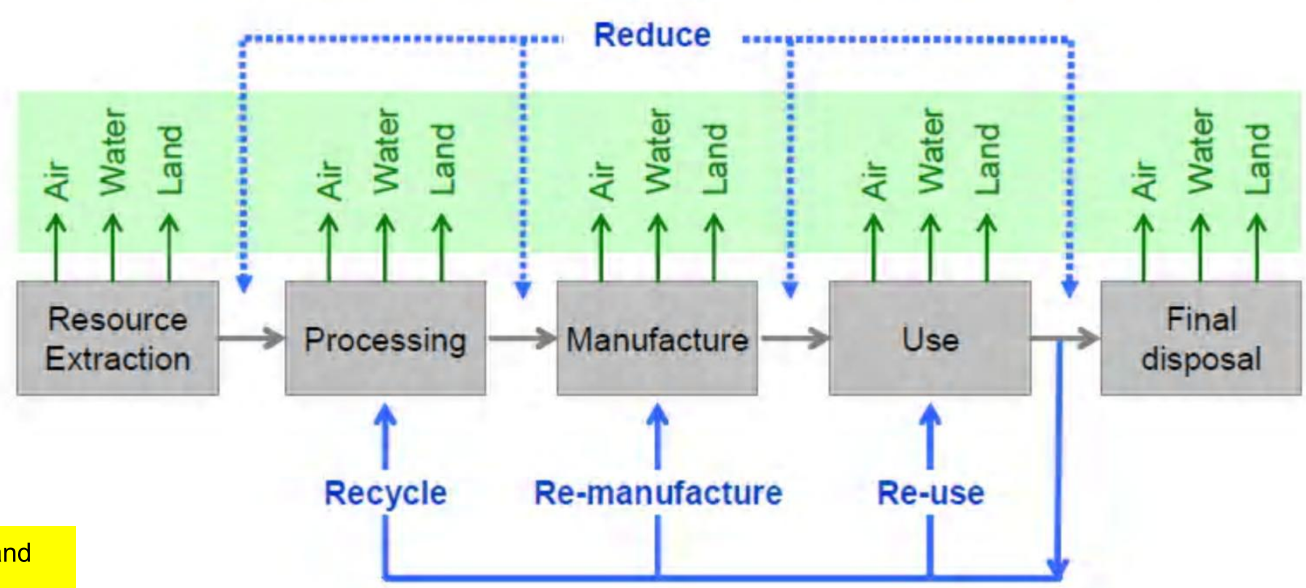
1. ***Need a holistic approach***
2. Crisis point could be reached as early as 2012 to 2014.
3. Issue requires ***Government-Industry partnerships***
4. Need for ***interagency*** working group

http://www.reitausa.org/storage/RareEarthMetalsRoundtableSummaryFindings.pdf

Holistic Approach

OECD (2008) "Measuring Materials Flows and Resource Productivity: Synthesis Report

Flows of materials through the commercial life-cycle

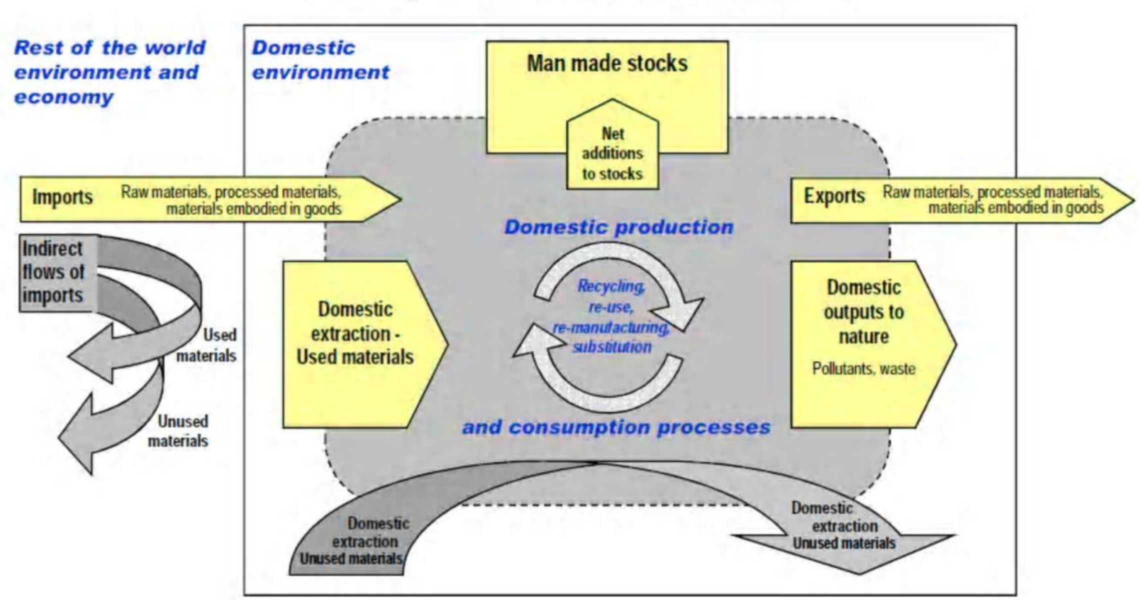


Holistic Approach:

with Supply Chain

OECD (2008) "Measuring Materials Flows and Resource Productivity: Synthesis Report

Economy-wide material balance scheme



Alaskan Humor:

Which "End" are you dealing with?

What is your approach?

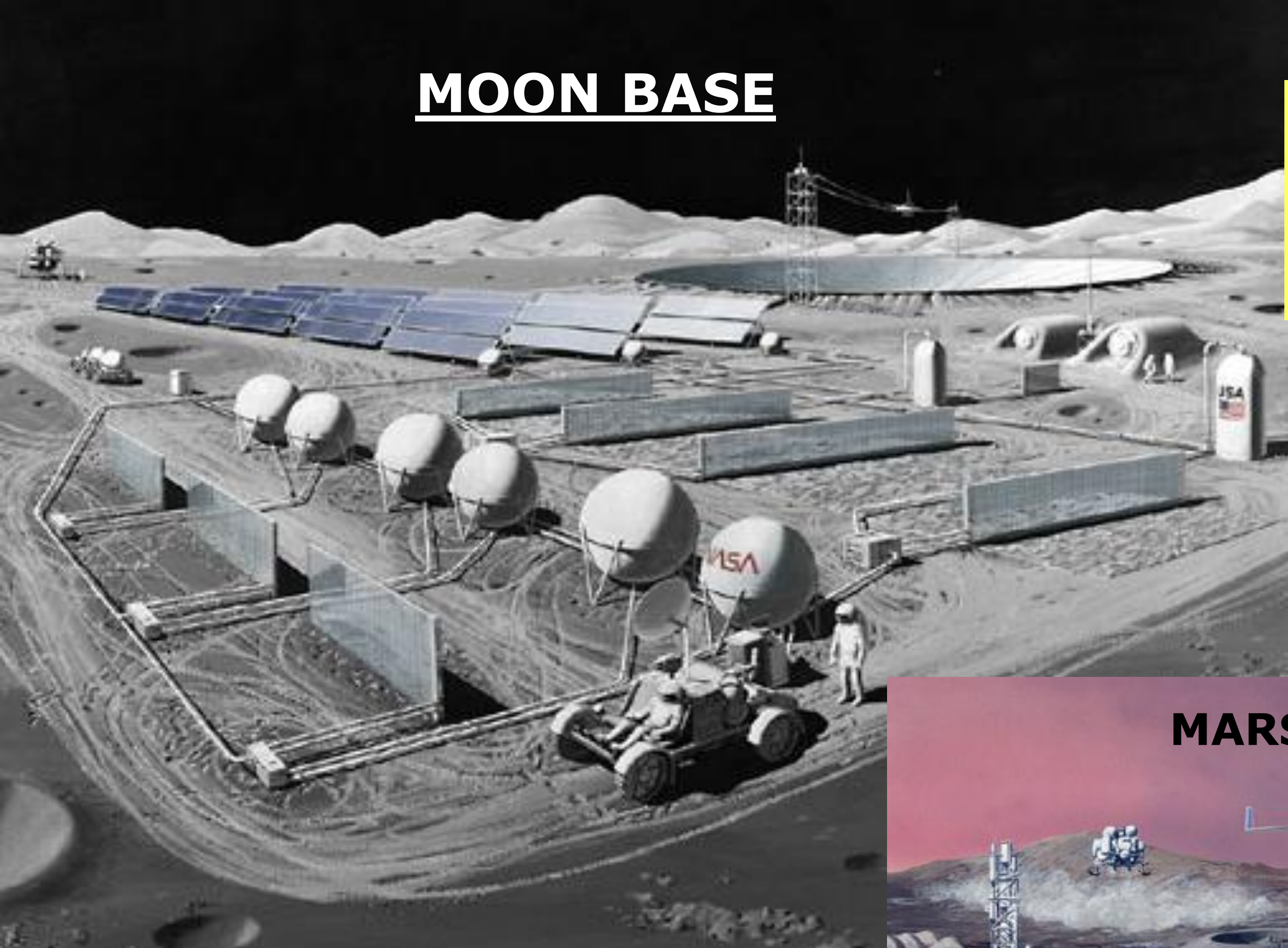
http://apps.atlantaga.gov/citycouncil/Members/ctmartin/gallery_photos/images/YF-horse3_jpg.jpg

http://www.msa.md.gov/msa/mdmanual/01glance/symbols/images/1198-1-542b.jpg

http://www.ers.usda.gov/amberwaves/September06/DataFeature/Photo/datafeature.jpg

REMOTE SITE RESEARCH:

"THE DREAM"



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http://www.nasa.gov/centers/glenn/images/content/101903main_C88_11517_516x387.jpg

MATERIALS MANAGEMENT

REMOTE SITE RESEARCH: *"THE REALITY"*

www.cep.aq/default. asp?casid=6896

http://web.archive.org/web/20051125095443/www.antarctica.ac.uk/About_BAS/Cambridge/Divisions/EID/Environment/fb_before.jpg

http://response.restoration.noaa.gov/pribilof/

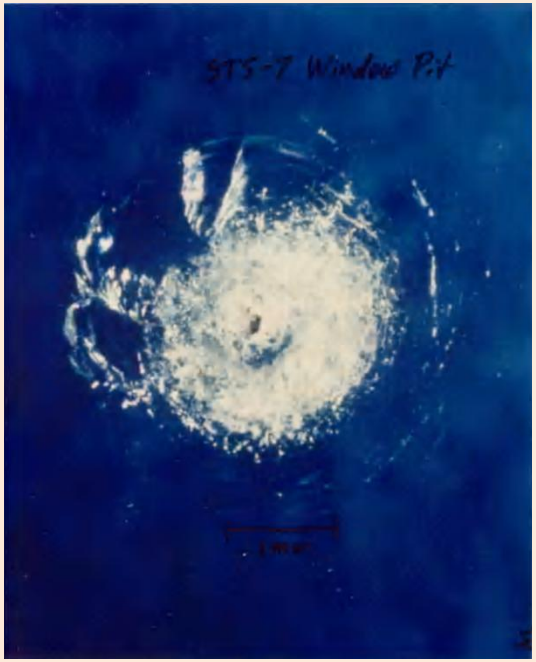
Sustainable Materials Management:

"Failure" - Space Debris

This image from the European Space Agency shows an artist's impression of the debris that orbits Earth. Scientists fear collisions of space junk may increase.

http://www.expressnightout.com/printedition/reader.php?date=2009-02-20. <accessed 20 Feb 2009>

In 1983, STS-7 (*Challenger*) window was struck by a space orbiting "paint fleck".

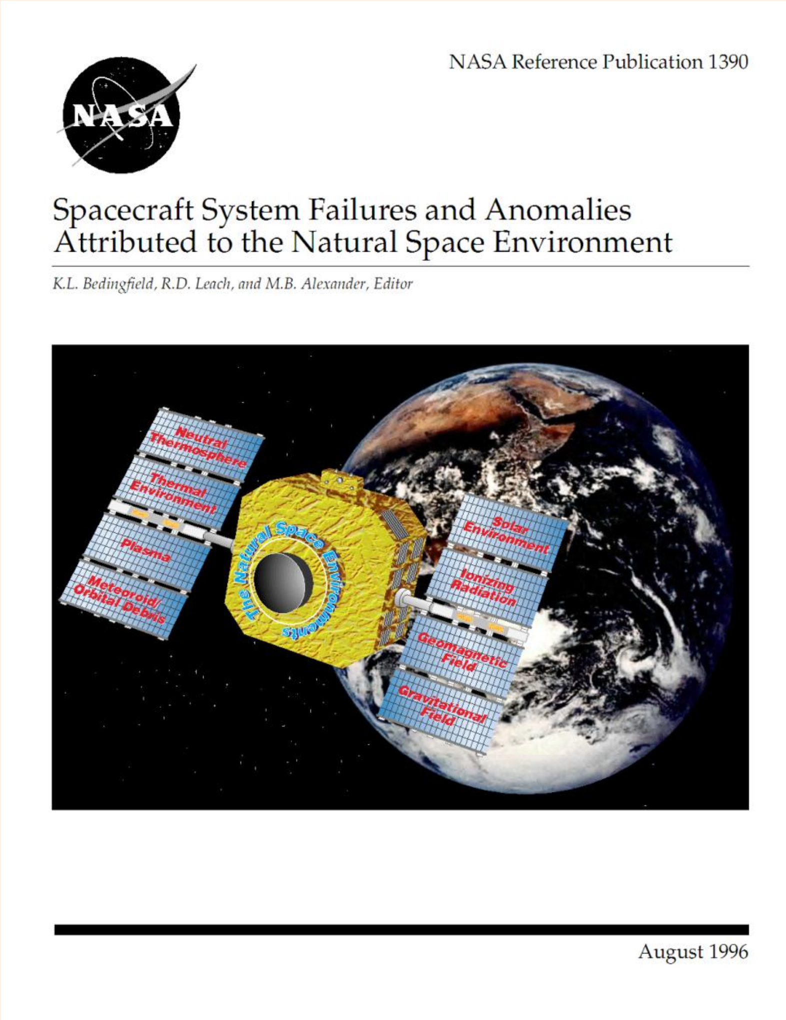


Thermal Control Surfaces – thermal protection coatings – thermal protection films – ***paints***.

[See for example – D R Wilkes (1999) Theramal Control Surfaces Experiment]

http://orbitaldebris.jsc.nasa.gov/photogallery/gallarypage/sts7crack.jpg

Gaining and understanding of how things (materials) fail in Space


NASA Reference Publication 1390

Spacecraft System Failures and Anomalies Attributed to the Natural Space Environment

K.L. Bedingfield, R.D. Leach, and M.B. Alexander, Editor

August 1996

Single-Event Gate Rupture *(SEGR)* of a power Metal-Oxide Semiconductor *(MOS)* Field-Effect Transistor *(FET)* [or MOSFET]

Damage is caused by a charge buildup – this is similar to lightning during a thunderstorm.

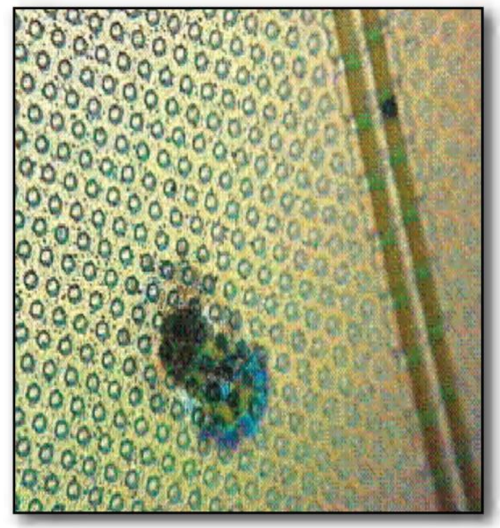


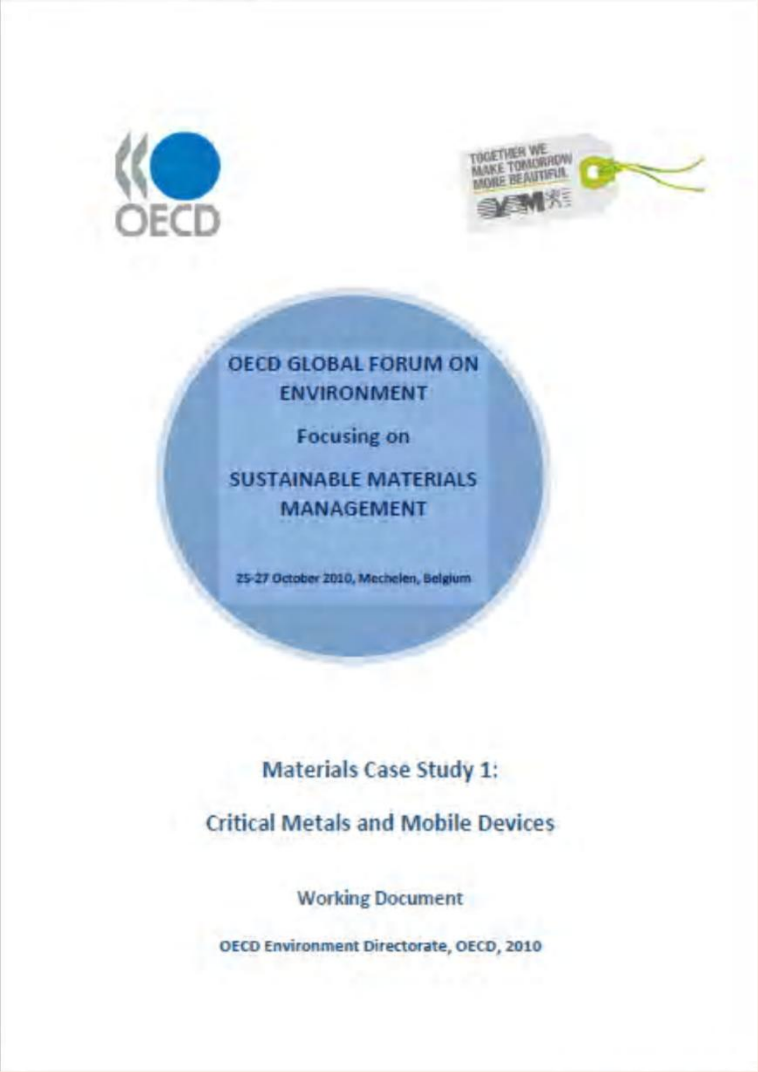
Figure 6. Photograph of a catastrophic SEGR in a power MOSFET causing functional failure.

R H Maurer, M E Fraeman, M N Martin, & D R Roth (2008) "Harsh Environments: Space Radiation Environment, Effects, and Mitigation", John Hopkins APL Technical Digest. http://techdigest.jhuapl.edu/td2801/Maurer.pdf

OEDC Global Forum on Environment:

Focusing on **Sustainable Materials Management**

25-27 October 2010


OECD

TOGETHER WE MAKE TOMORROW MORE BEAUTIFUL

OECD GLOBAL FORUM ON ENVIRONMENT

Focusing on

SUSTAINABLE MATERIALS MANAGEMENT

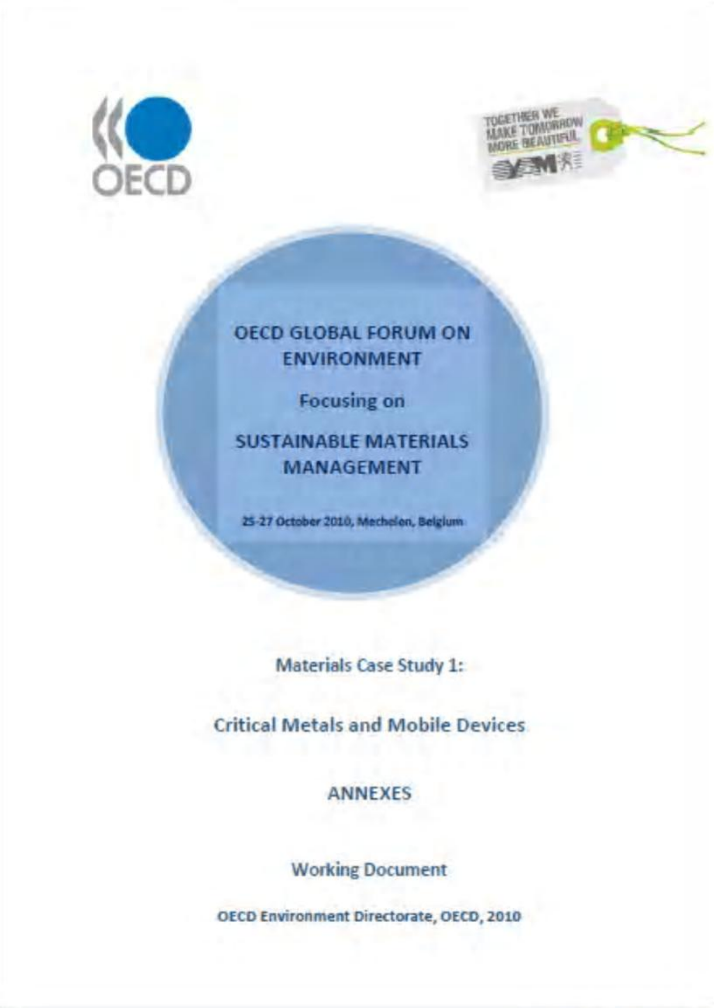
25-27 October 2010, Mechelen, Belgium

Materials Case Study 1:

Critical Metals and Mobile Devices

Working Document

OECD Environment Directorate, OECD, 2010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Materials Case Study 1:

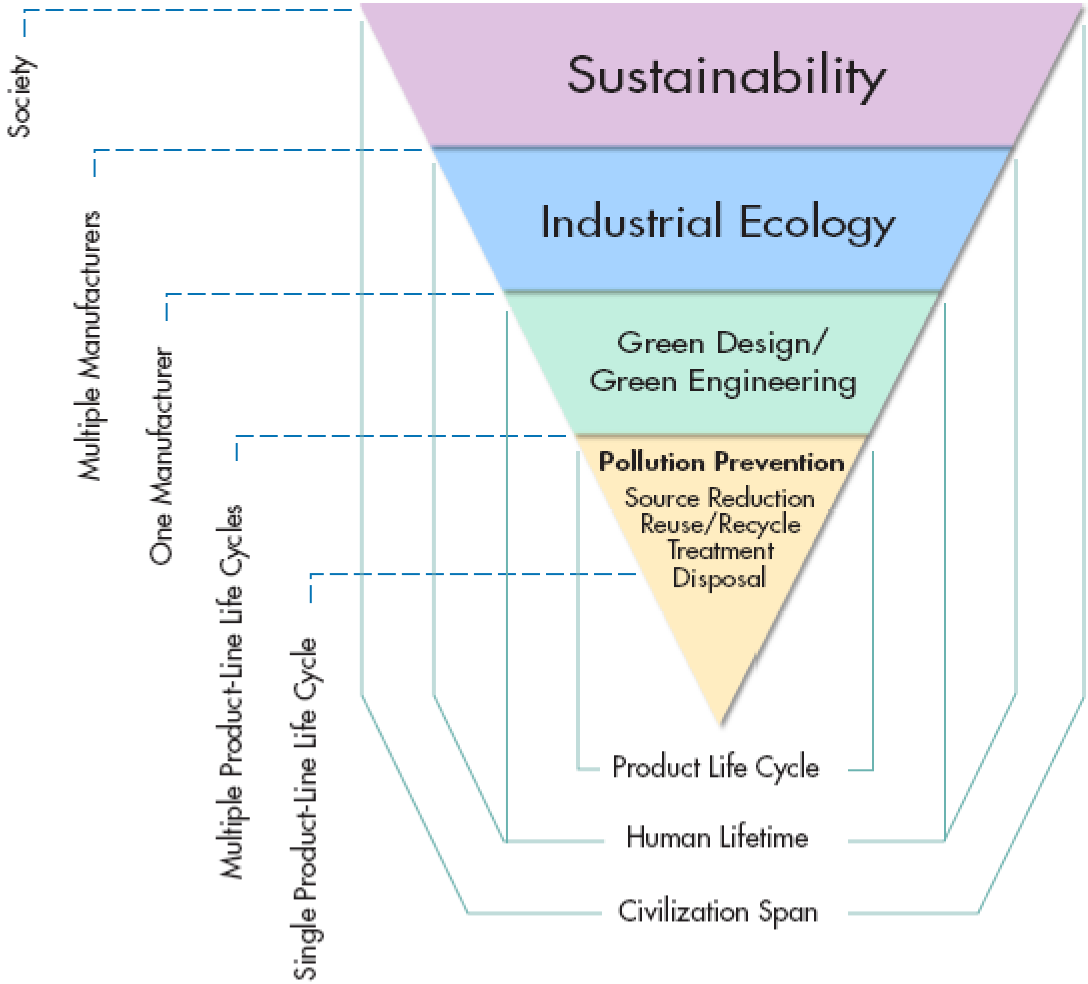
Critical Metals and Mobile Devices

ANNEXES

Working Document

OECD Environment Directorate, OECD, 2010

Environmental and Organizational Scales of Environmental Impact Reduction Approaches



Modified by I. S. Higuchi & C. C. Hudson (2005) from Coulter, Bras et al. 1995.

Sustainability: ***Optimizes*** the following three items ***simultaneously ("Triple Bottom Line")***:

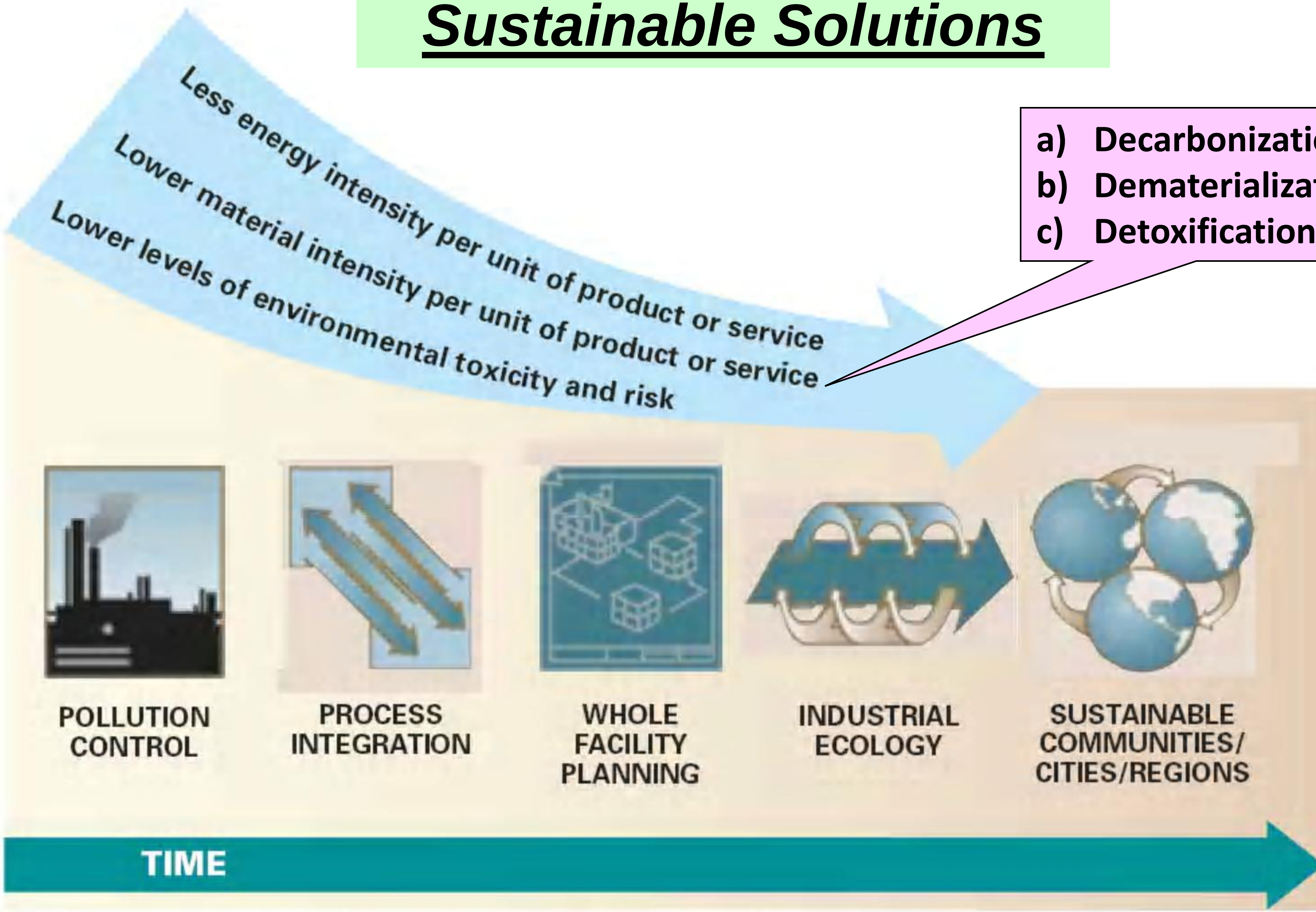
1) Renewable over non-renewable resources,
2) Ecosystem health, ***and***
3) Human welfare.

Traditionally Pollution Prevention: ***Minimizes*** one ***or*** more of the following:

1) Non-renewable resources, ***or***
2) Environmental impact, ***or***
3) Safety & health hazards.

Sustainable Solutions

a) Decarbonization
b) Dematerialization
c) Detoxification



Moving toward sustainable solutions. Adapted from the Interagency Working Group on Industrial Ecology, Material and Energy Flows, 1998, p. 21.

W. M. Brown III, G. R. Matos, & D. E. Sullivan (2000) **Materials and Energy Flows in the Earth Science Century A Summary of a Workshop Held by the USGS in November 1998 (**U.S. Geological Survey Circular 1194)

Solid Waste

Balad, Iraq

http://www.defendamerica.mil/articles/oct2004/a102104c.html

This is why Sustainable Materials Management is needed:

<u>Forward Basing challenges --</u>

1) ***Solid waste***
2) ***<u>Toxic & hazardous substances – spills, releases and contamination</u>***
3) ***Huge fuel needs for energy***

Toxic & Hazardous releases

Balad, Iraq

http://www.defendamerica.mil/archive/2004-10/20041021pm1.html

Energy (Tanker Trucks fuel & water)

Trebil, Iraq

http://www.mnf-iraq.com/index.php?option=com_content&task=view&id=351&Itemid=132

SEMI-CONDUCTOR CHALLENGE

"GLASS COCKPIT"

During the 1970s and 1980s, NASA created and tested the concept of an advanced cockpit display that would replace the growing number of dial and gauge instruments that were taking up space on an aircraft's flight deck. Called a "glass cockpit," the innovative approach uses flat panel digital displays to provide the flight deck crew with a more integrated, easily understood picture of the vehicle situation. Glass cockpits are in use on commercial, military, and general aviation aircraft, and on NASA's space shuttle fleet.

The glass cockpit replaces 4 cathode ray tube displays, 32 gauges and electro-mechanical displays.

http://spaceflight.nasa.gov/gallery/images/shuttle/sts-101/hires/s99_01418.jpg

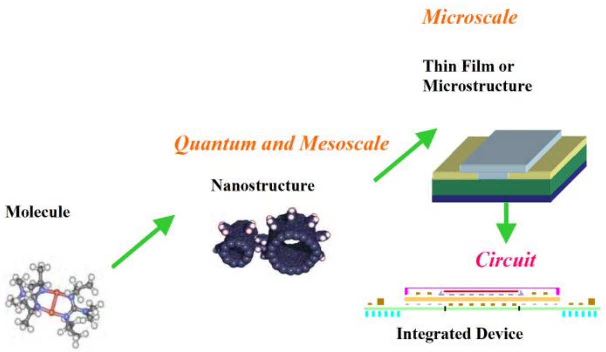


Figure 5 Multi-scale Perspective in Nanotechnology where Materials Form an Important Role at Different Levels.

INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS

2009 EDITION

EMERGING RESEARCH MATERIALS

http://www.itrs.net/Links/2009ITRS/2009Chapters_2009Tables/2009_ERM.pdf

Assessment of the Potential & Maturity of Selected Emerging Research Memory Technologies Workshop & ERD/ERM Working Group Meeting (April 6-7, 2010)

Jim Hutchby & Mike Garner

July 23, 2010

Executive Summary

With the support of the International Technology Roadmap for Semiconductor (ITRS) International Roadmap Committee (IRC), the ITRS Emerging Research Devices (ERD) and Emerging Research Materials (ERM) Technology Work Groups (TWGs) completed an assessment of eight memory technologies to determine whether one or more should receive increased focus to accelerate technology development toward commercialization. To be considered for increased focus, the memory technology needs to have demonstrated good performance with an understood storage mechanism and be scalable multiple generations beyond the 16nm technology generation. Further, it should be ready for manufacturing within the next 5 to 10 years. After reviewing white papers on each memory technology, the cases for each technology were presented by advocates and challenged by "friendly critics". Following review and discussion, the ERD and ERM Work Groups recommended to the IRC that STT-MRAM and Redox RAM receive additional focus in research and development to accelerate progress toward commercialization of one or both of these technologies. The IRC approved communication of these recommendations to the Research community and to funding agencies. A subsequent workshop will be held to identify specific materials and process research needed to enable critical progress on these technologies.

Introduction

Current memory technologies, such as DRAM, SRAM, and NAND Flash, are approaching very difficult issues related their continued scaling to and beyond the 16nm generation. Fortunately, research over the past ten – fifteen years has led to discovery of several new memory technologies, many in the category of Resistive RAMs. These emerging research memory technologies include the Ferroelectric-gate FET, Nanoelectromechanical RAM, Spin Transfer Torque MRAM, Nanoionic or Redox Memory (including the Fuse/Antifuse Memory and related Electrochemical Metallization, Programmable Metal Cell and the Atomic Switch), Nanowire Phase Change Memory, Electronic effects Memory (i.e., Charge trapping, Mott transition, Ferroelectric barrier effects), Macromolecular memory, and Molecular memory. Research has provided some clarification and insight to the physical storage mechanisms and the limits of several of these approaches, which can provide a basis for judging their long-term potential. Further, the International Technology Roadmap for Semiconductors' (ITRS) Emerging Research Devices (ERD) and Emerging Research Materials (ERM) International Technical Working Groups (ERD/ERM ITWGs), for the past nine years, have evaluated the viability of the more promising approaches for new memory technologies using a set of relevant metrics. The most recent ITRS/ERD projections for several current memory technologies are given in Appendix 1 and projections for emerging research memory technologies are given in Appendix 2. Long-term projections for the emerging research memory technologies assessed in this study are summarized in Appendix 3.

A classification of memory technologies is given in Fig. 1 below.

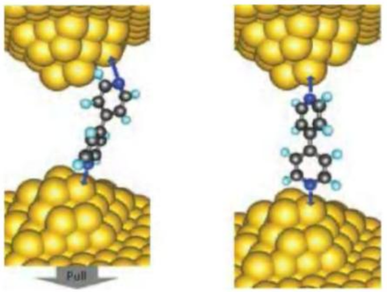
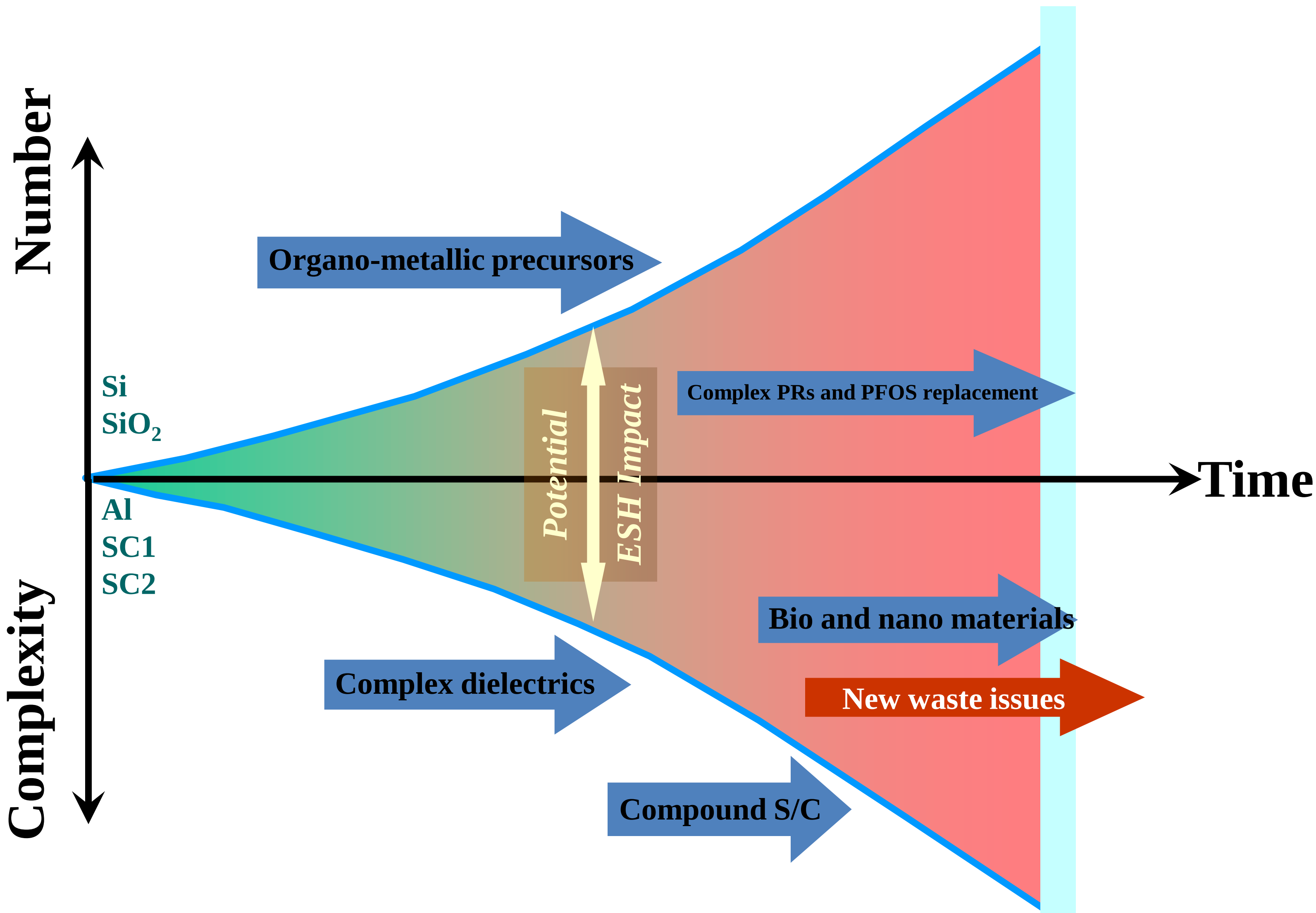


Figure 41. The conformation of a Au-bipyridine molecule is changed with mechanical distortion and this changes the conductivity of the molecule.

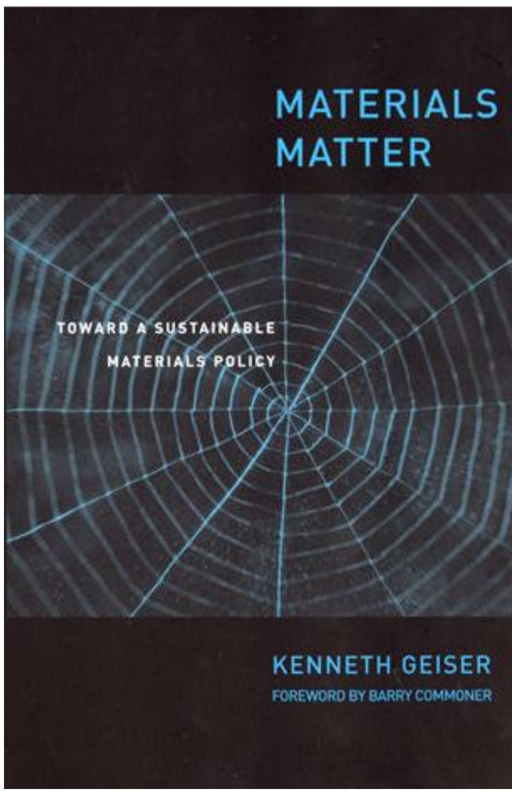
http://www.itrs.net/Links/2010ITRS/2010Update/ToPost/ERD_ERM_2010FINALReportMemoryAssessment_ITRS.pdf

Potential Risks of Introducing New Materials



F Shadman (May 2008) EPA Science Forum: <u>Environmental Challenges and Opportunities in Nano-Manufacturing </u>(Semiconductor Manufacturing)

Sustainable Materials Management = *"an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life-cycle of materials, taking into account economic efficiency and social equity."* – OECD (2007) "Working Group on Waste Prevention and Recycling: Outcome of the First OECD Workshop on Sustainable Materials Management"



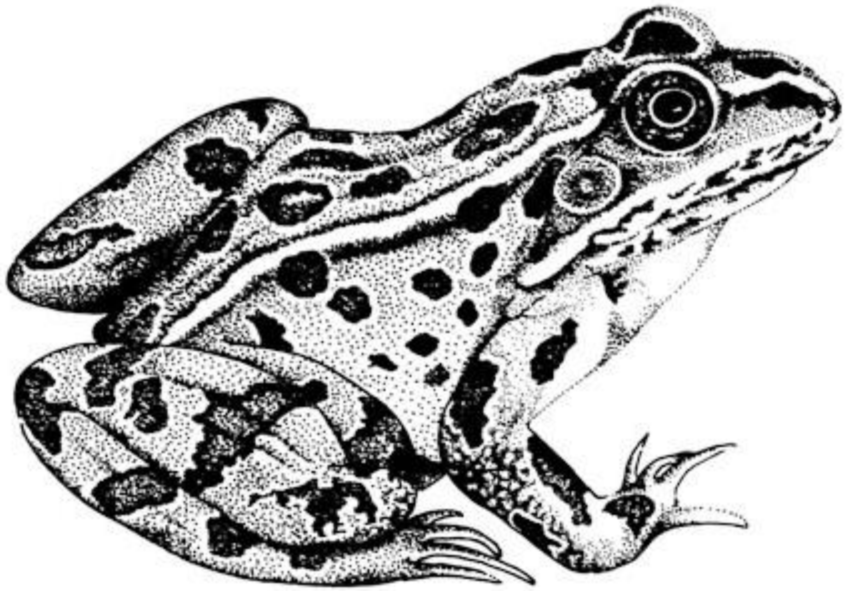
Promoting Sustainable Materials

(Modified from K Geiser (2001))

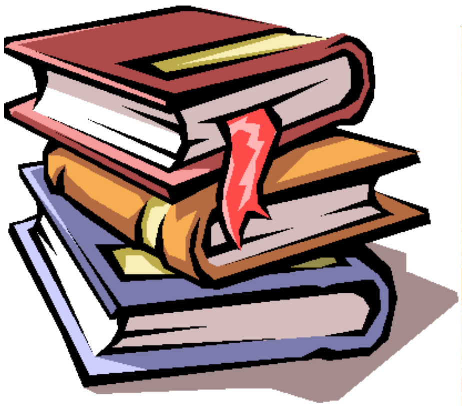
The Strategies

- ***a) Detoxification***
- ***b) Dematerialization***
- ***c) Decarbonization***

5 Action Areas	Activities
1) Create new information systems	X
2) Reducing materials markets	X
3) Reconfiguring corporate culture & mission	X
4) Redirecting government policies	X
5) Promoting public engagement	X

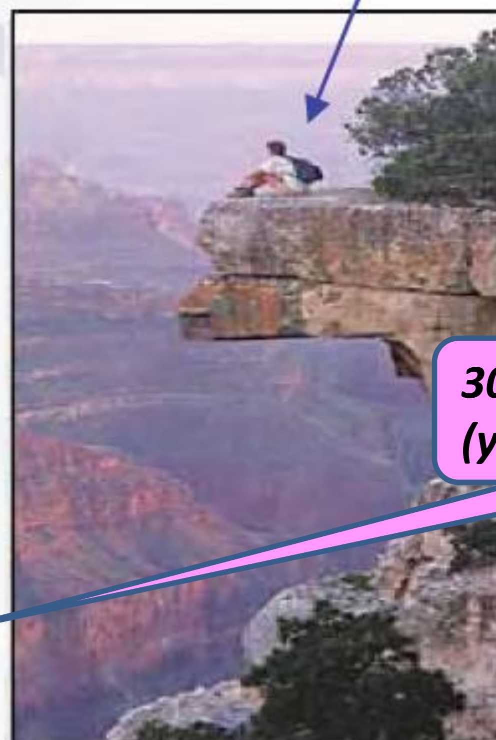


<u>"Leap-Frogging" Technology</u>



What is the Problem?

Materials efforts (new compositions, processing, manufacturing) are not linked with the design process.



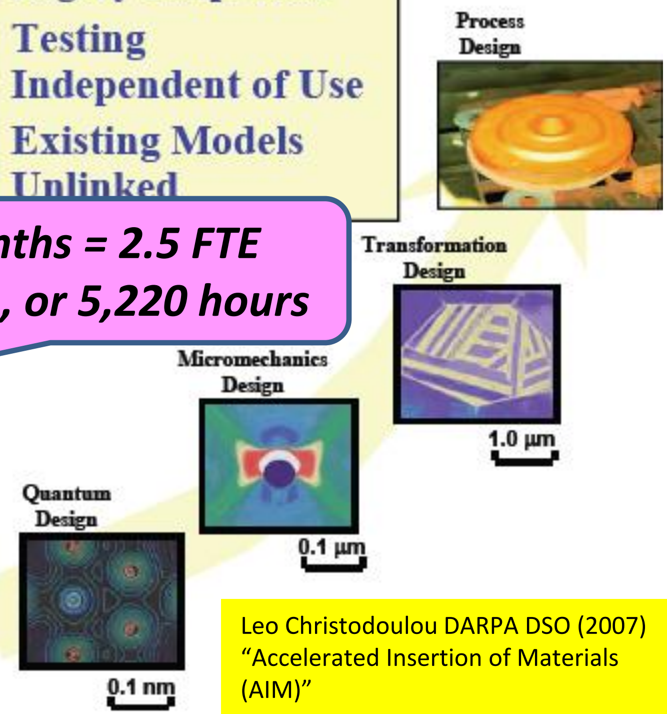
<u>Systems Design</u>

- Materials Input from "Knowledge Base" of Data (Data Sheets, Graphs, Heuristics, Experience, etc.)
- System/Sub-System Design is Heavily Computational and Rapid
- Clean Sheet of Paper to Engine Design - 30 Months
- Well Established Testing Protocols

30 months = 2.5 FTE (years), or 5,220 hours

<u>Materials Development</u>

- Highly Empirical
- Testing Independent of Use
- Existing Models Unlinked



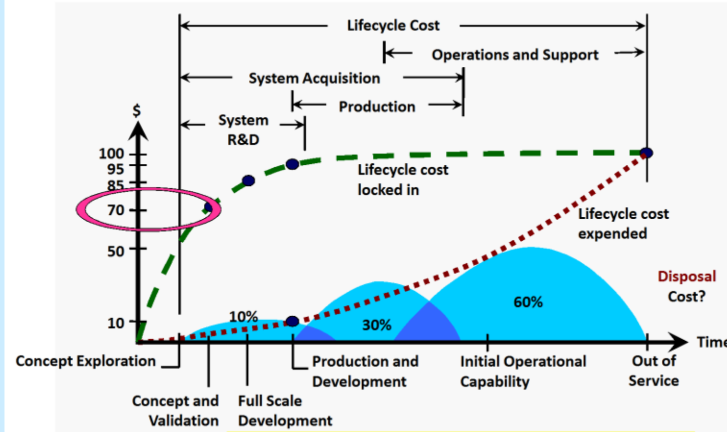
Leo Christodoulou DARPA DSO (2007) "Accelerated Insertion of Materials (AIM)"

Materials and Processes Technical Information System (MAPTIS)

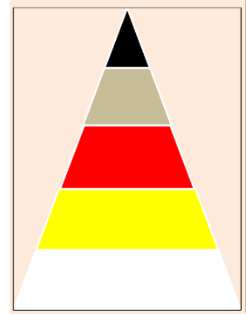
Provides Aerospace materials **design support:**

1) Information on **40,000 materials** (e.g., materials test data, materials properties, design allowables);
2) Contains space flight hardware candidate for **over 32,000 materials** test results for usability and safety issues (e.g., toxicity, flammability, fracture, off-gassing);
3) Enhanced information capabilities for **regulated materials-chemicals**.

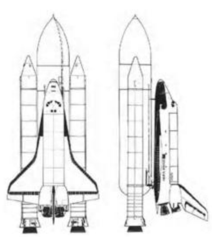
Percentage of Cost Locked In by Phase



From W. J. Larson & L. K. Prance (1999) Human Spaceflight: Mission Analysis and Design



MATERIAL STATUS	REMARKS	Color Key
"Banned	*Cannot use*	
"To be phased out"	*Needs to be replace*	
"Restricted"	*Funds needed to manage*	
"Caution"	*Negative attribute*	
"No Information"	*No information*	



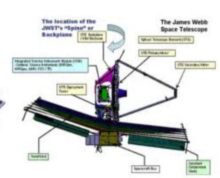
http://history.nasa.gov/rogersrep/v1p3.jpg

http://aerospacescholars.jsc.nasa.gov/has/Modules/Earth-to-Mars/8/12_clip_image009_0000.jpg

http://www.nasa.gov/images/content/123126main_rockets_full.jpg

http://quest.nasa.gov/hst/about/hst.gif

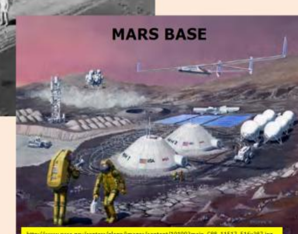
http://www.nasa.gov/images/content/155379main_jsc2006e33312_low.jpg



http://www.nasa.gov/centers/goddard/images/content/167893main_spine_image2_large.jpg

REMOTE SITE RESEARCH:

"THE DREAM"



MATERIALS MANAGEMENT

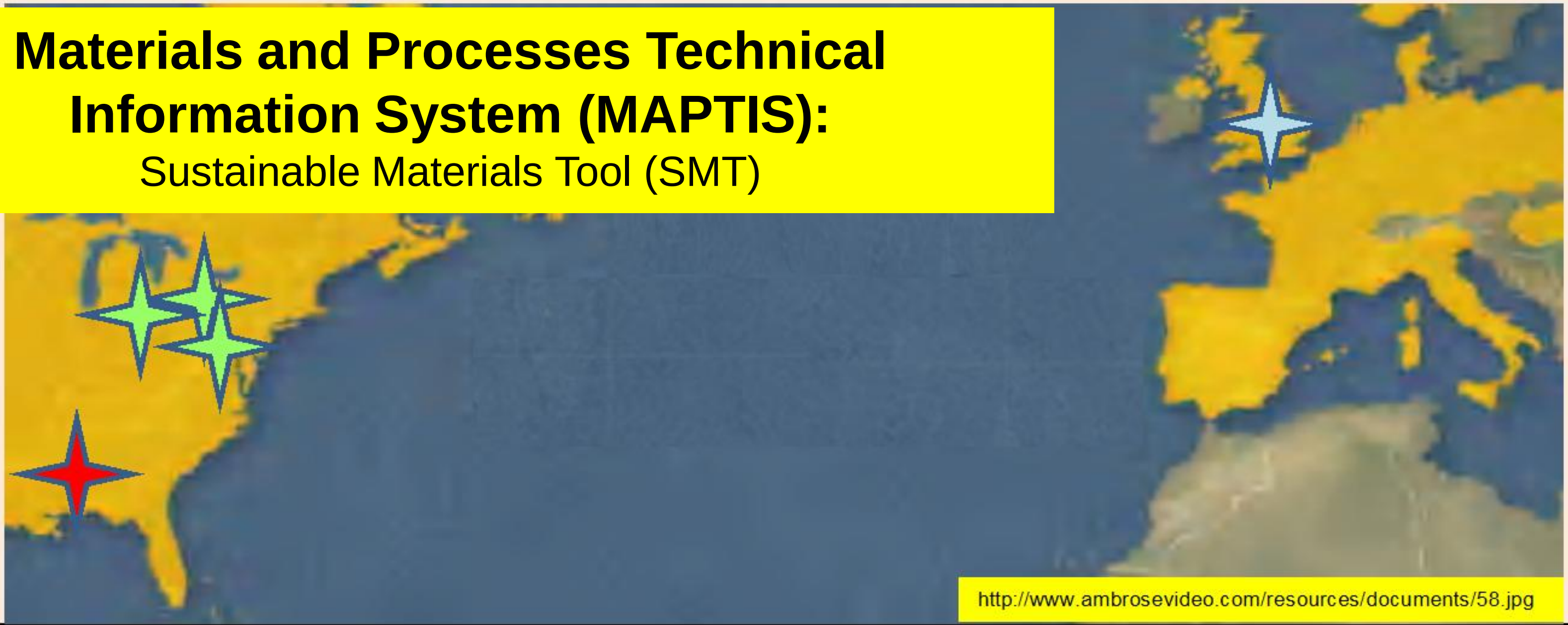
REMOTE SITE RESEARCH:

"THE REALITY"

http://response.restoration.noaa.gov/pribilof/

Materials and Processes Technical Information System (MAPTIS):

Sustainable Materials Tool (SMT)



http://www.ambrosevideo.com/resources/documents/58.jpg

NASA IMPLEMENTATION TEAM:

Marshall Space Flight Center (MAPTIS)

- ***Dennis Griffin – Chief, Materials & Processes Laboratory Lead Engineers Office***
- ***Marceia Clark-Ingram – Materials Engineer***

SUPPORT TEAM (MAPTIS):

Dyne tics (Huntsville, AL)

- ***Billy Elliot – Information Technology***

MEI Technologies (Huntsville, AL)

- ***Ben Henrie – Engineering, Information Technology***

CORE NASA STEERING TEAM:

Marshall Space Flight Center (MAPTIS)

- *Dennis Griffin – Chief, Materials & Processes Laboratory Lead Engineers Office*

Glenn Research Center (& Plum Brook Station)

- *Steven Arnold – Chief, Mechanics and Life Prediction Branch*
- *Tim Polich – Senior Nuclear Engineer*

Headquarters

- *I. Sam Higuchi – Coordinator, Staff Engineer (Christina Hudson – SAIC – NASA-HQ support contactor)*

EXTENDED SUPPORT TEAM:

University of Cambridge (UK) – Granta Design, Ltd.

- ***David Cebon – Professor, Mechanical Engineering***

International Consortia (membership):

- *Materials Data Management Consortium* - S Arnold
- *Materials Strategy Consortium* - T Polich
- *Environmental Materials Information Technology (EMIT) Consortium* – D Griffin

Informal Collaboration on Rare Earth Metals

Informal International Collaboration on:
Rare Earth Metals – scope of the challenge
(precursor for Sustainable Materials Management approach)

➢ U.S. Army Entities ➢ NASA HQ and 2 Centers	➢ U.K. Governmental Entities

EXAMPLE

Commercially available information:

Granta Design, Ltd.

Granta MI and ***CES Eco-Selector***

Granta Design's has Geo-Economic Data for over 3000 materials in its

1) *Granta MI (service-product)*
2) *Granta CES Eco-Selector (product)*

Table 5 The eco-attributes of one grade of aluminium alloy.

WROUGHT ALUMINIUM PURE, 1-0

Geo-Economic Data for Principal Component				
Principal Component	Aluminium			
Annual world production	2.1e7	-	2.3e7	tonne/yr
Reserves	2e10	-	2.2e10	tonne
Typical exploited ore grade	30	-	34	%
Minimum economic ore grade	25	-	39	%
Abundance in earth's crust	7.8e4	-	8.6e4	ppm
Abundance in seawater	2.5e-4	-	2.8e-4	ppm
Material production: energy and emissions				
Production energy	1.9e2	-	2.1e2	MJ/kg
Carbon dioxide	* 12	-	13	kg/kg
Nitrogen oxides	* 72	-	79	g/kg
Sulphur oxides	* 1.2e2	-	1.4e2	g/kg
Indicators for principal component				
Eco indicator	7.4e2	-	8.2e2	millipoints / kg
Material processing energy at 30% efficiency				
Min. Energy to Melt	3.5	-	3.8	MJ/kg
Min. Energy to Vaporisation	29	-	32	MJ/kg
Min. Energy to 90% Deform.	0.039	-	0.044	MJ/kg
End of life				
Recycle	True			
Downcycle	True			
Biodegrade	False			
Incinerate	False			
Landfill	True			
Recycling Energy	* 23	-	26	MJ/kg
Recycle as fraction of current supply	34	-	38	%
Bio-data				
Toxicity rating	Non-toxic			
Approve for skin & food contact	True			
Sustainability				
Sustainable	No			

Possible Substitutes for Principal Component

Copper can replace aluminum in electrical applications; magnesium, titanium, and steel can substitute for aluminum in structural and ground transportation uses. Composites, wood, and steel can substitute for aluminum in construction. Glass, plastics, paper, and steel can substitute for aluminum in packaging.

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M F Ashby, A Miller, F Rutter, C Seymour, & U.G.K Wegst (2005) "The CES Eco-selector: background reading"

Components for a Materials Strategy

- ✓ **Holistic Approach**
- ✓ **Enterprise Risk Management**
- ✓ **Sustainable Materials Management**
- ✓ **Systematic Framework for Actions**
  - ➢ ***Information Systems*** *(Special Focus)*

Why Information Systems?

Economic Productivity **is increased through investments in three areas:**

- ➢ **Education & Training**
- ➢ **Infrastructure**
- ➢ **Research & Development**

Information Systems are linked to all three.

Sustainable Materials Management: Technology Innovation

http://www.tremcenter.org/index.php?option=com_content&view=article&id=419&Itemid=474

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