MONASH University Engineering

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# "Abiotic Resource Depletion & LCA: Where From Here?"

Presented at the

"EXPERT WORKSHOP

SECURITY OF SUPPLY AND SCARCITY OF RAW MATERIALS:

A METHODOLOGICAL FRAMEWORK FOR SUPPLY CHAIN SUSTAINABILITY ASSESSMENT"

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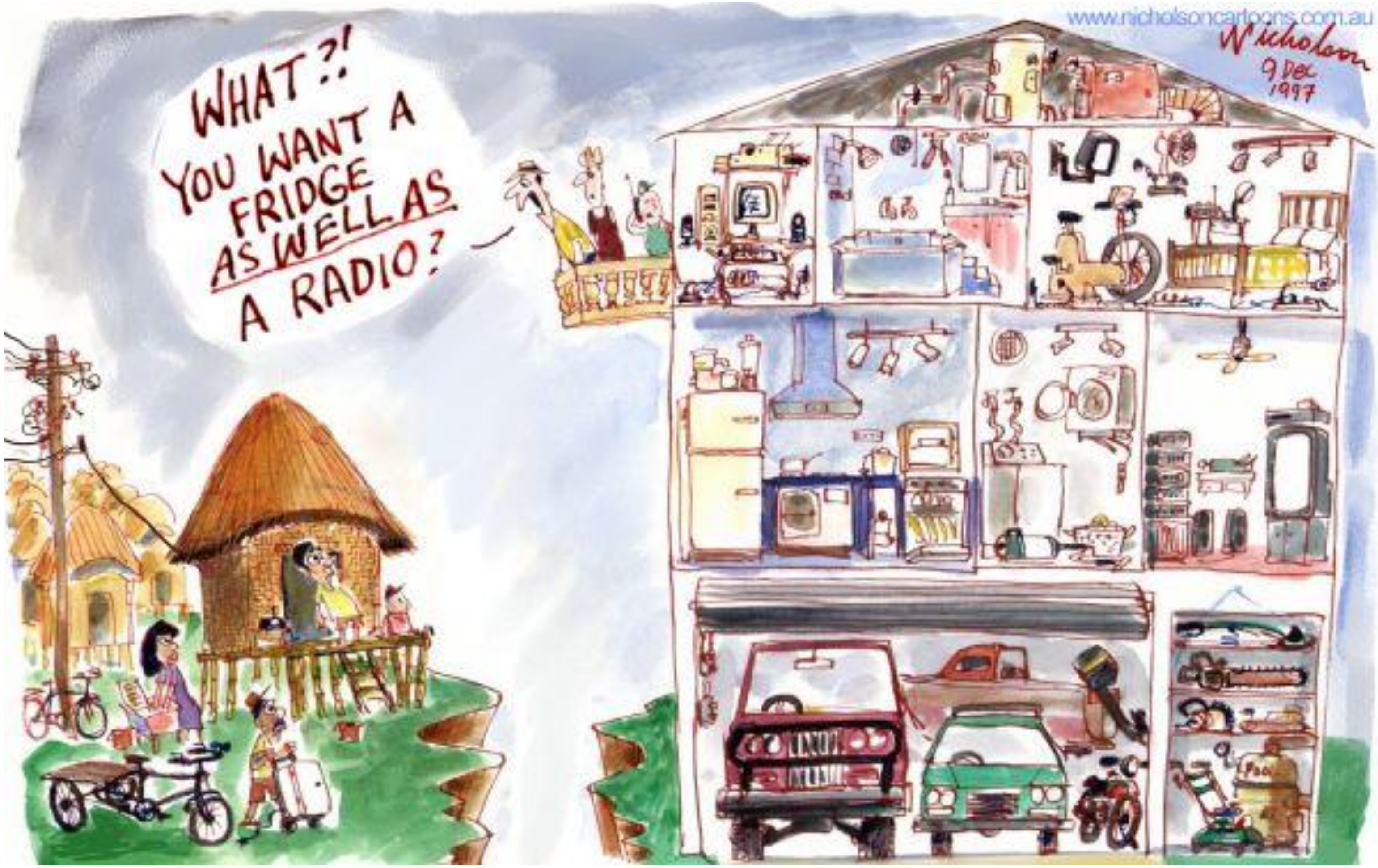
**Dr Mohan Yellishetty**
**Department of Civil Engineering**
**Monash University**

**eMail:** mohan.yellishetty@monash.edu

# Outline of the Presentation

- Introduction
- A Brief Outlook on the current State-of-the Art about ARD in LCA
- Need for the Resource Debate to continue
- Methodological Frameworks – a Review
- What Framework is Needed
- Conclusions

# A Sustainability Nightmare



# Introduction - LCA

- is a technique used in environmental analysis of potential environmental impacts of any product or process over its entire life cycle, ***from raw material acquisition*** to ultimate disposal
- addresses the *potential environmental impacts, human health and resource concerns for a product system*, including raw material acquisition through manufacture, use, end-of-life treatment, recycling and final disposal.
- was developed directly from a desire to *limit the energy used* in manufacturing processes
- is a major **sustainability** assessment tool for industrial sectors

# Introduction – LCA – Abiotic Resources

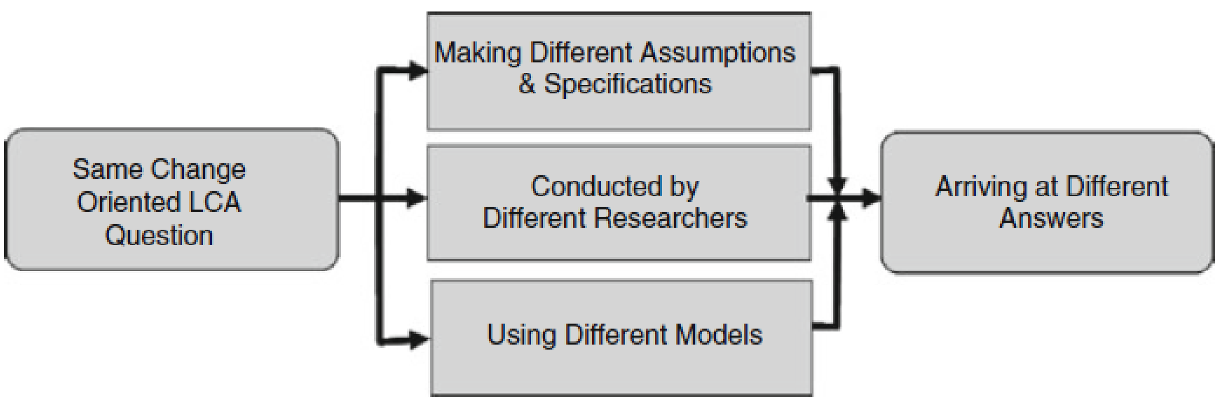
- entities that are valued for the functionality that they deliver to human society.
- “raw materials or means for production or consumption activities”

***Ore Reserves***: assessments demonstrate at the time of reporting that economic extraction could reasonably be justified. Ore Reserves are sub-divided in order of increasing confidence into Probable Ore Reserves and Proved Ore Reserves. (JORC)

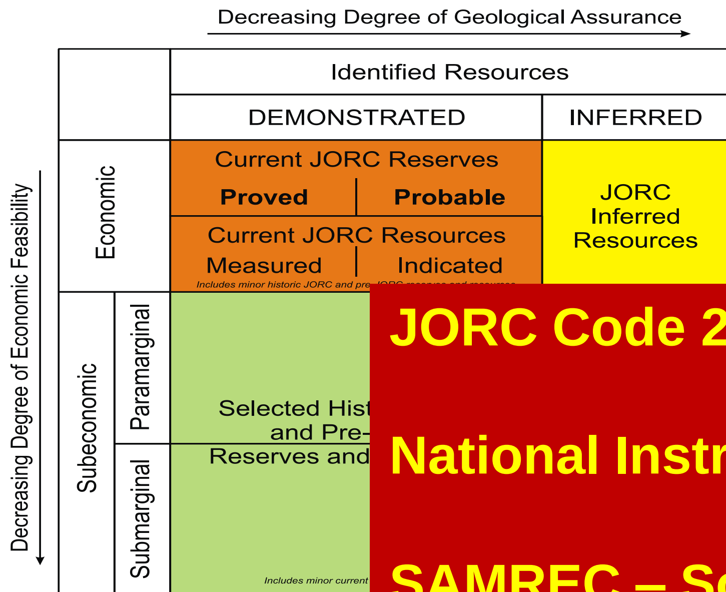
***Mineral Resources***: the location, quantity, grade, geological characteristics and continuity of a Mineral Resource are known, such that there are reasonable prospects for eventual economic extraction; not all modifying factors have been assessed and hence some uncertainty remains. (JORC)

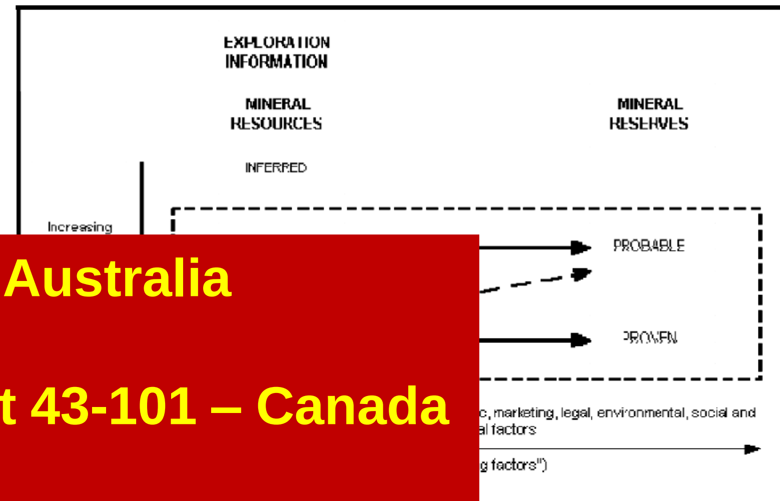
# LCA : an Evolving Sustainability Assessment Tool

| Year | Major events in LCA development as a technique |
|---|---|
| 1960s | LCA was performed by the Midwest Research Institute (MRI) (Giudice et al. 2006) |
| 1970s | The US Department of Energy commissions' studies on 'Energy Analysis' titled 'Resources and Environmental Profile Analysis' (REPA) (Guinée 2002) |
| 1980s | 'Green Movement' in Europe brings focus back on emissions and the need for recycling. European industries study their pollution releases and begin comparing alternatives (Guinée 2002) |
| 1989–1990 | SETAC is first involved in LCA. The first-ever SETAC workshop was held to define LCA (Guinée 2002) |
| 1992 | First Dutch guide on LCA was published (Guinée 2002) |
| 1994 | First involvement of International Organization for Standardization (ISO) (Giudice et al. 2006) |
| 1995 | UNEPs' first involvement through publication first document – 'LCA: what it is and how to do it'. Subsequently, in 1996, releasing 'Towards the Global Use of LCA' (Giudice et al. 2006) |
| 1997 | First-ever ISO 14040 standards series on LCA brought into force (Giudice et al. 2006) |
| 2002 | UNEP/SETAC Life Cycle Initiative began (Guinée 2002)<br>International Council on Mining and Metals (ICMM) and Natural Resources Canada (NRCan) joined hands with UNEP-SETAC (Dubreuil 2005) |
| 2010 | The European Commission/Joint Research Centre launches the International Reference Life Cycle Data System Handbook (http://lct.jrc.ec.europa.eu/publications) |



# Resources – A Loose Definition




JORC Code 2004 – Australia

National Instrument 43-101 – Canada

SAMREC – South Africa

The USGS

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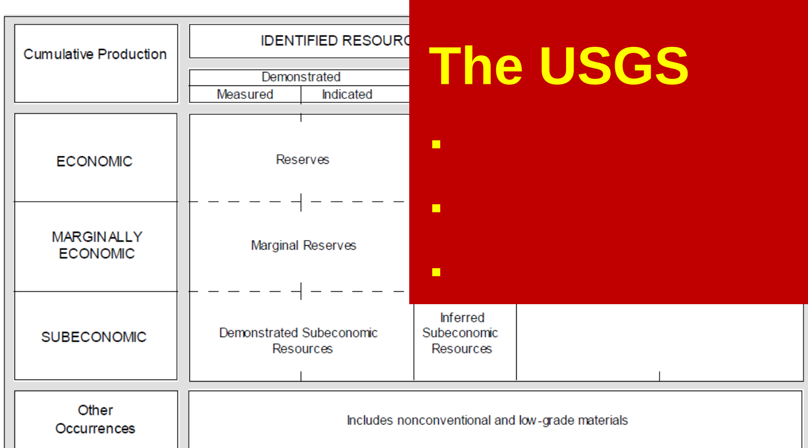
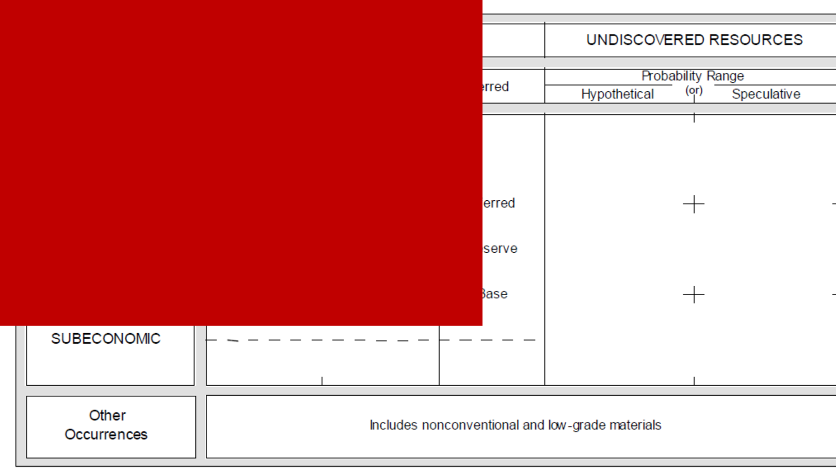
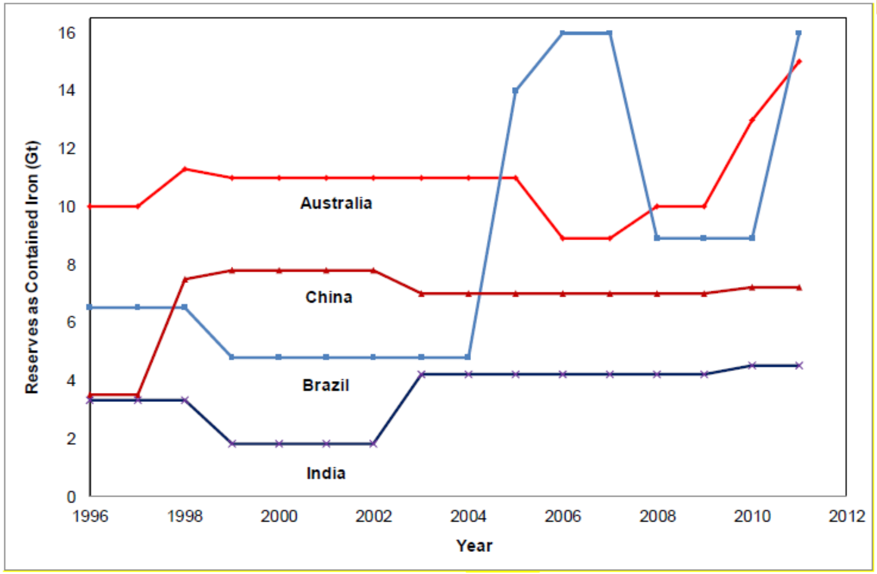


# Iron Ore Reserves (USGS)




| Ore/Mineral | Units | World (1974)[e] | | World (1999)[f] | | World (2007)[f] | | % increase/ decrease (1974–2007) | | % increase/ decrease (1999–2007) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | R[c, a] | RB[d, b] | R | RB | R | RB | R | RB | R | RB |
| Iron | Mt | 87,001 | 1,400,013,970,788 | 140,000 | 300,000 | 150,000 | 340,004 | 72 | (99) | 7 | 13 |
| Boron | Mt | | | 170 | 470 | 170 | 410 | – | – | (0.001) | (13) |
| Cobalt | kt | 2000 | 600,005,987,000 | 5000 | 10,000 | 7000 | 13,000 | 192 | (99) | 48 | 24 |
| Columbium | kt | | | 4000 | 6000 | 2700 | 3000 | – | – | (30) | (51) |
| Copper | Mt | 390 | 1,500,014,969 | 340 | 650 | 490 | 940 | 26 | (99) | 44 | 45 |
| Lead | Mt | 145 | 290,002,894 | 66 | 140 | 79 | 170 | (46) | (99) | 20 | 21 |
| Manganese | Mt | 1900 | 31,200,311,349 | 680 | 5000 | 460 | 5200 | (76) | (99) | (32) | 4 |
| Molybdenum | Mt | 5 | 31,200,311 | 6 | 12 | 8.6 | 19 | 72 | (99) | 56 | 58 |
| Nickel | Mt | 44 | 2,100,021 | 44 | 154 | 67 | 150 | 51 | (99) | 52 | (3) |
| Selenium | tonnes | – | – | 77,160 | 143,299 | 82,000 | 170,000 | – | – | 6 | 19 |
| Vanadium | Mt | 10 | 3,400,033,929 | 11 | 30 | 13 | 38 | 34 | (99) | 18 | 28 |

# Resources – A Loose Definition

| Country | Iron Ore Reserves (Gt) | Iron Content (Gt) | Production in 2009 (Mt) | | Rank in 2009 | |
|---|---|---|---|---|---|---|
| | | | Iron Ore | Crude Steel | Iron Ore | Crude Steel |
| Australia | 20 | 13 | 370 | 5.25 | 3 | 23 |
| Brazil | 16 | 8.9 | 380 | 26.51 | 2 | 9 |
| China* | 22* | 7.2* | 900 | 567.84 | 1 | 1 |
| Ind | | | | | | |
| Ru | | | | | | |
| Uk | | | | | | |
| US | | | | | | |
| **Wo** | | | | | | |

| Ore Type | Count | Ore (Mt) | %Fe | %P | $\%SiO_2$ | $\%Al_2O_3$ | %S | %LOI |
|---|---|---|---|---|---|---|---|---|
| G | 2 | 37 | 41.2 | 0.20 | ~27 | ~3.1 | ~0.03 | ~7.5 |
| G-h | 10 | 7,968 | 56.9 | ~0.06 | ~6.8 | ~2.7 | ~0.02 | ~9.5 |
| H | 63 | 20,466 | 49.0 | ~0.06 | ~18.5 | ~3.8 | - | ~6.5 |
| H-g | 32 | 28,133 | 60.2 | ~0.11 | ~5.1 | ~2.8 | - | ~6.2 |
| M | 54 | 35,802 | 27.9 | ~0.08 | ~42.5 | ~3.0 | ~0.1 | ~2.7 |
| M-h | 1 | 19 | 42.3 | - | - | - | - | - |
| Total | 162 | 92,425 | 44.9 | 0.08 | 22.7 | 3.1 | - | 5.2 |

## What Are the Current Issues?

- resource scarcity is becoming increasingly imminent - BRICS
- the quantification of abiotic resource depletion in LCA – ie. how to account for resource depletion in the life cycle impact assessment (LCIA) stage is unclear
- no definitive approach for quantifying the effects of ARD and the current LCA models fail to recognise the ARD as a potential problem and therefore do not address the issue

# Characteristics of Main Material Families

– a useful backhand information to underpin the depletion concerns

| Characteristics | Details | | |
|---|---|---|---|
| | Metals | Plastics | Wood and paper |
| Resource stock | Metal ore/minerals | Crude oil | Forests |
| Source | Lithosphere | Lithosphere | Biosphere |
| Extraction method | Mining: opencast/underground | Drilling and extraction | Harvest |
| Material structure | Elemental (metals/alloys) | Molecular | Cellular |
| Material renewal | Recyclable | Recyclable but quality degrades | Recyclable but quality degrades |
| Final fate | Elements are permanent and may remain for a long time | Combustion, degradation and landfill | Biodegradation, combustion and landfill |
| Losses | Corrosion, wear, process loss | May return to carbon cycle | May return to carbon cycle |
| Time scale of material stock | Theoretically unlimited | Days to years | Days to decades |
| Applications | Beverage cans, consumer products, auto components, motors, structures, etc. | Furniture, coatings, packaging, appliances and auto parts, etc. | Building, books/news papers, packaging and furniture, etc. |

# Impact Assessment Methods in LCA

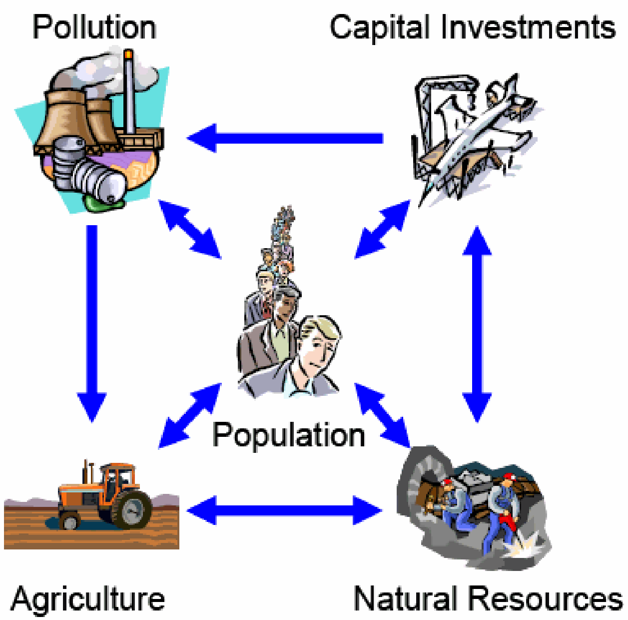
**Methodologies either focus on current consumption, Or on the future consequences.**

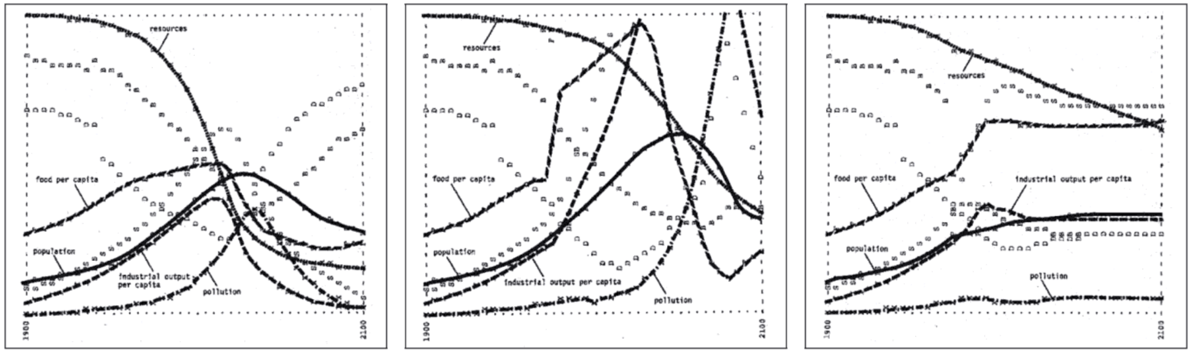
| Group | Assessment method | Empirical formula |
|---|---|---|
| Group 1 | Aggregation of natural resource extraction on mass basis (Lindfors et al. 1995) | $ADP_i = \sum_i CF_i \times m_i$ where $CF_i = 1$ |
| Group 2 | Aggregation and assessment based on energy impacts, which are based on substitution of the current extraction process or improved future processes (Steen 1999) | $ADP_i = \sum_i WTP \times m_i$ |
| Group 3 | Aggregation and assessment based on the exergy or entropy content or change (Bösch et al. 2007) | $ADP_i = \sum_i CF_i \times m_i$ where $CF_i = Ex_{ch,i}$ |
| Group 4 | Aggregation and assessment based either on the quantity of resource that is ultimately available or the part of the reserve base that can be economically extracted and the extraction rate at the time of the assessment (Guinée and Heijungs 1995; Guinée 2002) | $CF_i = ADP_i = \frac{DR_i}{(R_i)^2} \times \frac{(R_{ref})^2}{DR_{ref}}$ |
| Group 5 | Aggregation and assessment based on the change in the anticipated environmental impact of the resource extraction process due to lower-grade deposits that have to be mined in the future (Goedkoop and Spriensma 2001; Müller-Wenk 1998) | $ADP_i = \sum_i CF_i \times m_i$ where $CF_i = SPE_i$ |

$ADP_i$ abiotic depletion potential of resource i (kg Sb-equivents/kg resource i), $CF_i$ characterisation factor for abiotic depletion of resource i, $m_i$ mass of resource i consumed in the process, *WTP* is the willingness to pay to restore impacts to the 'safeguard subject', in this case abiotic stock resources, expressed in environmental load units (*ELU*, €), $Ex_{ch,i}$ chemical exergy of resource i (MJ/kg), $DR_i$ the extraction rate of resource i (kg/year), $R_i$ the ultimate reserve of resource i (kg), $R_{ref}$ the ultimate reserve of the reference resource antimony (kg), $DR_{ref}$ the extraction rate of the reference resource antimony (kg/year), $SPE_i$ is the surplus energy (*MJ*) needed to extract 1 kg of a resource from a lower-grade ore

**(Yellishetty et al *.* 2010 )**

# The Seminal Study - Limits to Growth: the Concern




(a) Standard Run (b) Comprehensive Technology (c) Stabilised World

- **Using the systems model, 'World3', the MIT team *qualitatively* assessed future growth scenarios and possible societal futures**

# Highlights from Case Studies

**Mineral Futures Collaboration Cluster**

**For**

**CSIRO Minerals Down Under National Research Flagship**

**We have produced a research report**

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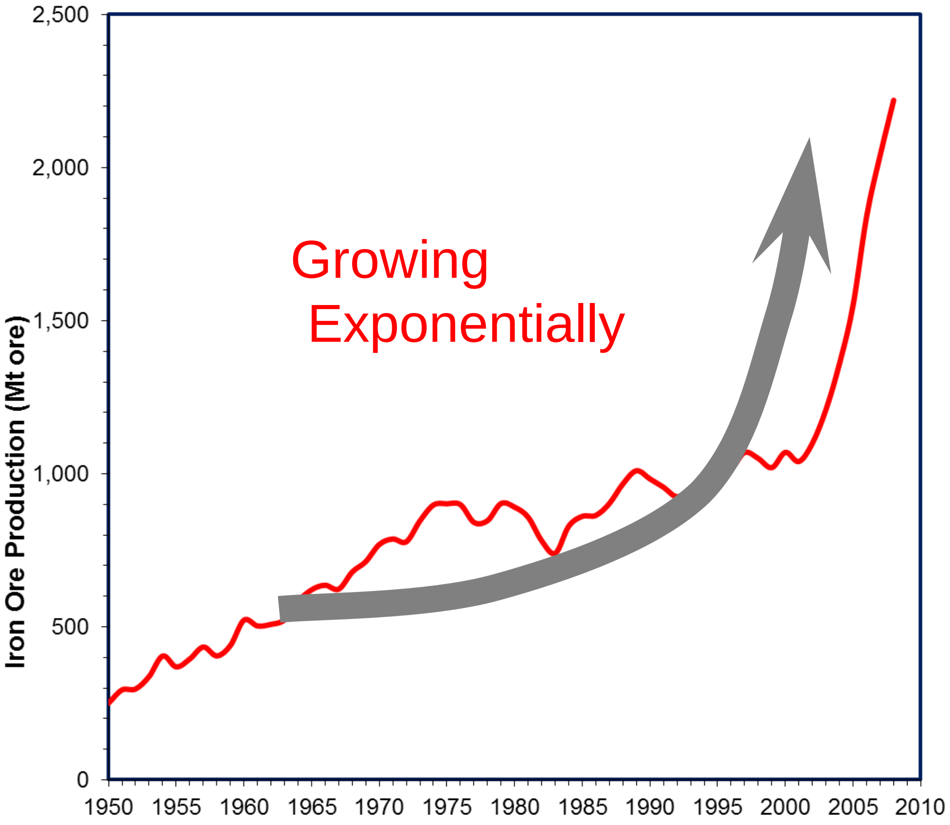
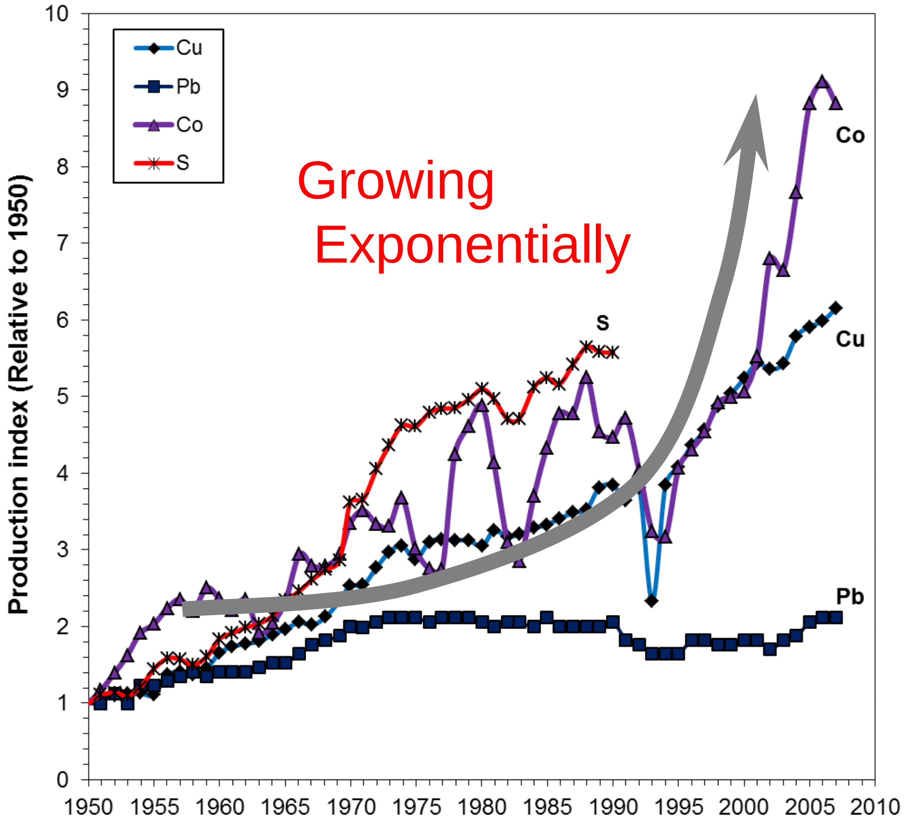
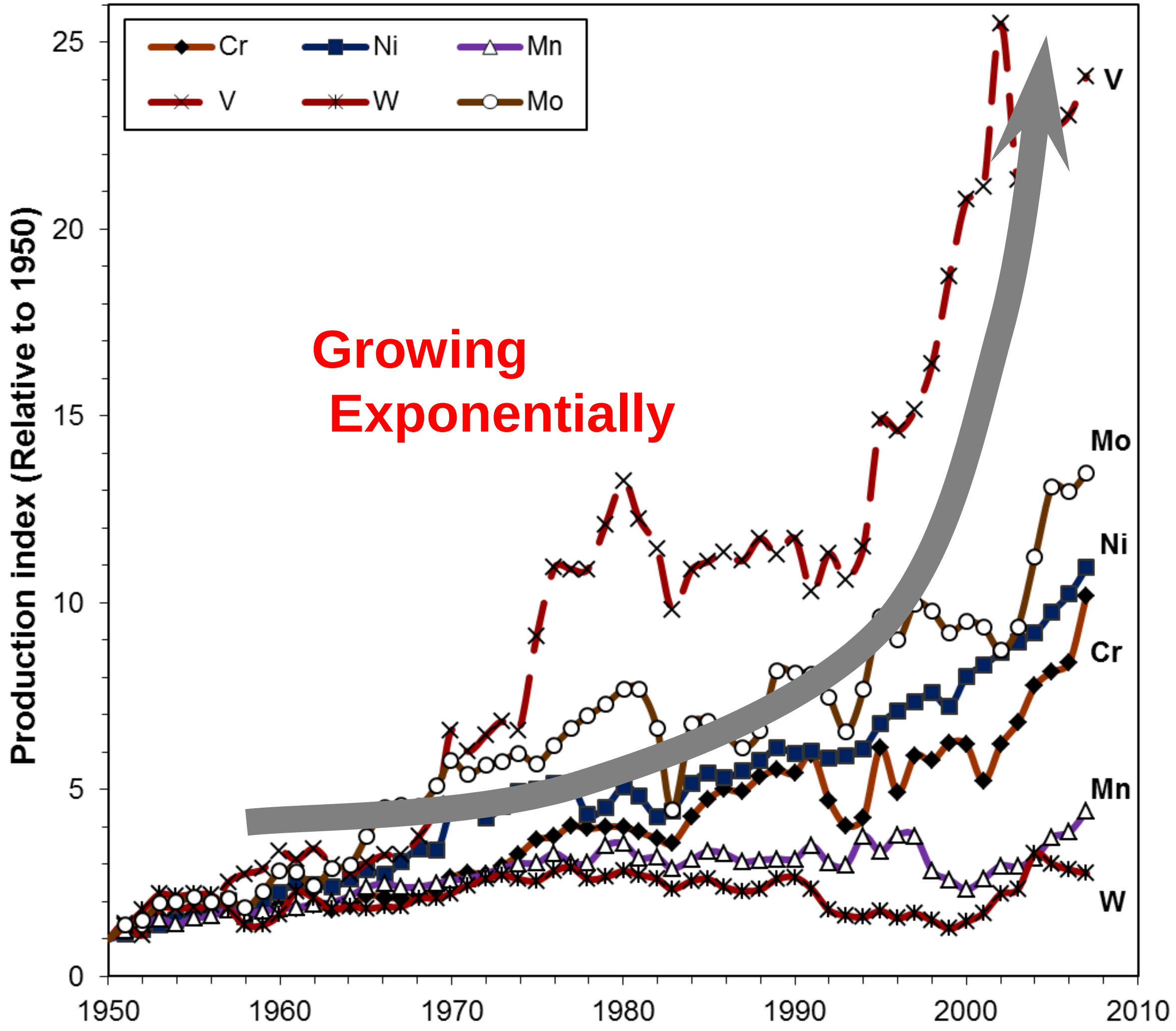
# Annual Production Mineral Trends

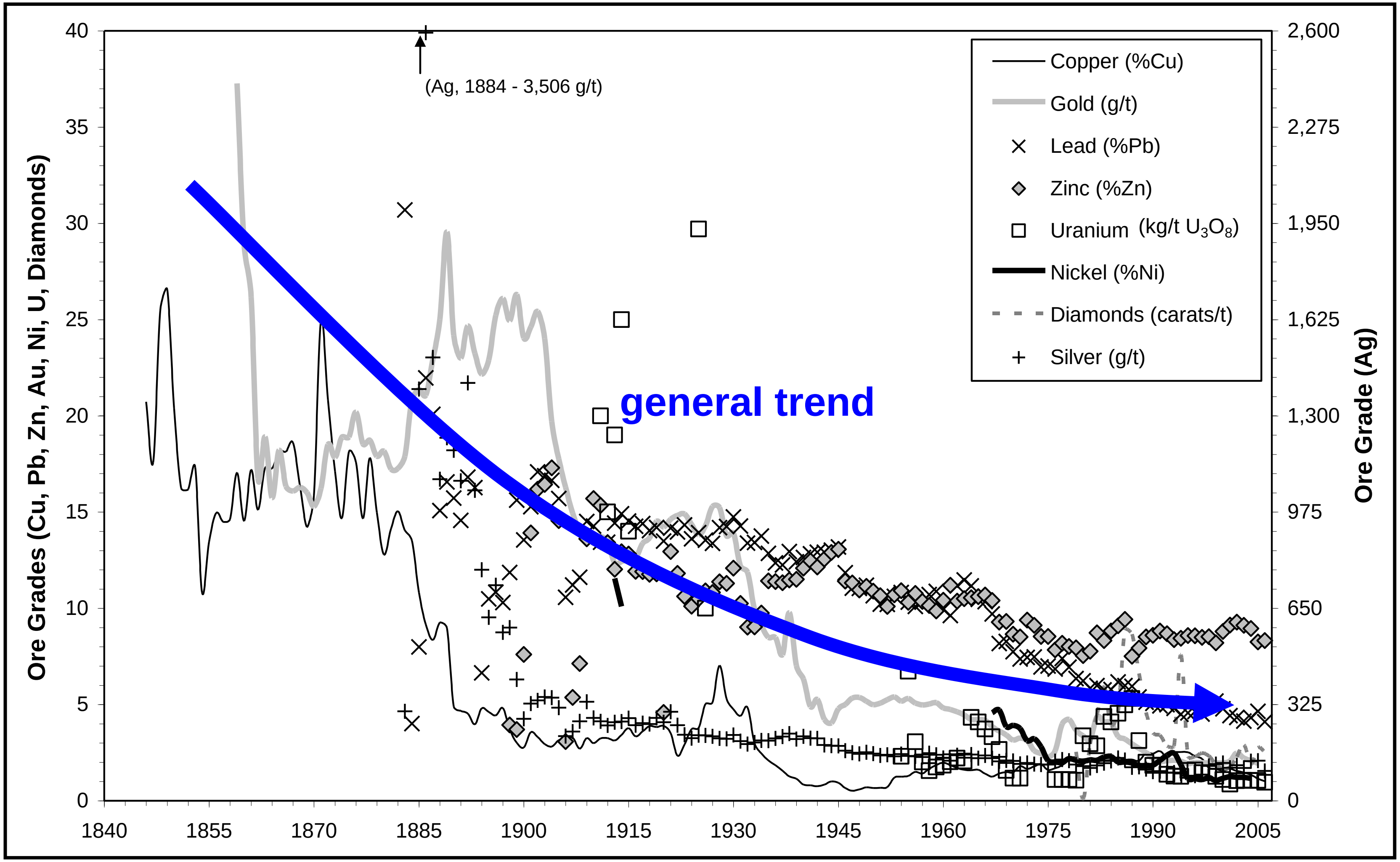


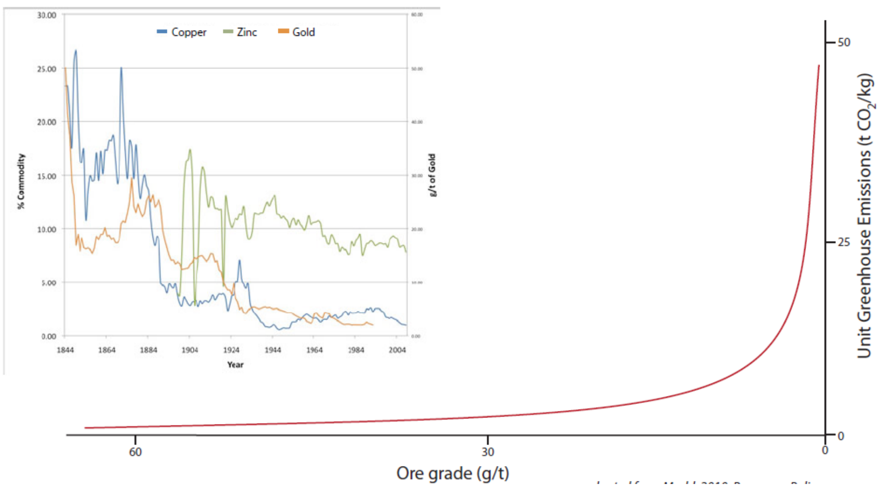
# Annual Production Mineral Trends



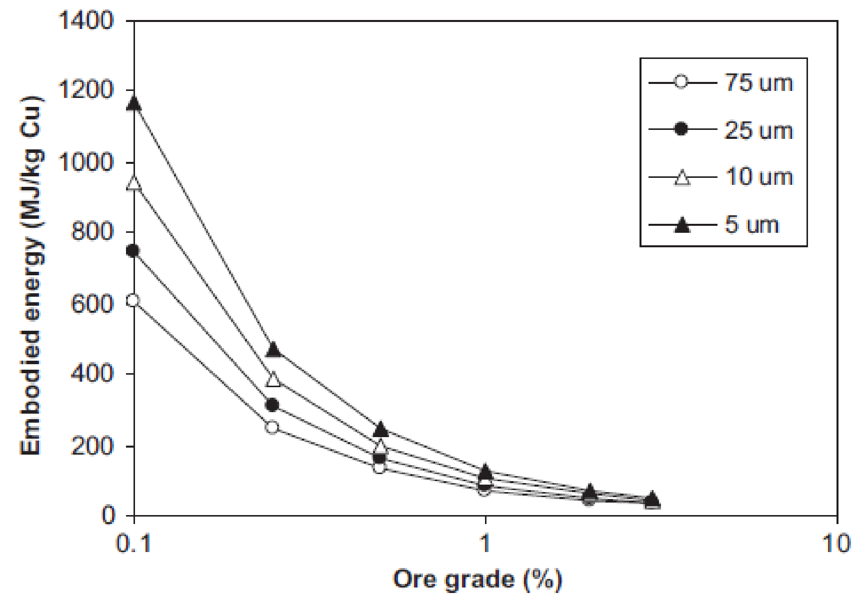
# Declining Ore Grades



# Declining Ore Grades – Implications!

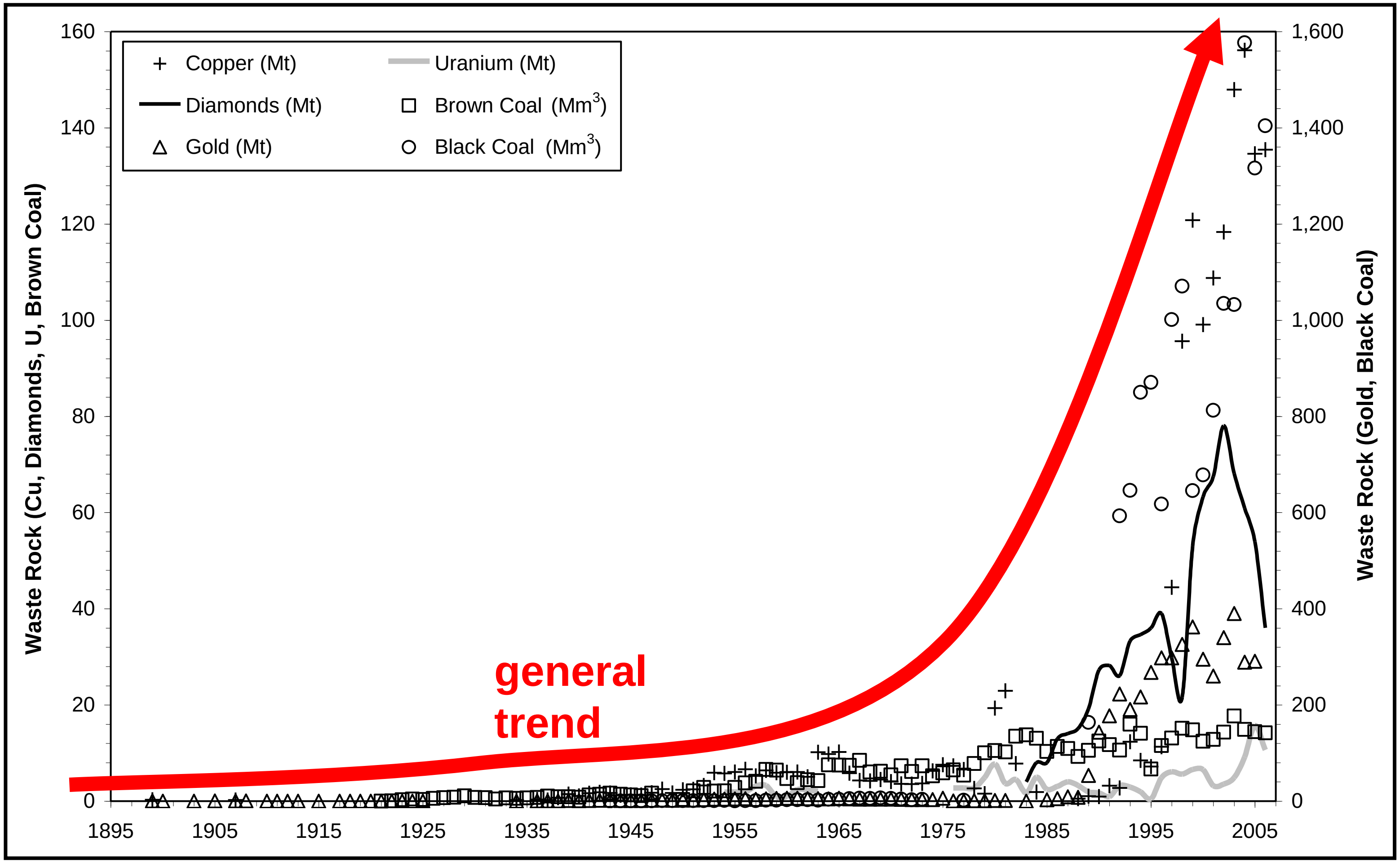



*(adapted from Mudd, 2010: Resources Policy)*

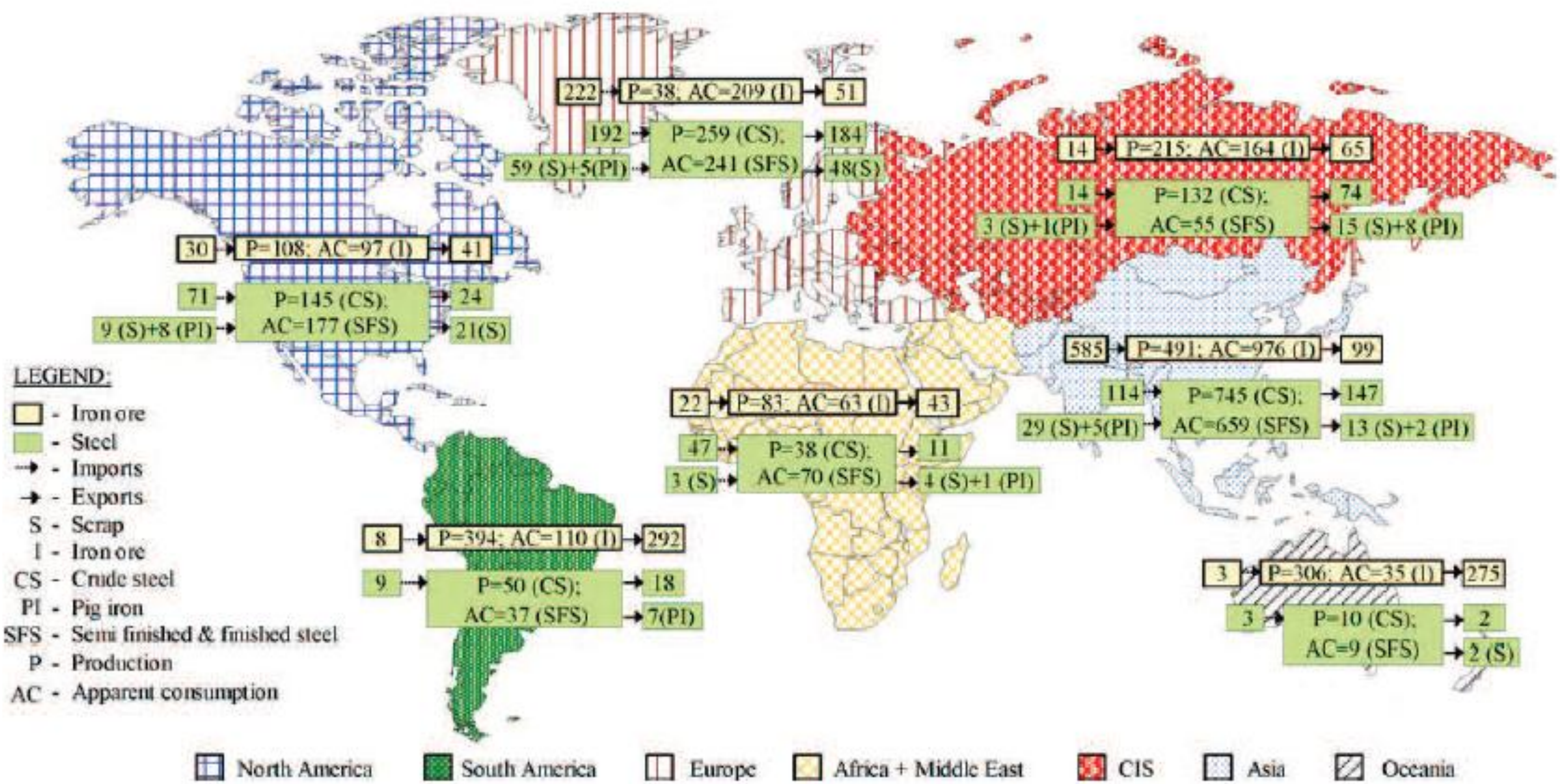



*(adapted from Norgate& Haque, 2010: Journal of Cleaner Production)*

# Waste Rock Generation



# Material Flows in the World (2006)



# IPAT Equation – its relevance

- Another famous 1970’s book was Professor Paul R Erhlich’s “Population Bomb” (1968)
- It describes the multiplicative contribution of population (P), affluence (A) and technology (T) to environmental impact (I). Environmental impact (I) may be expressed in terms of resource depletion or waste accumulation
- In it, proposes the now famous equation:

$$I = P \times A \times T$$

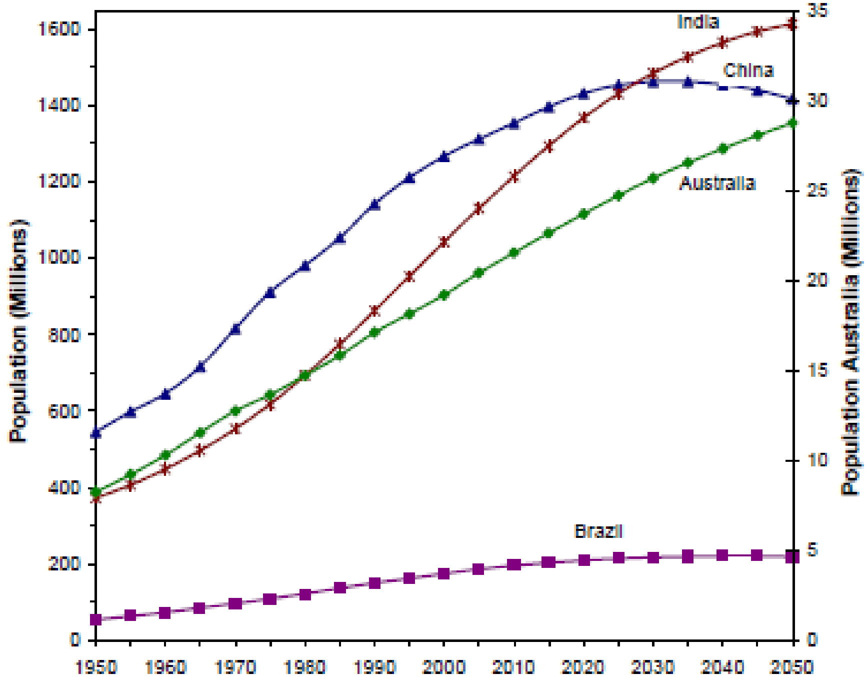
**I** = Impact,

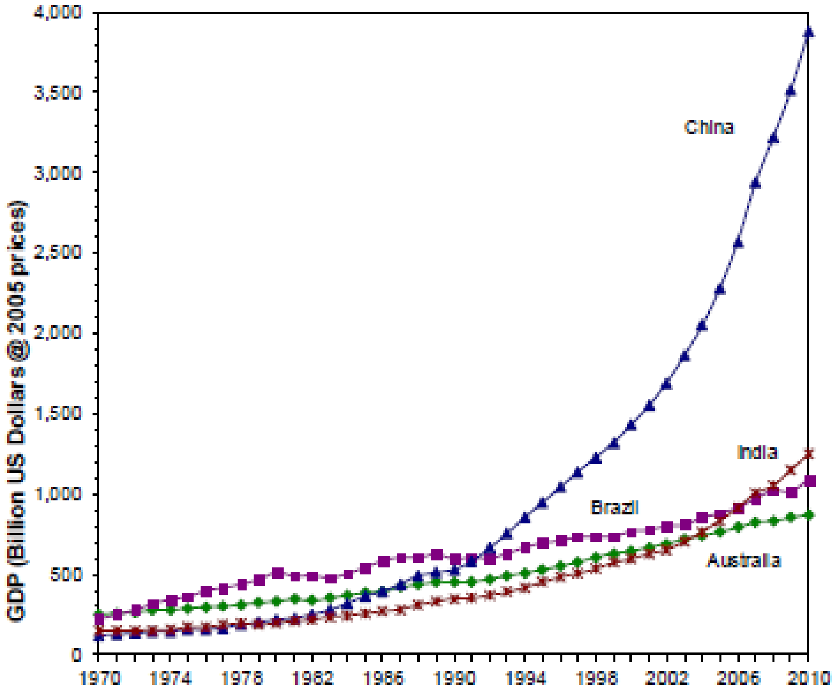
**P** = population,

**A** = affluence (ie. consumption),

**T** = technology

# Substance Flow Analysis of Steel and Long Term Sustainability



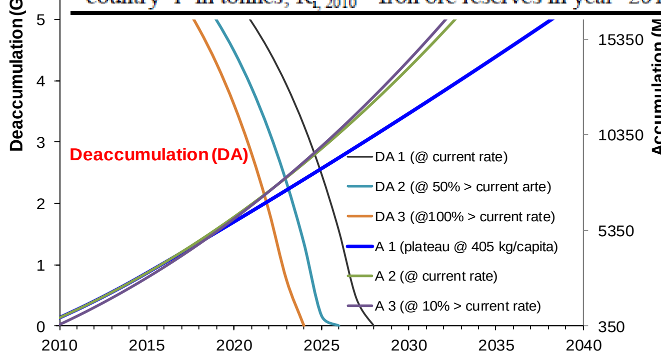



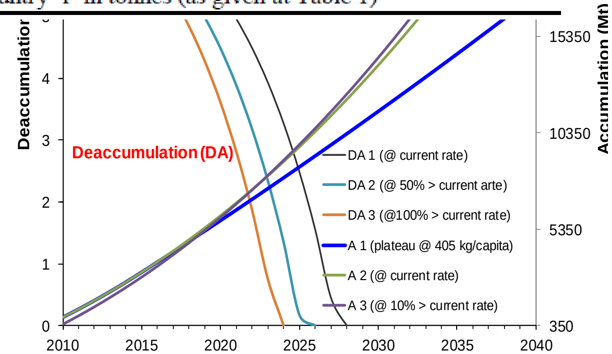
# Accumulation and De-accumulation of Steel



| Country | $DA_{Y(i)}$ (tonnes of crude steel equivalents) | $A_{Y(i)}$ (tonnes of crude steel equivalents) | |
|---|---|---|---|
| Australia | $A_1 \times e^{k_1(Y-2000)}$ | $\left[\frac{CS_Y \times p_{Y(i)}}{1000}\right] + \left[\frac{R_{i,Y} - R_{i,2010}}{1.725}\right]$ | if $A_{Y(i)} > CS_Y$ |
| Brazil | $A_2 \times e^{k_2(Y-2000)}$ | $\frac{p_{Y(i)}}{1000}\left[a_1[Y-2000]+102\right] + \left[\frac{R_{i,Y} - R_{i,2010}}{1.725}\right]$ | if $A_{Y(i)} \leq CS_Y$ |
| China | $A_3 \times e^{k_3(Y-2000)}$ | $\frac{p_{Y(i)}}{1000}\left[a_2[Y-2000]+105\right] + \left[\frac{R_{i,Y} - R_{i,2010}}{1.725}\right]$ | if $A_{Y(i)} \leq CS_Y$ |
| India | $A_4 \times e^{k_4(Y-2000)}$ | $\frac{p_{Y(i)}}{1000}\left[a_3[Y-2000]+33.1\right] + \left[\frac{R_{i,Y} - R_{i,2010}}{1.725}\right]$ | if $A_{Y(i)} \leq CS_Y$ |

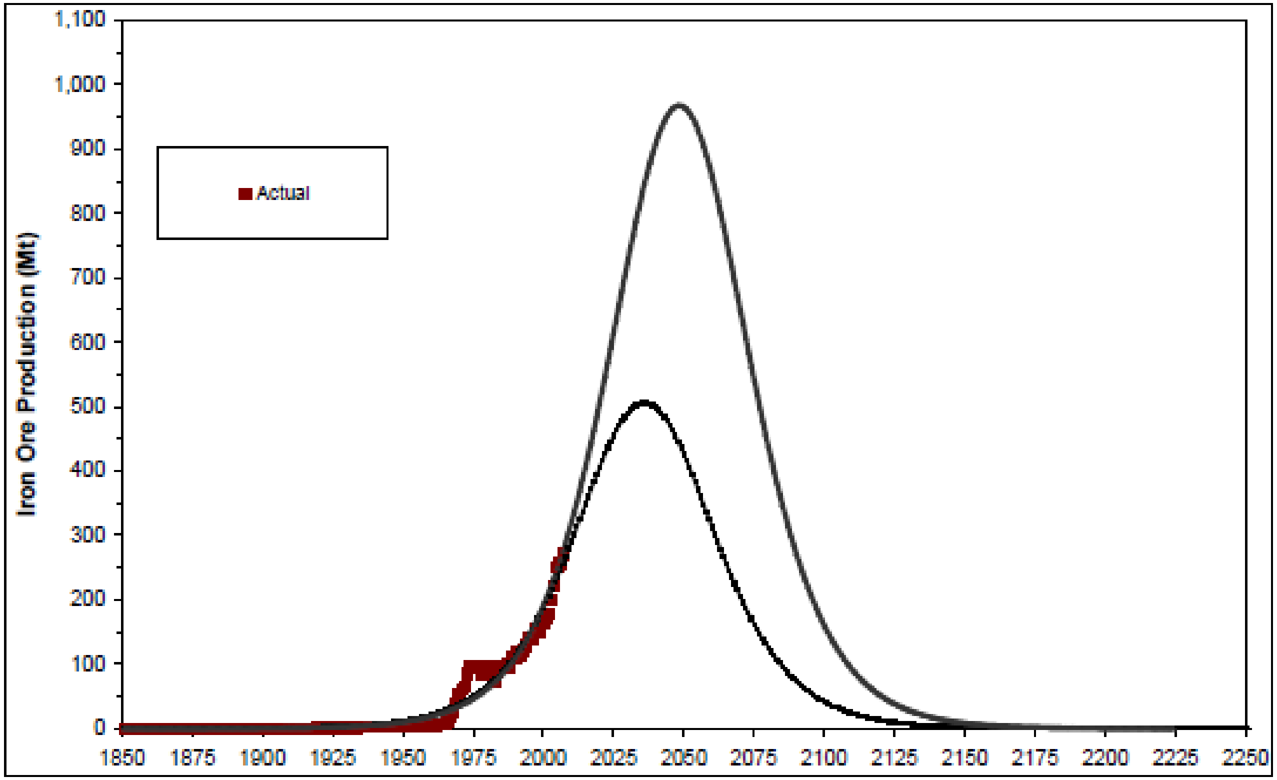
Where: $DA_{Y(i)}$ = de-accumulation in year 'Y' of country 'i' (tonnes of crude steel equivalents); $A_{Y(i)}$ = accumulation in year 'Y' of country 'i' (tonnes of crude steel equivalents); $A_1$ to $A_4$= production constants (year 2000 as base: $A_1$ = 99,402,908; $A_2$ = 100,436,104; $A_3$= 11,168,960 and $A_4$ = 19,862,648); $CS_Y$ = Crude steel per capita in the year (405 kg/year); Y = Year; $k_1$ to $k_3$ = depletion coefficients ($k_1$ = 0.0472; $k_2$ = 0.0426; $k_3$ = 0.17; $k_4$ = 0.051); $a_1$ to $a_3$ = accumulation coefficients ($a_1$ = 2.43; $a_2$ = 15.23; $a_3$ = 1.33) ; $p_{Y(i)}$ = population in year 'Y' of country 'i' (millions); $R_{i,Y}$ – Iron ore reserves in year 'Y' of country 'i' in tonnes; $R_{i,2010}$ – Iron ore reserves in year '2010' of country 'i' in tonnes (as given at Table 1)



# Peak Iron of Australia – Hubbert's model

$$Q(t) = \frac{Q_{max}}{(1 + a\exp(bt))}$$




**Qmax = 33.72 Gt; with Qmax = 64.52 Gt (EDR + Sub-economic and Inferred Resources)**

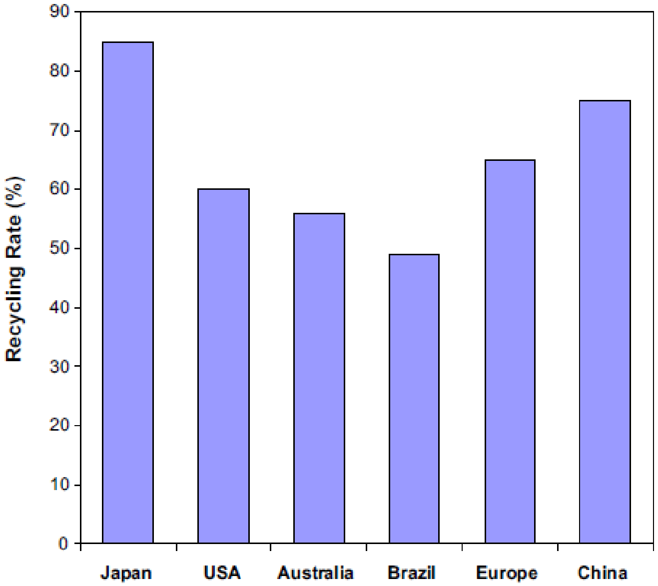
# Peak Minerals: What does that mean ?

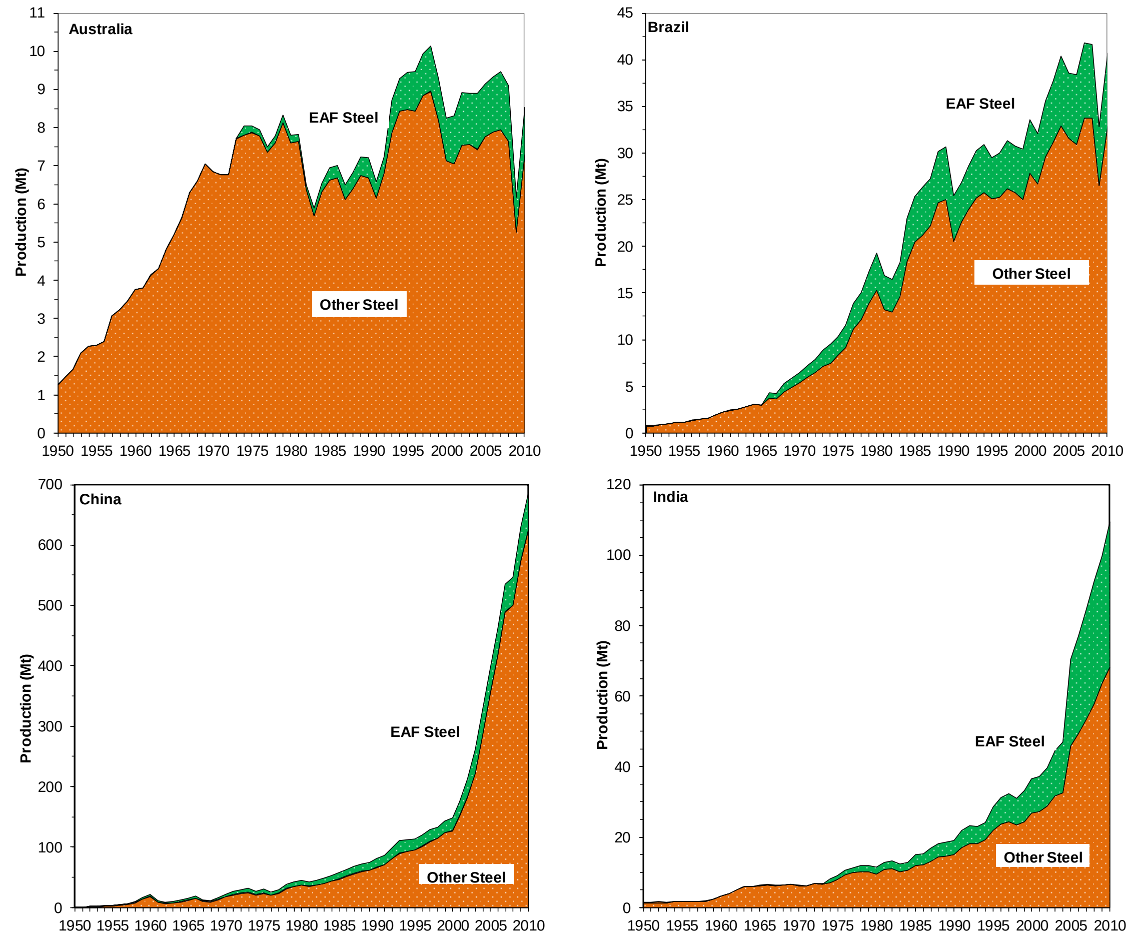
Unlike ‘Peak Oil’ we may not encounter peak minerals, but the future mineral production will be constrained by environmental sustainability issues :

- Declining ore grades are indicative of a shift from ‘easier and cheaper’ to more ‘complex and expensive’ processing – in social and environmental terms as well as economic.
- greenhouse emissions, energy, water, chemicals, …

# Recycling: How Efficient We Are?

"the cities of today are the mines of tomorrow" - Jacobs (1969)



# Summary & Thoughts for the Future

- Mining has continued to expand, and this looks set to continue for some decades …
- Fundamentally, mineral resources could be considered ‘finite’ – but not due to a “limited” quantity : future constraints will be environmental
- Transition from cheap and easy extraction to complex and expensive
- Many authors seem to have a fairly optimistic view on our ability to cope with resource depletion and see substitution, recycling and general development of economy and technology as efficient means for resource housekeeping.
- A Consensus need to Evolve: Inclusive, Sensitive and Consistent

**Acknowledgements:**

**Dr Gavin M. Mudd**

**for sharing his invaluable wealth of data and profound knowledge!**

Thank you Very Much for Your Attention!