PEAK MINERALS IN AUSTRALIA:
A REVIEW OF CHANGING IMPACTS AND BENEFITS

Cluster research report 1.2

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EXECUTIVE SUMMARY

The benefits and impacts of mineral resource extraction and processing in Australia are changing. As Australia's largest export industry, mining brings financial benefits to the nation and whilst our vast endowment of minerals will not be exhausted soon, extraction and production are becoming more challenging. 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. Declining resource quality has also lead to declining productivity and the energy intensity of processing has subsequently risen by 50% over the last decade.

Global demand for Australian minerals and metals continues to rise. However, as a mineral dependent economy facing the challenges of adapting to carbon constraints and a new tax structure, a comprehensive assessment of the industry's current and future role in the Australian economy is imperative. The following questions are relevant in such an assessment: What will the world need minerals and metals for in future? What role will Australia play in the supply and reuse of metals? How do we ensure benefits outweigh costs? What will we do with the proceeds of mining to sustain long-term benefit? Where are the opportunities for innovation and transition in technology and policy?

Whilst peak oil will directly affect the minerals industry through rising fuel costs, it also offers a useful conceptual model for understanding the impact of going from 'easier and cheaper' to 'complex and expensive' resource processing, and critically, to planning a transition to new ways of providing energy services. There are fundamental differences between oil and many minerals (e.g. the recyclability of metals). Notwithstanding, this paper establishes a conceptual model of 'peak minerals' as a powerful tool for communicating the cross scale impacts (i.e. local, national, global) of 'complex and expensive' processing with respect to economic, social and environmental issues. As with energy services provided by oil, the peak minerals model helps to open the discussion regarding the ultimate use of minerals and metals. With an understanding of when processing becomes 'very complex and expensive', it then focuses on what transitions can deliver the same useful functions that minerals and metals perform (e.g. ocean-based resources, greater recycling or reprocessing, dematerialisation, substitution with other materials); and which enabling technologies and policies can support these transitions.

The key findings of this report are:

- Mining represented approximately 7.7% of Australia's GDP in 2008-09 and combined mineral and energy exports of $160b represented nearly 56% of the total in that year.
- Minerals processing faces higher energy costs and is becoming more energy intensive despite technological improvements, as a result of processing lower grade more complex ores in more challenging locations (i.e. refractory, more remote, deeper).
    - Peak minerals offers a useful model for representing the 'easier and cheaper' then 'more complex and expensive' impacts associated with processing declining resource qualities.
    - As an example, copper fits the peak curve well and is approaching a peak in Australia. Gold reflects multiple peaks in production due to technological transitions that have occurred in the industry.
    - This presents opportunities for innovative technologies, policies and business models along the production, consumption and reuse cycle for minerals and metals to underpin future prosperity.
- Australia is heavily dependent on mining exports and should develop strategies to ensure long-term national benefits from minerals – social, economic and environmental – whilst acting decisively to avoid the resource curse.

1. INTRODUCTION

This paper reviews Australia's current use of its mineral resources, future issues that will affect processing and use of minerals and metals, and the long-term benefits that Australia may derive from such use.

This work is part of the Mineral Futures Research Cluster within the Mineral Futures Initiative of the CSIRO Minerals Down Under Flagship comprising the University of Queensland (Centre for Social Responsibility in Mining at the Sustainable Minerals Institute); University of Technology, Sydney (Institute for Sustainable Futures with input from Dr. Gavin Mudd, Monash University); Curtin University of Technology (Research Centre for Stronger Communities); CQ University; Australian National University and CSIRO.

Specifically it is part of the P1 cluster project, which together with research on strategic foresight forms the 'Commodity Futures' program of work. Other research is being undertaken concurrently on 'Technology futures' (P2) and 'Regions in Transition' (P3).

1.1. OVERVIEW OF DOCUMENT

An overview of the document is provided in Figure 1. Following this introduction, Section 2 provides a background to minerals as resources, their role in the Australian economy, how wealth from minerals can be assessed and the role of technology in transitions that strengthen long-term benefit for Australia. Section 3 then introduces the 'peak minerals' framework, drawing on similarities and differences to peak oil. An overview of economics and scarcity with respect to resource use is given in Section 4. Section 5, then shows where historical technological breakthroughs have been and re-examines how peak minerals and economics suggest an expanded future focus. Sections 7 and 8 explore the changing environmental and social issues associated with processing increasingly challenging ores. The final section frames the key elements to be considered in further developing strategies to realise long-term national benefit from the current and future use of Australia's mineral resources.

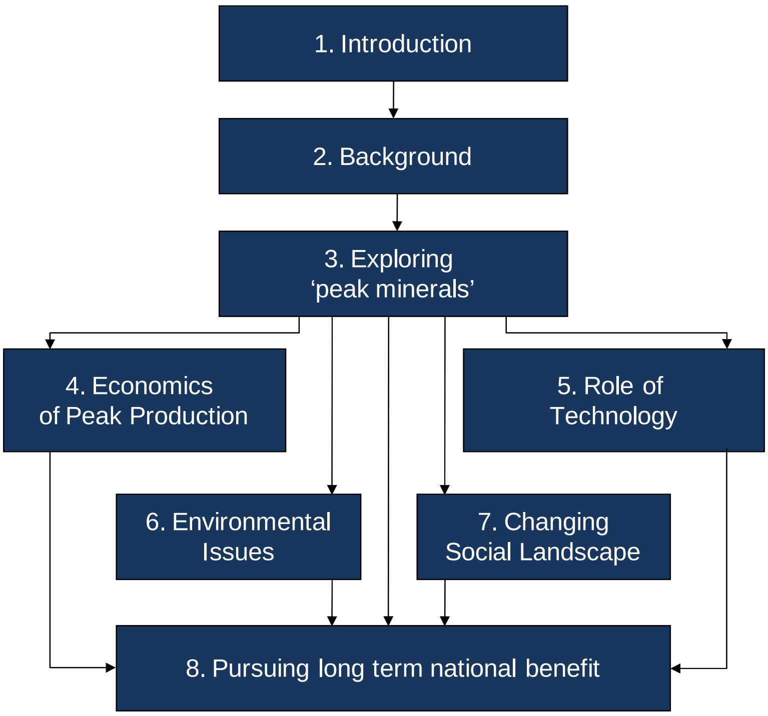

Figure 1: Overview of document

2. BACKGROUND

SECTION TWO: OUTLINE

This section explores:

- *minerals as resources; outlining their function in society and specific definitions (2.1)*
- *the role of minerals in the Australian economy; their dominance of export markets, the rising energy costs of production and declining productivity of the sector;. the impacts of rising global demand for minerals and metals, and the uses to which they are put. (2.2)*
- *approaches for assessing wealth from minerals; this provides an important background to future work that will develop strategies to ensure long-term benefit from resources use (2.3)*
- *resource depletion, technology and transitions; framing the intersection of issues important to future use of minerals and metals (2.4)*

2.1. MINERALS AS RESOURCES

2.1.1. Resources are valued for their function in society

Natural materials and objects hold different meaning for different members of our society, and this influences how we attribute value. Whether economic, cultural or physical, the attribution of value designates what we consider to be resources (Blunden, 1985). The value we place on *resources* is determined by the function or functions those materials or objects perform in our society.

> *"While consumers demand precious metals and gems as final goods, these only account for a small fraction of total mineral demand. The main use of minerals is as inputs for final products and services." Australian Mineral Economics (2006, p.39)*

Minerals and metals are among Australia's most valuable natural resources because of the diversity of their uses, for which demand on the world market is increasing. The current and future value Australia derives from mining and processing minerals into metals is twofold:

1. **they can provide metals**, used in equipment to harvest and transport our food; in the construction of our buildings; in the pipes that supply our water; and in wires that power our lighting and telecommunications infrastructure; in the jewellery and medical devices supporting our cultural and physical wellbeing – *we value the properties and functionality of metal-containing goods and the services they provide.*

2. **they can provide monies**, via revenue and royalties, which are used to purchase goods and services – *we value the properties and functionality of metal and non-metal containing goods and the services, which can be purchased with the proceeds of mining and mineral processing.*

As Australia purchases more goods and services from overseas than the value of goods and services it exports (ABARE, 2009a), what we choose to spend our export proceeds on (of which mining and energy exports represents over 50%) and how we structure an economy that can continues to pay for these goods and services in the longer term is a fundamentally important question. Notwithstanding our economic dependence on mineral resources, many aspects of our global society are socially and/or culturally dependent on minerals and metals. Consequently, almost every aspect of our daily lives is affected by the availability of many mineral resources, and the current mineral production and consumption patterns reflect the values we implicitly or explicitly attribute to these resources.

2.1.2. Defining mineral resources

There are a variety of common terms used to describe or quantify mineral resources, including some that have statutory significance. As described above, a mineral resource can, at its most simple, be considered as something that has inherent value to society. A mineral resource can therefore be identified through geological exploration, and when profitable, this can be mined to produce a given mineral. The challenge, therefore, is to ascertain and describe what is a potentially profitable mineral resource. This can vary due to market conditions (e.g. price fluctuations), input costs (e.g. fuels, labour), ore processability (how easily the minerals can be extracted), or even social issues (e.g. bans on mining in national parks).

Given the complexity of defining a mineral resource as profitable, and the need to provide clear communication of such results to the public and investors (since most mining companies are publicly listed on the stock exchange), the Australian mining industry established the Joint Ore Reserves Committee (or 'JORC') Code for reporting mineral resources (AusIMM et al., 2004). Any mining company listed on the Australian stock exchange is required by law to use the JORC code to report on mineral resources they control. There are also equivalent codes in other major mining countries such as Canada and South Africa.

The two primary aspects which the JORC code considers are geological and economic probability in claiming a mineral resource as 'economic'. A range of important 'modifying factors' are compulsory to consider – such as mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. Furthermore, there are two primary categories of mineral resources – ore reserves and mineral resources. The typical distinction is that ore reserves have a very high economic and geologic probability of profitable extraction, while mineral resources have a reasonable geological probability but are less certain economically. Short definitions are:

- *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.
- *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. Mineral Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories

To avoid possible confusion with the JORC code, all reference to 'resources' will be used in the general sense as discussed in Appendix A. When the specific terms of *ore reserves* or *mineral resources* are used, they are intended to be consistent with the JORC code. For completeness, the full definitions of ore reserves, mineral resources and their sub-categories are included in Appendix A. A conceptual relationship of ore reserves and mineral resources is shown in Figure 2.

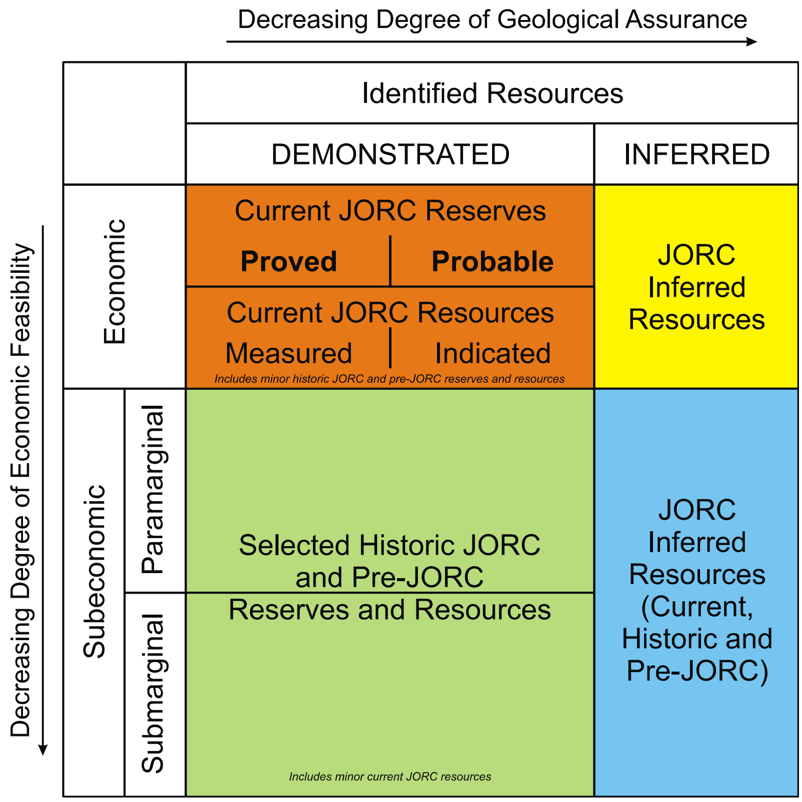

Figure 2: Differing categories and relationships between ore reserves and mineral resources (Lambert et al., 2009)

The United States Geological Survey (USGS) use the categories of *reserves* and *reserves base* (see USGS, 2009). These are broadly similar to JORC's ore reserves and mineral resources, respectively, although the USGS also allows for greater inclusion of inferred mineral resources in the reserves base category (Appendix A). An excellent analysis of JORC, and its comparison to other systems is given by Lambert and colleagues (2009).

2.2. MINERALS IN THE AUSTRALIAN ECONOMY

This section gives an overview of the role of the minerals sector in the Australian economy, the structure of the minerals sector and its exports to meet global commodity demand.

2.2.1. Contribution of mining to the Australian economy

Minerals are one element of Australia's natural resource base. Other key natural resources include forestry and fisheries, and together with agriculture, they make a significant contribution to the Australian economy and Australia's Gross Domestic Product (GDP). Table 1 shows a comparison of various industries in Gross Value Added (GVA) to the Australian economy over the 2008-2009 period and provides useful context for understanding the contribution of mining and minerals (in bold) to Australia's GDP. Mining contributed 7.7% GVA in 2008-2009, up from 4.9 % [1] in 2005-2006. Manufacturing represents 9.4% GVA, some of which is linked to downstream processing from mining. Specific minerals contribute to varying degrees with black coal contributing the most (1.3%), compared to 0.49% for Gold and Lead and 0.06% for Silver and Zinc)[2].

[1] Based on calculations using table 15.1 in ABS figures in ABS Yearbook 2008
[2] Figures compiled from Balancing Act CSIRO 2005 volume 2

Table 1: Industry Gross Value Added 2008-09 (Source: ABS 5204.0 Table 5)

ANZIC Division	2008-09 $million Gross Value Added	Percentage of total
Agriculture, forestry and fishing	30 979	2.6 %
Mining (total)	**80 830**	**7.7 %**
Mining	***72 599***	
Exploration and mining support services	***8 231***	
Manufacturing (total; only sectors related to mining itemised below)	**103 139**	**9.4 %**
Petroleum, Coal, Chemical and Rubber	***16 969***	
Non-metallic mineral products	***5 388***	
Metal products	***25 560***	
Electricity, gas and water supply	27 806	2.5 %
Construction	81 601	7.4 %
Wholesale trade	53 842	4.9 %
Retail trade	54 189	4.7 %
Accommodation, cafes and restaurants	26 801	2.5 %
Transport, postal and storage	59 499	5.8 %
Information media and telecommunications	34 234	3.4 %
Financial and insurance services	118 181	10.8 %
Rental, hiring and real estate services	36 033	3.0 %
Professional, scientific and technical services	70 517	6.1 %
Administrative and support services	28 182	2.7 %
Public administration and safety	60 677	5.3 %
Education and training	48 731	4.3 %
Health care and social assistance	66 654	6.1 %
Arts and recreation services	10 112	0.8 %
Other services	21 837	2.0 %
Ownership of dwellings	85 311	8.0 %
Total gross value added at basic prices	**1 099 137**	**100.0 %**
Taxes less subsidies	89 266	
Statistical discrepancy	6 093	
GROSS DOMESTIC PRODUCT	119 4496	

Export value dominated by mineral and energy resources

Mineral and energy resource have dominated Australian exports for the past decade. Today they represent over half of total exports on a balance of payments basis (Table 2), and the total value has increased four-fold. By contrast, the export values from forestry has nearly doubled, as have merchandise and services. The value of farm exports has increased by 40% whilst the contribution from fisheries has remained constant.

Table 2: Contribution to Australian total exports by sector (Balance of payments basis) (ABARE, 2009b)

	2008/09 $m	2008/09 Percentage	1998/99 $m	1998/99 Percentage
Farm	32 027	11.2%	23 009	20.2%
Forestry	2 343	0.8%	1 347	1.2%
Fisheries	1 529	0.5%	1 511	1.3%
Mineral and Energy Resources	**159 677**	**55.9%**	**39 213**	**34.4%**
Merchandise	36 152	12.7%	20 703	18.1%
Services	53 973	18.9%	28 312	24.8%
Total	285 701	100.0%	114 095	100.0%

These figures place Australia firmly within the UN's criteria for a mineral-dependent economy (AusIMM, 2006), and focuses attention on how these revenues are being used for longer-term benefit. The rise in value of mineral exports is more a result of increasing prices than volumes (Figure 3). Figure 3(a) shows the value added in the Australian mining industry between 1989/90 and 2005/06 in terms of value and volume. It highlights that whilst production volumes have risen by 60% at the end of the period, prices for commodities have more than trebled in value.

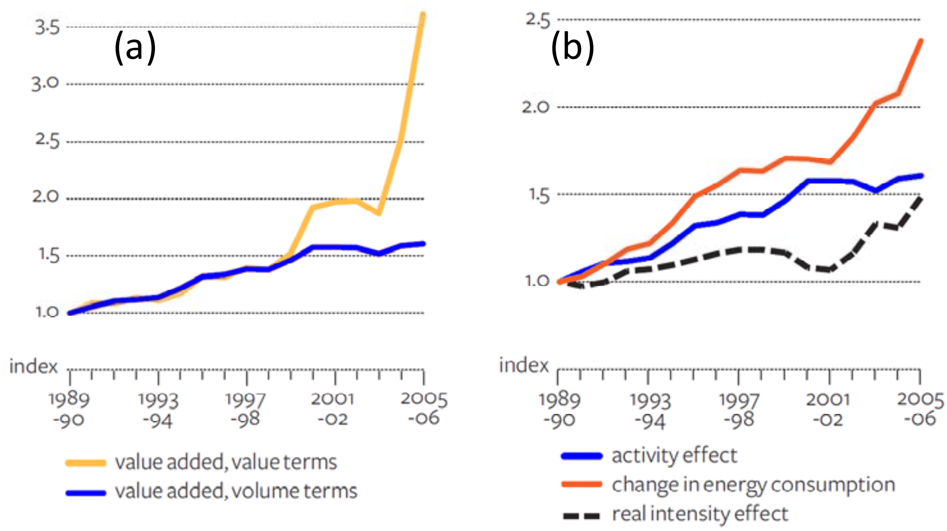

Figure 3: (a) Growth in the mining sector in Australia relative to 1989/90 and (b) Growth in energy intensity of mining sector in Australia relative to 1989/90 (Sandu and Syed, 2008)

Energy inputs to mining are rising

Figure 3(b) shows that energy consumption has risen from 1989/90 to 2005/06 by 220 PJ (red line). This can be attributed to a rise in production activity (solid blue line in both Figure 3(a) and Figure 3(b)) and a concurrent rise in real energy intensity (dashed line).

Direct employment from mining is relatively low

Whilst the mining sector contributes significantly to gross value added and exports, its direct contribution to employment is low compared with other sectors (Figure 4), and has not increased significantly over the decade. Also of note in this figure is the steady decline of employment in manufacturing, agriculture, forestry and fishing, and in wholesale trade. Employment has risen considerably in construction, property and business services and health and community services.

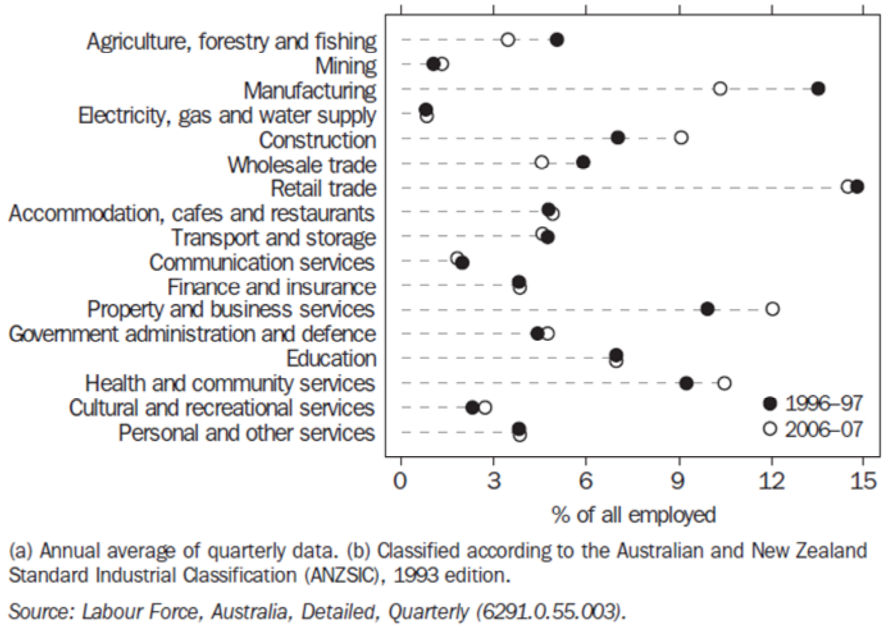

Figure 4: Percentage employment by sector

Productivity is declining

In 2008, the Productivity Commission released a report entitled *Productivity in the Mining Industry: measurement and interpretation*. It shows the multi-factor productivity[3] of the mining industry declining from 2000/01 to 2006/07 as shown in Figure 5 (Topp *et al.*, 2008).

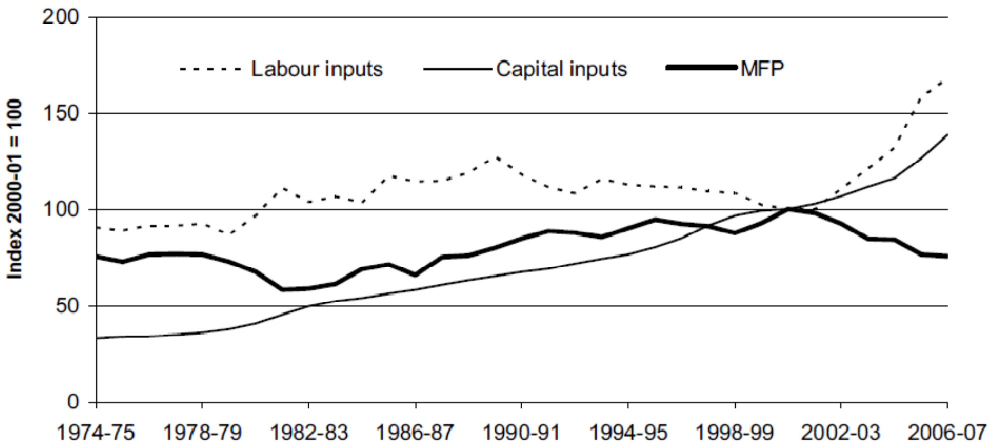

Figure 5: Capital and labour inputs to the mining industry and multi-factor productivity

It states that approximately one third of this effect is explained by capital investment in new capacity that is yet to begin production due to long lead times. However, the continued depletion of the quantity and quality of Australia's resource base was proposed to have a significant and adverse effect on the long-term multi-factor productivity of mining:

> *"While natural resources are obviously a major input into mining production, changes in their quality are not generally taken into account in standard measures of*

[3] Multi-factor productivity is an indicator of the efficiency with which capital and labour inputs are used to generate goods and services (Topp et al. 2008).

productivity. This omission would not be a problem if natural resources were in infinite supply and of homogeneous quality — that is, available without constraint at the same unit cost of extraction. But neither is the case: resource deposits are non-renewable, and depleted by ongoing extraction. And as mineral and energy deposits are depleted, the quality and accessibility of remaining reserves generally decline. Miners, by choice, focus initially on high-quality, readily accessible deposits, since they produce the highest returns. As these deposits are depleted, remaining deposits may be of lower grade, in more remote locations, deeper in the ground, mixed with greater impurities, require more difficult extraction techniques and so on.

As the quality and accessibility of deposits decline, greater commitments of capital and labour are generally needed to extract them. When deposits are deeper, more development work is needed to access the desired resources. If there are greater impurities, greater costs may be incurred in extracting and processing the material into saleable output. In short, more 'effort' is needed to produce a unit of output.

The additional capital and labour required per unit of output show up as a decline in measured productivity." (Topp *et al.*, 2008, p xvii)

The Productivity Commission's analysis emphasises the importance of developing a strategy to link the use of Australia's mineral resources to national long-term benefit and anticipate a future characterised by greater efforts to produce desired outputs. Such a strategy must be informed by a deeper understanding of the role of technology, changed impacts and practices, and ultimately what minerals and metals are used for and how they deliver value; all of which are explored in subsequent sections of this report.

2.2.2. Australian mineral production: society's use of metals and minerals

Current production and future demand

An overview of Australia's mineral industry is provided in Table 3 (p. 12). Australia is a significant global supplier of minerals (and metals) to a market where demand is expected to increase (Figure 6).

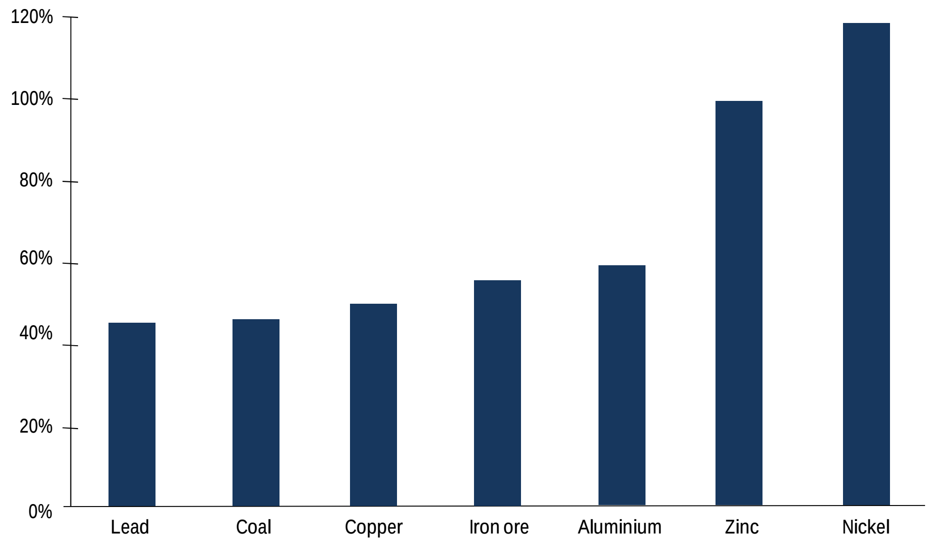

Figure 6: Australian production increase required to meet 2020 demand (Access Economics, 2008)

These increases are driven by increasing global GDP growth as shown in Figure 7 for steel and increasing per capita consumption for China in Figure 8. Understanding the current and future impacts of Australian production, including the role of new technologies in meeting this demand, is discussed later in this report.

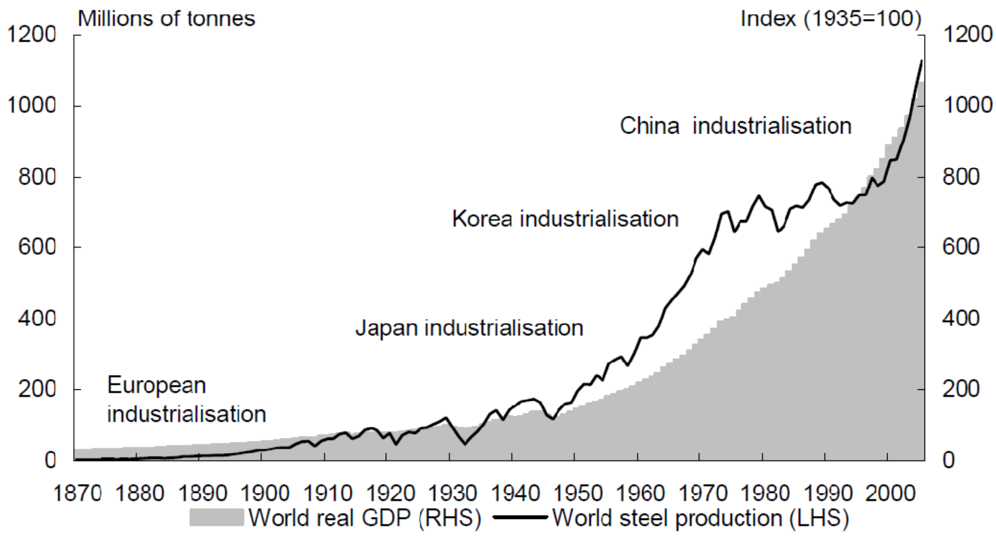

Figure 7: World GDP and steel production (Grant *et al.*, 2005; citing Maddison, 2003 and Mitchell, 2003)

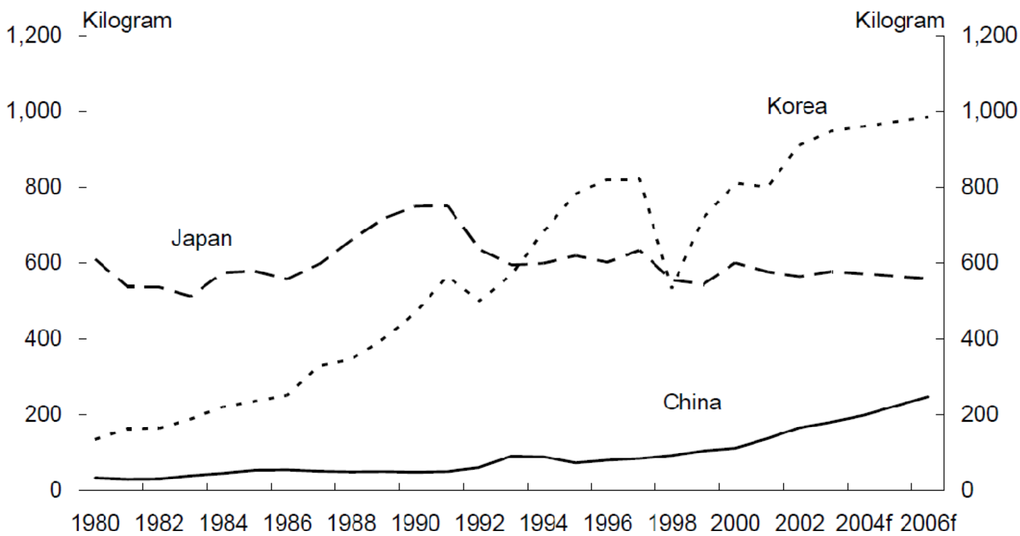

Figure 8: Increasing per capita steel consumption of China still rising (Grant *et al.*, 2005)

Society's use of minerals and metals

Metals commonly fill a variety of uses (Table 4) that will continue into the future, while new uses will emerge with new needs, technologies and practices. Other uses may be substituted with different metals or non-metals. The important point to emphasise is that consideration of long-term national benefit from minerals will depend on:

- the services demanded by metals in the future global economy (health, education, housing, transport, defence and so on);

  - the level of global demand for services depends on population, and the intensity of services per person (itself dependent on wealth and resource availability, sustainability, geopolitical drivers and the structure of our economies and societies)

- the degree to which Australian minerals and metals are used in providing these services;

  - dependent on role of metals (e.g. copper or plastic for water pipes; steel or timber for construction)

  - Australian resource development, technology development, financing, market access and competition (both from other mineral and metal supplying countries and non-metal substitution)

  - the minerals intensity of the economy and of services provided by minerals and metals

- the degree to which wealth from the use of Australian mineral and metal resources is realised and used to support long-term national benefit – whether these are resources from terrestrial ore, ocean resources, re-processed tailings dumps, landfills or other sources of secondary scrap.

Subsequent sections explore the issues which must be considered in framing Australia's response to these challenges.

Table 3: Overview of Australian minerals industry in 2008 – production statistics, mineral resources, exports and economic value

Commodity	Mine Production	Ore Grade	Identified Resources	Inferred Resources	Consumption	Exports	Export Value (millions)	World Production
Black Coal (raw)	430.61 Mt	-	47.4 Gt[b]	66.7 Gt[b]	-	-	-	-
Black Coal (saleable)	332.11 Mt	-	-	-	71.58 Mt[c]	261.21 Mt	$46,858	5,715 Mt
Brown Coal (raw)	66.03 Mt[d]	-	92.3 Gt[b]	101.1 Gt[b]	66.03 Mt[d]	0 Mt	$0	
Iron Ore	342.42 Mt	61.1% Fe	25.9 Gt	28.9 Gt	~32.95 Mt	309.47 Mt	$33,352	1,725 Mt
Steel	7.724 Mt	-	-	-	~5.913 Mt	1.811 Mt	$1,562[d]	1,330 Mt
Bauxite	64.04 Mt	36.9% Al_2O_3	8.8 Gt	0.91 Gt	~55.38 Mt	8.66 Mt	$226	216.4 Mt
Alumina	19.45 Mt	-	-	-	~3.54 Mt	15.91 Mt	$6,382	78.91 Mt
Aluminium	1.974 Mt	-	-	-	0.312 Mt	1.679 Mt	$5,244	39.26 Mt
Gold	215.2 t	~1.9 g/t Au	7,856 t	4,596 t	*no data*	415.2 t	$13,332	2,416 t
Lead	650 kt	3.50% Pb	33.9 Mt	18.6 Mt	23 kt	604 kt	$1,709	3,896 kt
Zinc	1.519 Mt	7.77% Zn	61.7 Mt	21.9 Mt	0.085 kt	1.497 Mt	$2,314	11.70 Mt
Silver	1,926 t	98.4 g/t Ag	79.6 kt	30.0 kt	*no data*	347 t	$212	19.84 kt
Copper	885 kt	0.95% Cu	85.4 Mt	34.2 Mt	154 kt	811 kt	$6,734	15.53 Mt
Rutile	325 kt	*no data*	29.5 Mt	32.1 Mt	*no data*	438 kt	$271	609 kt
Ilmenite	2.082 Mt	*no data*	236.2 Mt	123.2	*no data*	1.019 Mt	$120	11.33 Mt
Zircon	550 kt	*no data*	49.0 Mt	36.5 Mt	*no data*	655 kt	$476	1,235 kt
Diamonds	15.66 Mcarats	1.04 carats/t	419 Mcarats	-[e]	*no data*	15.67 Mcarats	$618	170 Mcarats
Manganese	4.812 Mt	48.0% Mn	371 Mt	133 Mt	*no data*	4.002 Mt	$2,021	34.51 Mt
Nickel	199.2 kt	~1.2% Ni	28.5 Mt	20.9 Mt	*no data*	209.8 kt	$4,173	1,509 kt
Tin	1,783 t	*no data*	252 kt	429 kt	*no data*	2,783 t	$45	312.4 kt
Uranium	9,989 t U_3O_8	0.098% U_3O_8	1,179 kt U_3O_8	500 kt U_3O_8	0	9,663 t U_3O_8	$737	51,598 t U_3O_8[f]
Lithium	~8,900 t Li[g]	~4% Li_2O[g]	609 kt Li	25 kt Li	*no data*	*no data*	*no data*	27,400 t Li[h]
Tantalum	435 t[i]	*no data*	66.3 kt Ta	80 kt Ta	*no data*	*no data*	*no data*	815 t Ta[h]

[a] Includes economically demonstrated resources and sub-economic resources from GA (2009). [b] Recoverable coal only (not in situ resources). [c] 2005/06 data since 2007/08 is not reported. [d] Data for 2007/08 financial year (not calendar year 2008). [e] Included in Identified Resources. [f] World uranium production from WNA (2009). [g] Lithium is produced as spodumene concentrate ($LiAlSi_2O_6$), the production estimate is based on data from WADMP (2009) and Talison (2009). [h] World production estimate from USGS (2009). [i] Tantalum is produced as tantalite concentrate ($(Fe,Mn)(Ta,Nb)_2O_6$) (680 t concentrate in 2008; WADMP, 2009), although the proportion of Ta is not reported in Australia, USGS (2009) report 435 t Ta.

Data from ABARE (2009a,b), GeoScience Australia (2009), Mudd (2009a). Some consumption data is not directly reported, and is estimated ('~') as the difference of production and exports.

Table 4: Minerals, metals and their common uses (adapted from IIED & WBCSD, 2002)

Mineral / Metal	Common uses
Aluminium	Aircraft & automotive parts, railroad cars, seagoing vessels, packaging, building construction, electrical applications, pharmaceuticals, water treatment
Coal	Electricity generation; steel making; chemical manufacture; production of liquid fuels, plastics & polymers
Cobalt	Superalloy (engines), magnets, stainless steel, electroplating, batteries, cemented carbides & diamond tools, catalysts, pigments, radiotherapy
Copper	Building construction (wire, cable, tubing/pipes, roofing, climate control systems), aircraft & automotive parts, industrial applications & machinery (tools, gears, bearings, turbine blades), furniture, coins, crafts, clothing, jewellery, artwork, musical instruments, cookware
Gold	Jewellery, electronics, dentistry, watchcases, pens and pencils, spectacle frames and bathroom fittings, decoration of china and glass, store of value
Iron	Steel (construction, vehicles), numerous alloys
Lead	Batteries, cable sheathing, lead crystal, solder and radiation protection, antiknock compound in petrol, plumbing, ammunition
Lithium	Lubricants, glass and ceramics, lithium carbonate (used for aluminium reduction, batteries, pharmaceuticals), high-performance alloys for aircraft, carbon dioxide absorber in spacecrafts, nuclear applications
Manganese	Steel making, alloys, batteries, colourants and pigments, ferrites, welding fluxes, agriculture, water treatment, hydrometallurgy, fuel additives, oxidizing agents, odour control, catalysts, sealants, metal coating, circuit boards
Magnesium	Alloys used for aircraft, car engine casings & missile construction, refractory material, agriculture (feed and fertilizer), filler in paper, paints & plastics, automobile & machinery, ceramics, fire retardant, pyrotechnics & flares, reducing agent for the production of metals from their salts
Molybdenum	Alloys, catalyst in petroleum refining, heating elements, lubricants, nuclear energy applications, missile & aircraft parts, electrical applications
Nickel	Stainless steel, corrosion-resistant alloys, gas turbines, rocket engines, plating, coins, catalysts, burglar-proof vaults, batteries
Phosphate rock	Fertilizers, detergents, flame retardants, food & beverages, animal feeds, metal treatment, water treatment, pulp & paper, glass & ceramics, textiles & synthetic fibres, plastics, rubber, pharmaceuticals, cosmetics, petroleum production, pesticides, toothpaste, mining, leather, paints, fuel cells
Platinum Group Metals	Jewellery, coins, autocatalysts, electronics, glass, dentistry, chemical & electrochemical, catalysts, petroleum, laboratory equipment, antipollution devices in cars, investment, anti-cancer drugs, medical implants (pacemakers, replacement valves)
Silver	Photography (including X-rays), jewellery, electrical applications, batteries, solder & brazing alloys, tableware, mirrors & glass, coins
Tantalum	Electrolytic capacitors, alloys, lining for chemical & nuclear reactors, wires, medical surgery, cameras
Titanium	Production of lightweight alloys, aircraft & automotive components, joint replacement, paints, watches, chemical processing equipment, marine equipment, pulp & paper processing equipment, pipes, jewellery
Tungsten	Alloys (electric lamp filaments, electron & television tube, metal evaporation work), ammunition, chemical & tanning industry, paints, X-ray targets
Uranium	Nuclear fuel, nuclear weapons, X-ray targets, photographic toner
Vanadium	Alloys (especially steel), catalysts, pigments for ceramics & glass, batteries, medical, pharmaceutical, electronics
Zinc	Galvanizing, alloys, brass, batteries, roofing, water purification, coins, zinc oxide (widely used in manufactured goods), zinc sulfide (luminous dials, X-ray & TV screens, paints, fluorescent lights)
Zirconium	Ceramics, refractories, foundry sands, glass, chemical piping in corrosive environments, nuclear power reactors, hardening agent in alloys, heat exchangers, photographic flashbulbs, surgical instruments

2.3. WEALTH FROM MINERALS

Wealth from minerals has monetary and non-monetary aspects. Different models for evaluating national wealth bring different perspectives to what 'mineral wealth' might represent, and how it can be managed. The range of approaches used are outlined in Table 5. Calculating Australia's mineral wealth requires careful assessment because of the diverse roles minerals and metals play in the provision of many of the goods and services required by industry, the public sector, or to the public in the form of consumer goods (CRU International 2001).

The first measure shown in Table 5 is contribution to Gross Domestic Product (GDP), which has become the world's ubiquitous indicator of economic prosperity (Talberth *et al.*, 2007). Governments, international agencies and economists have historically used this measure extensively. An evaluation of ways to measure sustainable development undertaken by the OECD in 2008 stated that the use of GDP (*per capita* or otherwise) was "unjustifiable" for use in a sustainability framework as it ignores changes in stocks of human, social, financial, manufactured and natural capital. GDP does not account for declines in stocks of minerals and metals yet is strongly linked to perceptions of national wealth. For example, if one imagines discovering gold in one's own backyard, and then, in a particular year exchanging it for cash (thereby contributing to GDP) – does this make one feel richer? Would the feeling of wealth be the same when exchanging a finite quantity of gold jewellery acquired by inheritance? What role do expectation regarding further high value discoveries play in perceptions of wealth?

In addition to GDP, other standard economic measures such as the Balance of Trade, Balance of Payments, Interest and Inflation Rates are used to assess conditions for purchasing goods and services.

Imputed Nett Value *in-situ* (or resource rent) is the monetary value attributed to Australia having stocks of mineral resources in, for example, terrestrial ores. This value can change over time, influenced by local and global supply, demand and scarcity. In his report *Managing Australian Mineral Wealth for Sustainable Economic Development* Willett (2002, p 8) writes that without imputed nett value for minerals *in the ground* "there is no mineral wealth to manage".

The Genuine Savings Rate developed by the World Bank is designed to monitor the levels of natural resource depletion and levels of investment in human and built capital. Whilst criticised by Pillarisetti (2005) for adopting a weak sustainability position allowing inter-changeability of capitals, Pearce and colleagues (2008) argue that countries failing on weak sustainability are also likely to be failing on strong sustainability. **Australia was the only developed country to register a negative per capita savings rate** resulting from low savings, high mineral depletion and substantial population growth (Hamilton, 2000).

The fourth approach, titled Measures of Australia's Progress (MAP) combine headline and supplementary indicators in the areas of individual, community, economic and environmental progress. Example indicators include net greenhouse gas emissions per person, number of threatened birds and mammals, life expectancy, and area of land cleared. The most recent 10 year assessment examined many economic and environmental indicators as having improved but social results were mixed (Australian Bureau of Statistics, 2009).

Finally, Genuine Progress Indicators assess *natural* and *social* capital stock to assess wealth.

Outlining a range of approaches to evaluate wealth highlights that minerals offer the potential to make ongoing, useful and significant contributions to the Australian economy. The method of wealth assessment will influence the development of strategies for maximising wealth.

Table 5: Approaches to measuring wealth

Approach	Description of Wealth	Indicators	Criticism / Comments
Gross Domestic Product (GDP) Simon Kuznets	GDP may be defined as the unduplicated **dollar value** of production that occurs in Australia during a year.	Increasing or decreasing dollar value of consumption. GDP Reported as annual country total or on a per capita basis.	*"… does not include adjustments for capital consumption, depreciation of natural capital, or environmental degradation."* (Australian Mineral Economics 2006 p10) *"…GDP fails to properly distinguish between welfare enhancing and welfare degrading expenditures and ignores non-monetized costs and benefits including all informal sector exchanges..*" The Genuine Progress Indicator 2006 (2007)
Resource Rent, Mineral Rents or Imputed Nett Value (in situ) Hotelling and a range of others.	**Dollar value** of the "resource rent, mineral rent" arising from possession of minerals that are in demand. "Imputed Nett Value has played a role in determining or informing "the price of a resource, a source of income and wealth, and a base for taxation,". Willett (2002)	Imputed nett value will be affected by: • Demand for minerals • Supply characteristics of Australian minerals • local exhaustibility, variability (heterogeneity) and global scarcity.	Does not capture other forms of wealth provided by these minerals, such as end uses or a material input to goods and services, or as an input to procuring such goods and services. *"…the development of competitive mineral economies in other nations may threaten the competitive position of the Australian resources sector…may have implications for the economic fortunes of states and smaller regions that depend on marginal mineral deposits for their economic wellbeing. It may also adversely affect Australian national welfare."* Australian Mineral Economics 2006 p17-18
Genuine Savings Rate (GSR) World Bank	Ongoing ability to translate funds from exploitation of natural capital into human capital (currently counted in terms of education) that can be sustained over the long-term. Tracks natural resource depletion and levels of investment in human/built capital.	GSR = [Gross Domestic Savings + Expenditure on Education - Depreciation of physical capital - Rent from depletion of natural capital (energy, mineral, forest are included) - Damage from CO_2 emissions] expressed per unit GDP per person.	Criticised for single focus on human capital as indicator (Brown *et al*. 2005). However, this substitution of one form of capital for another is highly contested, with the most recent discussion of OECD measurement of sustainable development divided on this issue (OECD 2008 p3). A study that applied GSR to Queensland also indicated that a sub-national region can achieve a GSR that runs counter to the national trend and vice versa (Brown *et al*. 2005).
Measures of Australia's Progress (MAP) Australian Bureau of Statistics	Not strictly a measure of wealth but a measure of "progress" – defined by ABS as "synonymous with life getting better".	Increasing progress in each domain important. • Social: increase wellbeing, reduce threats, increase social cohesion; protection and enhancement of rights • Economic: raise national income (real per person levels) while maintaining (or possibly enhancing) the national wealth that will support future consumption • Environment: reduce threats to environment, improve me health of ecosystems.	Each domain is comprised of a range of headline and supplementary indicators. Some key indicators include GDP per capita, victims of personal crime, net greenhouse gas emissions per person, number of threatened birds and mammals, life expectancy. The most recent 10 year assessment, issued in April of 2009 assessed many economic indicators as having improved but many social and environmental indicators have not. Full details of indicators can be found on the ABS website - http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/1383.0.55.001
Genuine Progress Indicators "variant of the Index of Sustainable Economic Welfare (ISEW)". GPI 2006	The **status** of **natural and social capital** upon which goods and services depend (i.e. the **materials** that go into goods and the **trust** that allows transactions to take place).	**Maintenance** or **improvement** of natural and social capital stocks are a potential **sign of increasing wealth. Declines; decreasing wealth.** *"… if GPI is stable or increasing in a given year the implication is that stocks of natural and social capital on which all goods and services flows depend will be at least as great for the next generation while if GPI is falling it implies that the economic system is eroding those stocks and limiting the next generation's prospects.*" GPI 2006	Privileges future welfare over present welfare. This issue split the OECD group evaluating measures of sustainable development in 2008 Some indicated a need to provide a system of indicators that accounted for present and future welfare not just future welfare (OECD Measuring Sustainable Development 2008). The Genuine Progress Indicator 2006 See also Index of Sustainable Economic Welfare (ISEW) (Cobb and Daly 1995)

2.4. RESOURCE DEPLETION AND NATIONAL WEALTH: MANAGING TECHNOLOGY AND TRANSITIONS

Having reviewed approaches to measuring wealth, this section introduces the concept of resource depletion in the context of Australia's national wealth. We briefly explore how mineral depletion drives new technology development, and the challenges presented in responding to changing technology. This leads to a discussion of our ability to capitalise on transition opportunities involving new modes of wealth generation that will deliver national benefit into the next century.

2.4.1. Mineral resource depletion

Australian mineral resources are finite, hence given continuing extraction, they will eventually be depleted well into the future. However, of more immediate importance than depletion *per se* is the changing attractiveness of the cost and impact profile of resource extraction in Australia.

Giurco *et al.* (2009) indicate that the debate about how to frame resource depletion is ongoing. Tilton and Lagos (2007) suggest that using a fixed stock paradigm (i.e. that there is a given quantity of a resource available in the Earth) is a misleading indicator of resource availability, and that an opportunity cost paradigm (that suggests a useable resource quantity is better represented by price and the opportunity cost of using the resource) gives a better picture of resource depletion and availability. They argue that while minerals such as copper may become scarce, and thus more expensive, those minerals may also become more available because technology has the capacity to move a mineral resource, to an ore reserve and into the stock in use, consequently increasing the amount in use or as waste. This will drive the development of new technologies that support the high returns on investment. Tilton and Lagos conclude that the resource base can be the only fixed stock, and there "…is no way to know the availability of copper decades in advance" (2007, p 23).

There has been little effort focussed on developing depletion models for mineral resources since the late 1990s. This can firstly be attributed to the general expectations within the industry that knowledge and technology will address any shortfalls in production (e.g. the ability to maintain high production output even when ore grades are declining). Secondly, the historical record of expanding resources with the globalisation of mining has made physical constraints at the national level less important beside considerations of how future needs will be supplied (Willett 2002, Tilton 1996). Many analyses also argue that depleted reserves could be effectively extended through interventions by government or private entities (regulation), or by "higher real prices" leading, for example, to technology development to profitably access lower grade ores.

Gordon and co-authors (2006) contend that the relative proportions of minerals in the lithosphere, in use, and in waste deposits, are a useful indicator of how scarce a particular resource will be under such circumstances. The technology trend predicted by Gordon and colleagues is one that tends towards high levels of recycling and reuse, and substitution of appropriate alternatives where minerals are locked into use phases or whose useful qualities are "dissipated" by their use in particular applications (Gordon *et al*., 2006).

An example of this trend in practice can be seen in Japan, where 'product stewardship' and 'extended producer responsibility' (EPR) initiatives are creating an increasingly large and progressively inexpensive pool of resources for use in new product lines. Metals (including copper, steel and aluminium) that may have originally come from a range of other continents are effectively captured by Japan's vertically integrated production, disassembly, recycling and reuse system (Department of Trade and Industry (UK), 2005).

The contrast between the fixed stock and opportunity cost paradigm aligns to some degree with technological pessimism versus technological optimism (see for example Foran and Poldy, 2001). Willett (2002, p 12) suggests that “the key issue is the appropriateness of the optimistic view of new discoveries and technological progress. The optimists, like the pessimists, have not provided adequate data to support their position, although history is on the side of the optimists.”

In any case, most minerals and metals are unlikely to run out in the near future. Whilst stocks of high grade oil or coal or phosphate can be exhausted, metals are inherently recyclable (and are more readily recoverable from end uses where the metal is used in a pure form and not dissipated) and also accessible at a range of grades. **So although few metals are currently facing physical depletion, they are becoming harder to obtain,** and the energy, environmental and social cost of acquiring them could constrain future production and usage.

2.4.2. Technology, transitions and sustainable resource management

Lower impact mining and minerals processing does not automatically equate to sustainable mining and resource processing. Australia must aim to shape its mining and minerals processing operations to underpin sustainable economies of the future – minimising negative impacts, strengthening positive and restorative impacts and embedding itself within systems of sustainable resource use and reuse.

Broad consideration must be given to the following questions:

- what are sustainable patterns of production and consumption, nationally and globally, with which Australian resource extraction and processing can link?
- what models of sustainable resource management are relevant for Australia and how can the be implemented?
- what role will mining and minerals processing play in the Australian economy of this century?
  - will Australia’s platform for prosperity be tied to the minerals sector?
  - how will the factors which favour location of minerals-related activities in Australia - relative to other countries – differ from those which underpinned activity in the 20th century?
  - what can be done to ensure current and future mining activity leads to long term national benefit?
- what role will new Australian technology play:
  - for primary processing from ores or ocean resources?
  - for developing product-service systems?
  - new business opportunities from dematerialisation or product leasing?
  - for recycling?
- how will existing operations be managed at end of life?
- what can be learned from foresight into expected transitions in global demand and end uses for metal in the global economy driven, for example, by responses to climate change?
  - what can be learned from the transition after peak oil to alternate energy ?
- how can this help the Australian minerals industry, government and community stakeholders plan our own transitions in technologies and practices which will bring about long-term wealth from our mineral resources?

As early as 1945, Williamson described the role of 'prophesies of scarcity' in generating a conservation response for both renewable and non-renewable resources (Williamson, 1945). He concluded that concepts of resource exhaustion are triggers for thinking about how a particular resource is managed. This has been explored in some depth where renewable resources are concerned, most notably with respect to forestry and fisheries. However, the depletion of non-renewable resources, such as minerals, have not received the same amount of attention. This review seeks to focus beyond scarcity *per se*, to a deeper understanding of the impacts of mining and processing 'harder' (more complex or difficult to access) ores as a basis for framing a considered response.

In addition to considerations of what mineral wealth and long-term national benefit might mean, the following key characteristics of the Australian economy are important for understanding how Australia's mineral wealth can be understood and managed in the long-term:

- abundant resource base
- comparatively small population
- limited manufacturing base
- geographic size (large land mass with great distances between population centres)
- remoteness from the rest of the world
- potential for land use conflicts.

While Australia's mineral endowment is vast, the characteristics listed above create a mineral income stream that has been, and may continue to be highly dependent upon demand from a global market, stable regulation, low costs for labour due to the availability of technologies, low costs for energy to run the technology, and low costs for international transport.

As such, **physical depletion is not the primary determinant of a mineral's availability**. Whilst a concern at the level of national and sub-national or regional economies (AusIMM, 2006; Willett, 2002), **it is economic depletion together with social and environmental constraints and impacts which will influence which ore bodies are exploited.** A consideration of each of these indicators will determine when other sources of metals become more profitable (for example, from ocean resources, tailings reprocessing or secondary scrap processing).

Examining how the future Australian economy will benefit from Australian mineral resources must take these points into consideration, and explore in more detail the impact on economic, social and environmental systems at the local, regional, national and global level.

SECTION TWO: SUMMARY

This section has explored the nature of minerals as resources and how these resources contribute to Australia's national benefit. Resources are defined within the context of the Joint Ore Reserves Committee Code, but generally represent objects or materials that are attributed value in our societies. Given mineral resources are finite, their depletion will have consequences for Australia's long-term prosperity because of the way in which minerals and metals contribute to Australia's wealth. Although physical depletion may not present an issue in the short-term, continued production combined with falling resource quality brings greater technological, environmental and social expense, and the likelihood of economic depletion. This raises questions relating to sustainable mineral resource management: how we can we better value resources in the future, and how can we recognise when and how to plan transition mechanisms to mitigate the impacts of resource depletion, or its consequences for an extractive minerals industry?

3. EXPLORING THE CONCEPT OF PEAK MINERALS

SECTION THREE: OUTLINE

This section explores:

- *the unsustainability of mineral use; not primarily due to being finite resources, but rather arising from the impacts of their use (3.1)*
- *the 'peak oil' model for understanding resource depletion and transitions to new ways of providing energy services (3.2) and the similarities and differences for minerals (3.3)*
- *a conceptual model of peak minerals based on distinguishing 'lower' then 'higher' costs after peak production with respect to social, environmental and economic costs (3.4)*
- *how higher costs can promote new ways of supplying metal to meet demand (3.5)*
- *the peak minerals concept for case study data on copper and gold for Canada, Australia and the United States of America(3.6).*

3.1. FINITE SUPPLY OF MINERAL RESOURCES

Mineral resources are generally considered finite in potential supply (for example, Young, 1992; Gordon *et al.*, 2006) – since they are not renewed by natural processes (excluding very slow geological processes of ore and mineral deposit formation). On this basis it would appear reasonable to conclude that mining of all mineral resources is unsustainable in the long-term.

At the same time, almost all minerals are being produced today at greater rates than at any time in history. This paradox has increasingly raised the prospect of traditional mineral supplies eventually being exhausted (the most famous example of such a view being *The Limits to Growth;* Meadows *et al.*, 1972). As mentioned earlier, practical exhaustion (i.e. the inability to develop resources) arising from economic, social and environmental constraints is of greater concern than physical exhaustion.

Global society's increasing production, use and disposal of minerals and metals has led to adverse environmental impacts: from global warming to local pollution affecting land, air and water. Such ongoing impacts will likely become unsustainable in the medium to long-term (Giurco and Petrie, 2007; OECD, 2001; McLellan *et al.*, 2009). In short, we must be concerned not only with how our use of minerals and metals contributes to their depletion, but also how pollution from the production, processing and use of minerals and metals should be considered in the context of our use – particularly because metals are highly recyclable.

3.2. PEAK OIL MODEL FOR RESOURCE DEPLETION , ENERGY SERVICES AND TRANSITION PLANNING

Given increasing global population and rapidly growing consumption (especially in China and India), frameworks for the analysis of resource depletion can assist in developing appropriate responses. The most popular contemporary focus for resource depletion is oil (or petroleum) resources. In 1956, oil geologist M M King Hubbert famously predicted that conventional oil production from the lower 48 (mainland) states of the United States would peak by 1970 and then enter a terminal decline, shown in Figure 9 (see Hubbert, 1956). This model was subsequently proven to be accurate (although the peak year was 1971). Hubbert also predicted that global conventional oil production would peak around the year 2000, which has proved to be slightly out given that conventional oil production has only plateaued recently (see Bardi, 2005). This phenomenon is now commonly called 'Peak Oil', with peak production curves known as 'Hubbert Curves'.

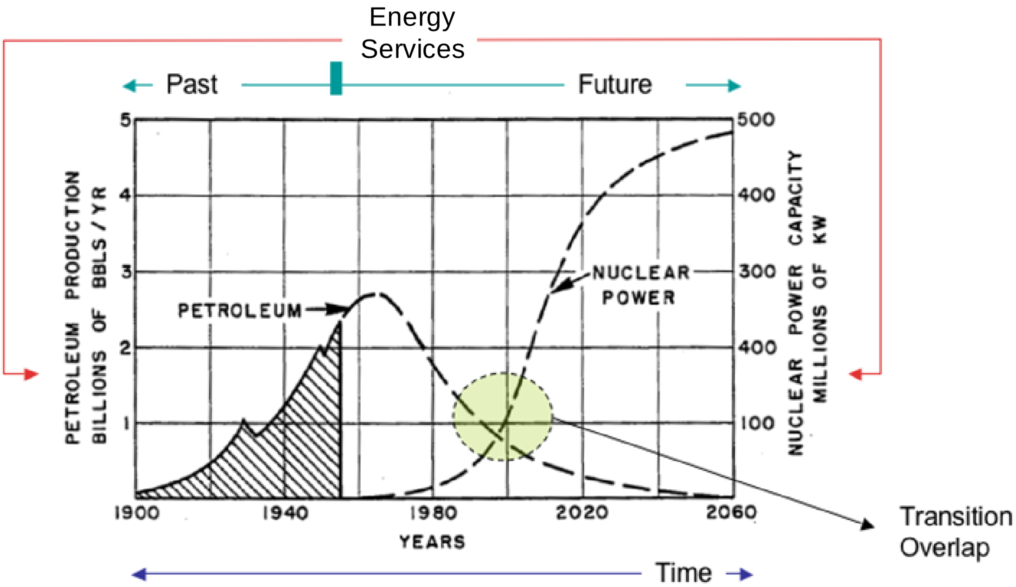

Figure 9: Hubbert's prediction for peak oil production in the lower 48 states of the United States and the energy transition to nuclear power (adapted from Hubbert, 1956)

Over the past decade there has been a rapidly growing global movement analysing and debating Peak Oil, which includes numerous former oil geologists like Hubbert. The collective work has helped to reach a broad consensus that Peak Oil will happen, though timing of the global peak is still contested and some argue that it has already passed. The use of the peak metaphor for resource management is interesting for several reasons. In addition to representing an approximate model for predicting annual production, it introduces a focus on the *services provided by the resource* – in this case the energy services provided by oil – and highlights the need to provide such services by different means post-peak to avoid disruptions to the economy. Hubbert, anticipated a transition to nuclear power to provide the energy services (Figure 9); forecasters would now add wind, solar, geothermal and biomass.

3.3. PEAK MINERALS VERSUS PEAK OIL: ASSUMPTIONS

3.3.1. Modelling assumptions

The mathematical methods used by Hubbert were based on logistic growth curves, commonly used to model population growth and other biological systems. The models have a minimal number of variables but require some key assumptions. The primary assumptions that Hubbert used to underpin the application of 'peak curves' to analyse conventional oil production are (see Bentley, 2002; Hubbert, 1956; Mohr and Evans, 2009):

1. The population of producing fields is sufficiently large so that the sum of all fields approaches a normal distribution.
2. The largest fields are discovered and developed first.
3. Production continues at its maximum possible rate over time.
4. Ultimate recoverable reserves are known.

Further factors that underpin the above assumptions include (e.g. Hewett, 1929; Cook, 1976; Laherrère, 2000; Cavallo, 2004):

- Accurate estimates of easily accessible proven reserves;
- Political and market stability;

- Affordable, stable prices for consumers and enticing profits for producers;
- Exponentially increasing consumption;
- Independent producers focused only on maximizing their immediate profits;
- Perceived abundance of and availability of other reserves (e.g. US, Middle Eastern).

These assumptions are less applicable to minerals than they are to oil. There is limited substantive work being undertaken to examine how the relationships between the concepts and assumptions of Peak Oil can be applied to minerals – 'Peak Minerals' (see for example Heinberg, 2007; Giurco *et al.*, 2010). It is therefore worth analysing these assumptions and factors in more detail with respect to minerals, as they provide a useful starting point to examine a conceptual framework for resource use and the services they provide.

3.3.2. Estimating resources and the role of exploration

Resources

Estimating economic mineral resources over time is a difficult task, and estimates are frequently under review. Some countries maintain simple national accounts (e.g. Canada – National Resources Canada; Australia – Geoscience Australia), while others undertake more regular, detailed assessments of mineral resources and 'strategic' mineral resources (e.g. United States – US Bureau of Mines; US Geological Survey). In Australia, stocks (as defined by the JORC code, see Appendix A) of several mineral resources have increased over the past 30 years although some, such as coal and iron ore, appear to have plateaued (Mudd, 2009). In contrast, Canada's estimates over the same period show long-term declines for most minerals (e.g. copper, nickel, gold; see NRC, various dates) – although by analysing formally reported company reserves and resources, it is easy to show for copper, nickel and gold that these significantly exceed national estimates.

Exploration

Mineral exploration plays a very significant role with respect to known economic mineral resources over time. Few detailed studies analyse discovery rates of numerous minerals over time, with most government agencies or other research groups relying on estimates of known economic resources. A range of anecdotal evidence, however, or industry observation, can be considered. As a case study, let us examine copper. National estimates of economic copper resources over time for Canada, USA, and Australia are shown in Figure 10.

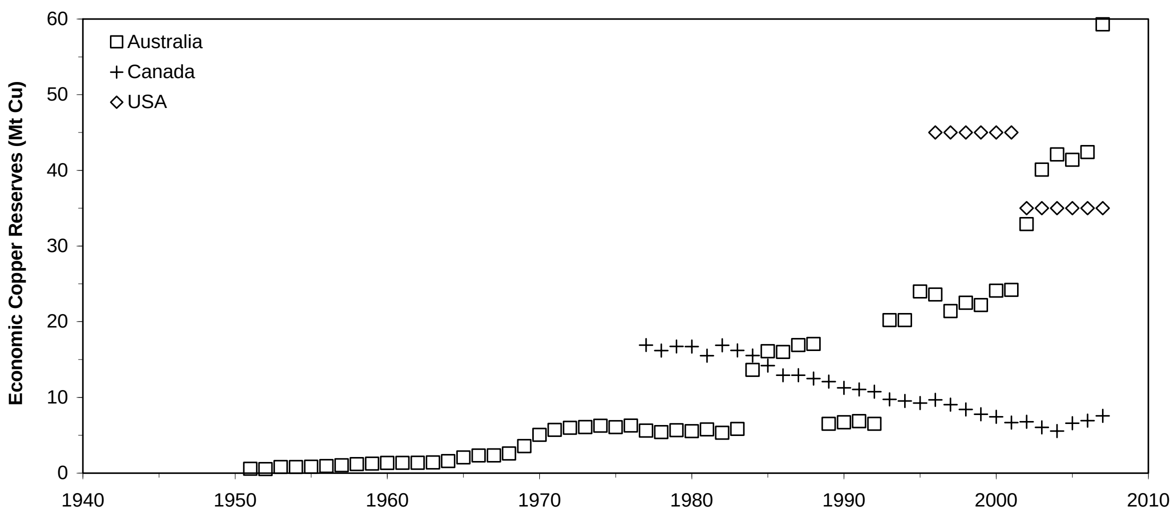

Figure 10: Economic copper resources in Australia, Canada and the USA (Mudd & Ward, 2008, including recent data)

There appears to have been no major copper discovery in Canada for many years, with all production from large-scale mines with substantive remaining resources (e.g. Highland Valley in British Columbia or the Sudbury district in Ontario). In contrast, there have been a range of major discoveries in Australia since the 1970s, such as the giant Olympic Dam copper-uranium-gold-silver deposit, the Ernest Henry, Cadia-Ridgeway, Northparkes and Prominent Hill copper-gold deposits and the Nifty copper deposit, as well as continued expansion of remaining copper resources at Mt Isa and Mt Lyell. The United States appears to be in between Australia and Canada, with only the giant Resolution copper and Pebble copper-gold deposits in Arizona and Alaska, respectively, being discovered in recent years and most remaining copper resources being related to existing large scale mines, especially in Arizona and Utah.

A major challenge is that exploration will often target new deposits that are within the range of existing technological and economic capacity but often lower grade than at present. Over time, this leads to a decline in average ore grade. However, it is not always this clear – since there are many examples where exploration discovers new deposits which are higher grade than the industry average. For example, the development of the Mt Isa copper deposits in the 1950s, with an ore grade of ~4% Cu, was some six times higher than other mines at ~0.7% Cu (Mt Lyell, Mt Morgan) (Mudd, 2009a). In Canada, the discovery of the rich uranium deposits in northern Saskatchewan in the 1970s to 1980s saw average deposit grades range from 1-20% U_3O_8, compared to the previous dominance of Elliot Lake mines in northern Ontario with typical ore grades of 0.1% U_3O_8 (Mudd & Diesendorf, 2008).

Furthermore, as the ore grade declines the tendency is towards larger deposit sizes – thereby offsetting lower grades and even allowing substantial increases in production. Over time, as demand grows and technology evolves to enable extraction, this leads to the case whereby average ore grades gradually decline. This is the classic case typified by gold, copper, lead-zinc-silver, nickel and other metals and minerals (as shown by Mudd, 2009a). Although there are always exceptions to this process, as noted above, the long-term trend for Australia is generally for an effectively terminal decline in ore grades. The reality is that exploration and mining-milling technology cannot be separated from economic considerations, nor environmental and social issues. The challenge for peak minerals is, therefore, understanding what this ongoing industry transition and evolution means for the future of the minerals industry generally.

3.3.3. Production assumptions

Mineral production can rise and fall in response to overall economic conditions, especially supply and demand balance and market prices (see section 4.3). Some mining companies will reduce production or even close mines temporarily (or permanently) during adverse economic conditions to ensure economic viability over price cycles. Peak curves are less useful for a particular mine; but more applicable to a collection of mines nationally or globally.

3.3.4. Real prices over time

One argument used to justify the ongoing availability of mineral resources is that real prices (i.e. adjusted for inflation) continue to trend downwards, as shown for copper, lead, zinc and nickel in Figure 11 (data for most other mineral commodities shows similar downward trends, or an even greater decline in real prices). However, recent research suggests that real prices over time are an unreliable indicator of scarcity over time, due to standard price deflators (e.g. US producer price index) overestimating inflation, to which the calculation is sensitive (see Svedberg and Tilton, 2006). Adjusting for this shows no trend over time or an increase in price over time depending on the level of adjustment. In any case, as shown in Figure 12, gold is a notable exception with real prices clearly trending up since the 1970s (when the gold price was deregulated) despite the development of carbon-in-pulp process technology and a massive boom in production.

The difficulty in relating real prices to the paradigm of peak minerals is that the historic patterns shown in Figure 11 and Figure 12 are mostly for more easily accessible resources – compared to the future of more difficult ores and higher costs, likely to include some environmental externalities such as a carbon price. Whilst it remains uncertain what real price patterns will emerge in time, economic, social and environmental costs are likely to rise.

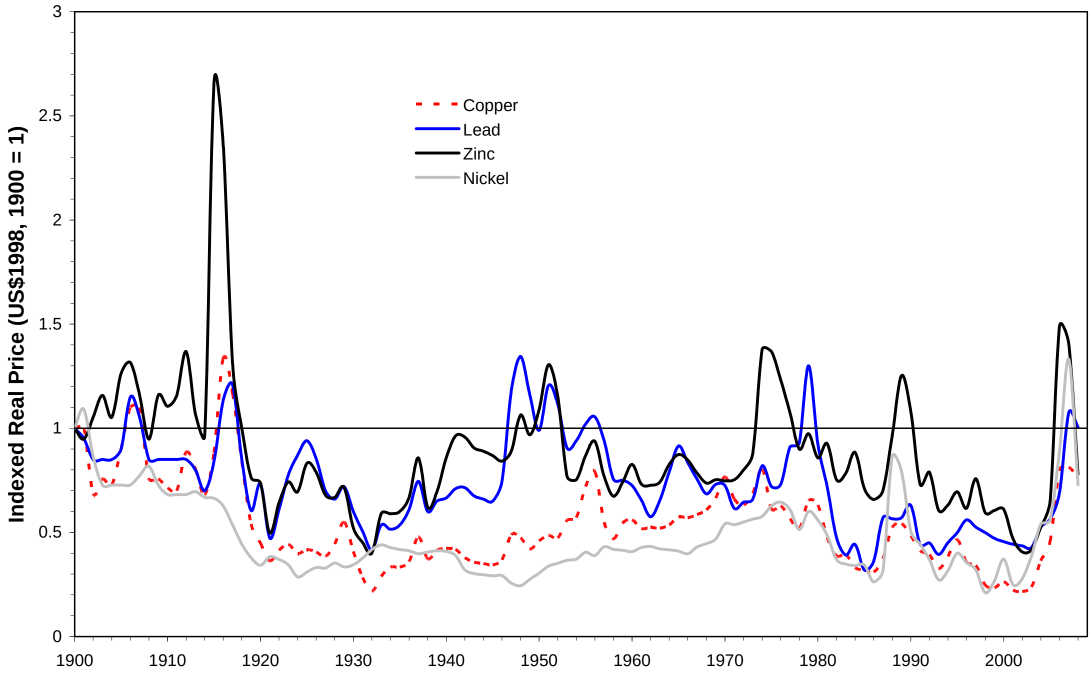

Figure 11: Indexed real prices (US$1998 where 1900 = 1) for copper, lead, zinc and nickel over time (data from Kelly et al., 2010)

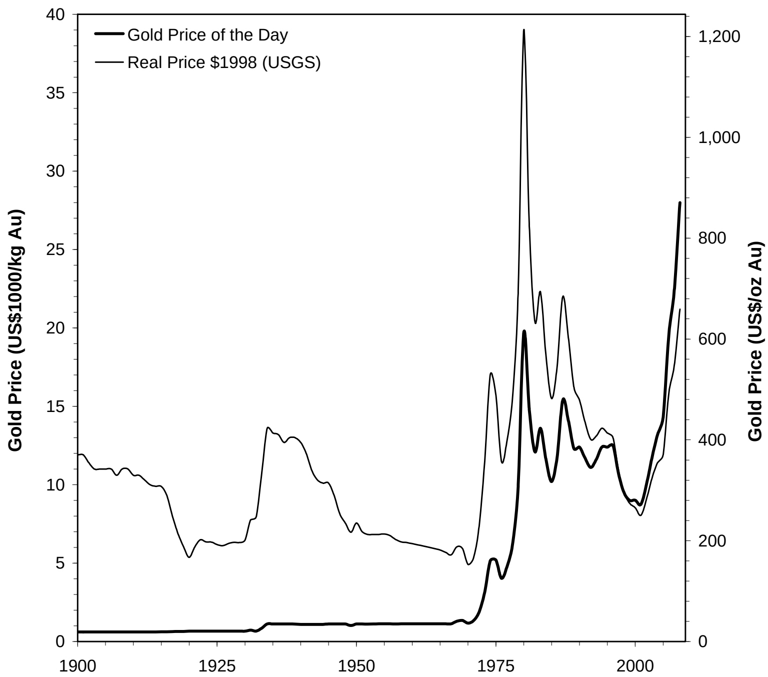

Figure 12: Gold prices over time (nominal and real as US$1998) (data from ABARE, 2009b; Kelly et al., 2010)

3.4. CHANGING ORES – FROM LOWER TO HIGHER PRIMARY PRODUCTION COSTS

A similar picture of changing availability could be developed for various minerals, or specific metals, such as gold, lithium, lead, zinc and so on. The role of continued mineral exploration is clearly critical in identifying the extent of economic mineral resources, meaning that the key assumption of knowing ultimate recoverable resources is problematic at best, or invalid at worst. **This makes using peak curves for accurate projections of long-term supply difficult to implement, although they remain a useful conceptual tool when used with assumptions concerning the possible extent of economic resources.** However, it is not only resource exhaustion that is of concern with respect to sustainability, but the change in costs and impacts from processing 'easier, lower cost' ores prior to peak production for a given mineral, to 'more difficult, higher cost' ores post-peak. This is illustrated conceptually in Figure 13.

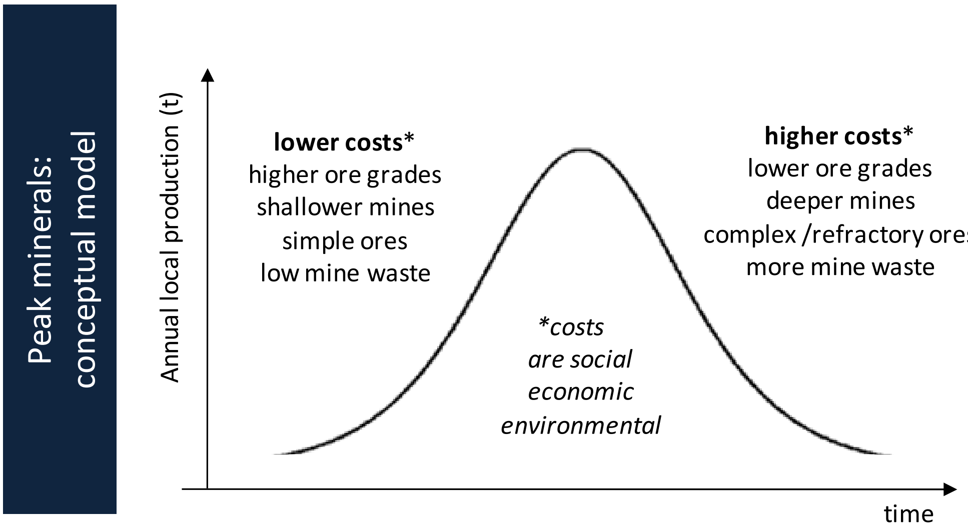

Figure 13: Conceptual model of peak minerals; illustrating higher costs post-peak

Additional issues exist with respect to exploration and ascribing mineral deposits as economic. Firstly, exploration for many minerals is increasingly targeting zones for new deposits deeper than existing mines. This increasing depth trend is evident in copper, nickel, platinum-group metals (PGMs) and gold, especially in the South African gold and PGMs industry and major Canadian nickel fields of Sudbury in Ontario and Thompson in Manitoba. Secondly, ores that are easier to treat are often developed first, with more refractory deposits remaining uneconomic until technology changes or supply shortages justify more expensive production. A good example of this is the lead-zinc-silver industry in Australia, where each major project from Broken Hill to Mt Isa to McArthur River became increasingly difficult to process – especially McArthur River which, despite being discovered in 1955, took some four decades of research to develop milling technology capable of economically treating the ore (Mudd, 2007c, 2009a). Finally, ore grades are in terminal decline for a wide array of minerals – especially gold, copper, nickel and lead-zinc-silver ores (Mudd, 2007a; 2009a,b; Mudd & Ward, 2008). Thus, although exploration can still discover new mineral deposits, the characteristics of a particular deposit that make it 'economic' continue to change and evolve as the mining industry faces these issues. It is important that social and environmental costs also be more explicitly included in future assessments of economic resources (as required by the JORC Code in any case when reporting reserves and resources; see Appendix A).

Furthermore, the ore grade decline, combined with increasing production, leads to an overall increase in environmental and social costs. This occurs despite step-change reductions due to technological breakthroughs, which generally delay increases in impact rather than reversing them – this is illustrated conceptually in Figure 14.

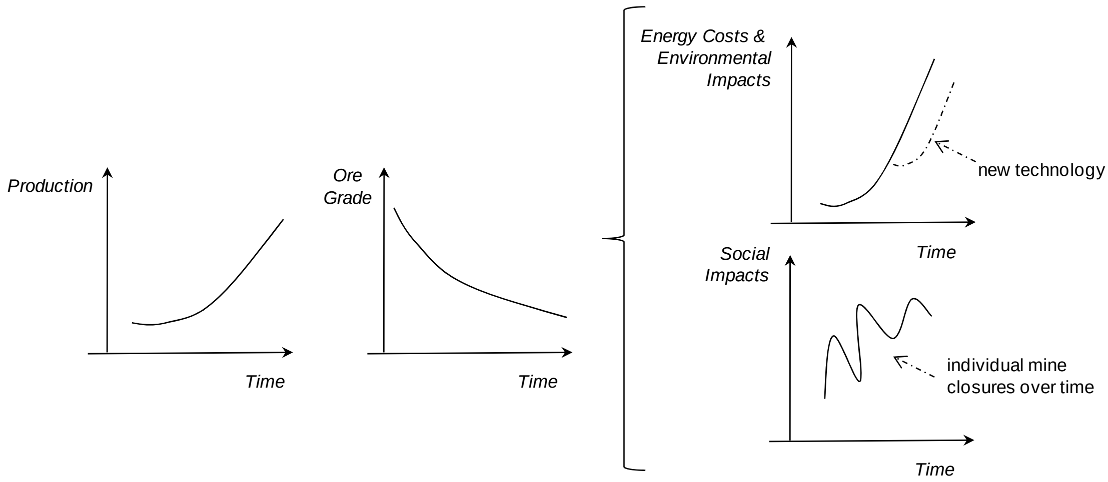

Figure 14: Rising energy, environmental and social impacts as a result of increasing production and declining ore grades, despite new technologies (adapted from Giurco, 2009)

3.5. MEETING FUTURE DEMAND – A MIX OF MINING AND RECYCLING

Ultimately, how long the historical pattern of discovery and expansion of resources at current mines can continue is very difficult to predict. There is certainly room for optimism over a medium term time frame to 2025, but beyond this is inherently uncertain. This dilemma also has to be considered in the light of continued demand, and consumption growth, lead presently by China, and increasingly by India in coming years.

Furthermore, most metals are recyclable, either easily (e.g. aluminium) or with careful programs (e.g. lead, platinum). This provides a potentially substantial resource, which effectively continues to grow over time as primary mining persists. At present, existing technology and economic conditions still favour primary mining as the economically cheapest supply, however this situation is likely to change in the future given energy, water, climate change and a range of other complex issues noted previously that already affect the mining industry.

3.6. CASE STUDY FOR COPPER AND GOLD

3.6.1. Peak minerals: Australia, USA, Canada

A recent study by Mudd & Ward (2008) modelled peak curves for copper and gold production in the USA, Canada and Australia (Figure 15). From these models, it is tempting to conclude that the USA and Canada have passed their peak in copper production, while Australia is still some years away from this point.

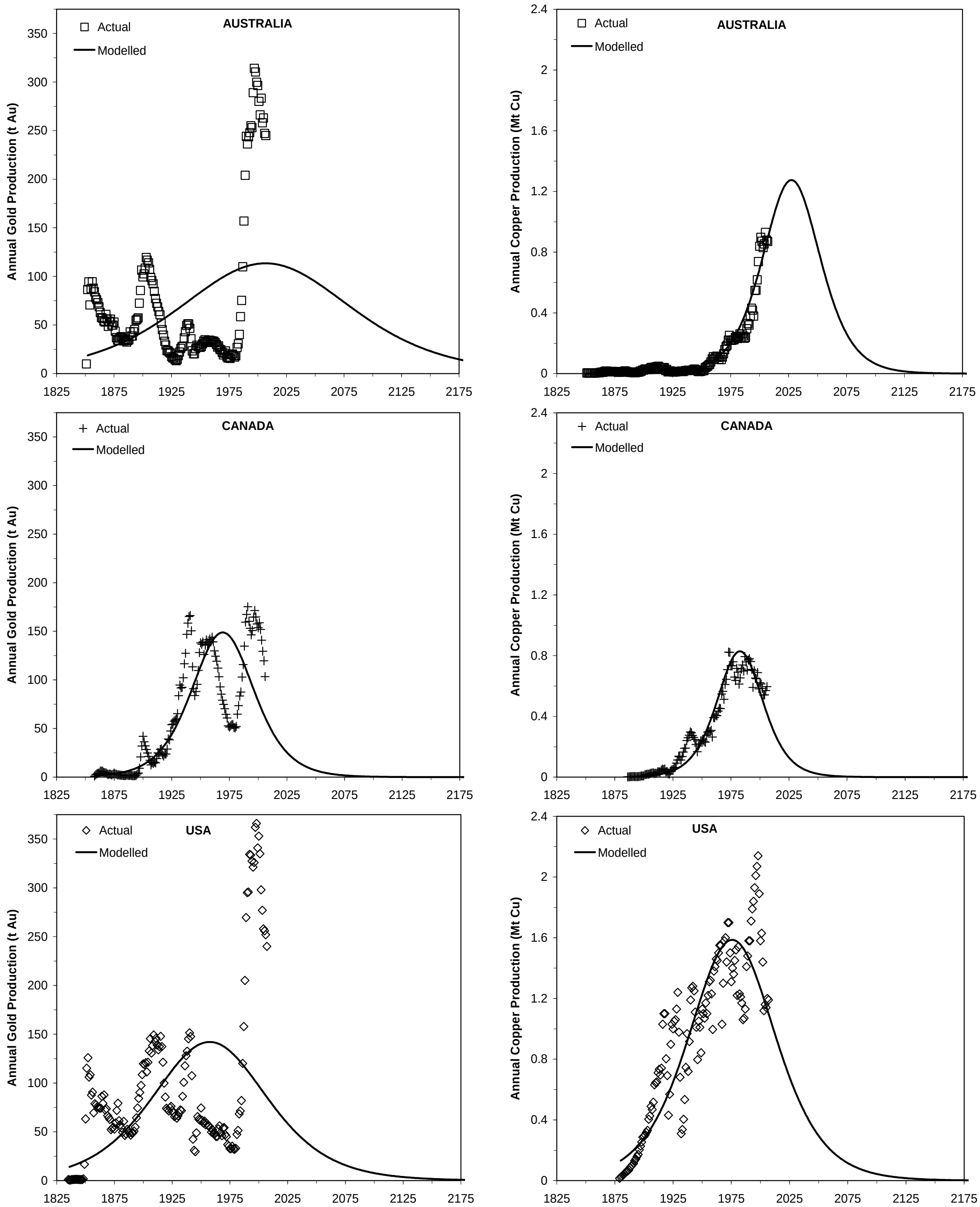

Figure 15: Examples of applying peak curves to Au (left side) and Cu (right side) production in Australia (top), Canada (middle) and the United States (bottom) (Mudd & Ward, 2008)

Based on visual observation, it is possible to say that the curves for gold fit poorly, while those for copper appear more reasonable. There are several fundamental reasons for this stark difference and why interpretations of being post-peak may be premature.

3.6.2. Gold: technology transition drives multiple peaks

For gold, there have been a number of gold booms due to discoveries of major new fields, particularly evident in Australia's production booming in the mid-1800s with the discovery of gold in eastern Australia, then a new boom in the 1890s as the major central Western Australia gold fields were discovered and exploited. The relatively minor booms of the 1930s were largely related to economic conditions favouring gold mining. The largest boom, recorded during the 1980s, was caused both by a major rise in the real price of gold (from ~$30/ounce to >$300/ounce) as well as the development and widespread adoption of the new 'carbon-in-pulp' (CIP) process technology. The use of CIP allowed low-grade ores to be processed economically, even with high salt brines if freshwater was unavailable. This most recent boom is also evident in Canada and the USA. Recently, French Peak Oil researcher Jean Laherrere has used several peak cycles to model Australian gold production (Figure 16). The essential basis for applying several peaks is that industry conditions were substantially different for each peak – driven by economic or technological factors. Consequently, the peak metaphor of rising and falling production under existing circumstances points to the possibility of new peaks being driven by changes in technology and economics. In future we should also anticipate peaks (and coincidental resource scarcity) driven by environmental and social factors in addition to economic and technological ones that have largely driven production peaks in the past. This raises the possibility of a situation where technology is no longer able to make continuing production economically viable.

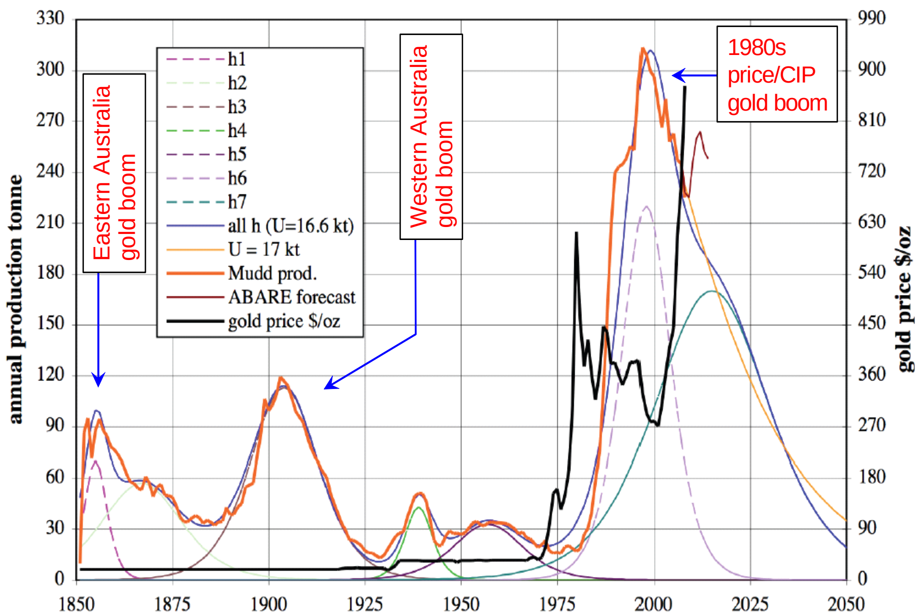

Figure 16: Applying multiple peak curves (h1–h7) to Gold (Au) production in Australia (courtesy J. Laherrere)

3.6.3. Copper: dominant technology fits single peak

Conversely, for copper, the curves appear reasonable since the economic conditions, extent of discoveries, process technology and other factors influencing copper production have been more stable over the time period, or at least change was more gradual and in line with demand. This does not mean, however, that the copper curves in Figure 17 are a perfect model of long-term copper production. As noted previously, exploration continues to expand known resources at existing mines, plus new discoveries are still being made (e.g. Australia). Thus the ultimate resource is not accurately known. The increasing role of hydrometallurgical solvent-extraction electrowinning technology in contrast to the historical dominance of pyrometallurgical smelting technology (both reverberatory and flash smelting) is also important to consider.

3.6.4. Major factors contributing to the 'peak'– declining ore grades, increasing footprints

A crucial aspect in determining the peak oil phenomenon is the declining quality of conventional crude, in either energy terms (e.g. energy return on energy invested), or deleterious impurities such as hydrogen sulfide. For minerals, the analogous aspect are ore grade and quality – that is, the concentration of a particular metal (or metals) being mined, as well as the quality of the ore with respect to processing (e.g. fine or coarse grained ore, mineralogy, impurities such as arsenic or mercury, etc). As ore grades and/or quality decline, the energy requirements and pollution burdens increase substantially. Based on recently compiled historical data sets, long-term trends for copper and nickel ore grades in Australia, Canada and the United States, as well as gold ore grades in several countries are shown in Figure 17. A recent analysis of the carbon intensity of gold production (i.e. t CO_{2-e}/kg Au) versus gold ore grade is also included, showing not only the effect of primary electricity source on overall carbon intensity but also that as ore grades decline the carbon intensity begins to increase significantly. The scatter is most likely due to the varying configurations of gold mines and mills (e.g. underground/open cut, several mines, heap leach versus CIP, relative energy sources (coal, hydro, diesel), project age, depth, ore types, etc.).

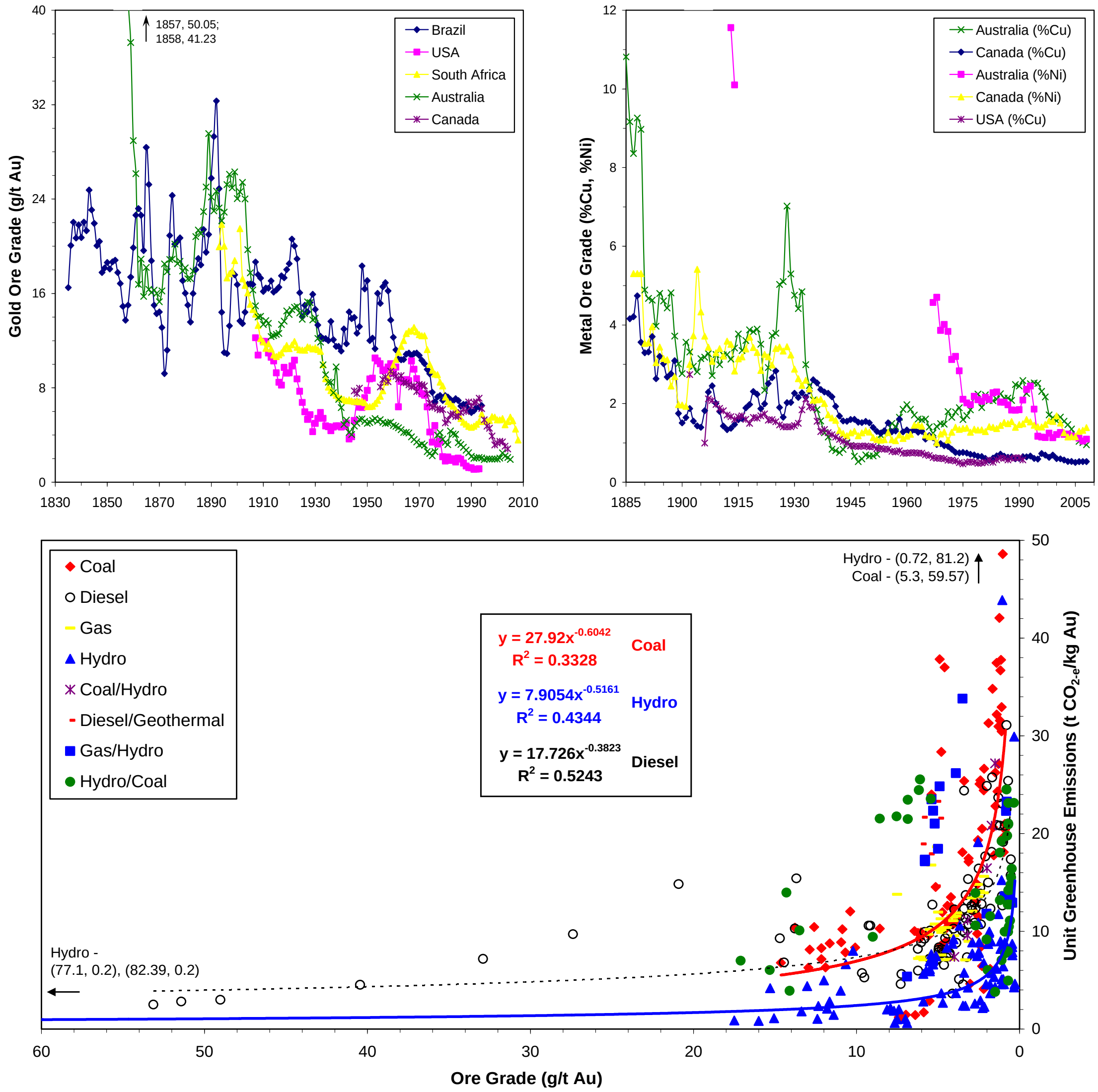

Figure 17: Declines in ore grades for gold (a: top left) and copper (b: top right), and (c: bottom) carbon intensity of Au production versus ore grade (Mudd, 2007b; Mudd, 2009a,b; Mudd, 2010 including unpublished data)

SECTION THREE: SUMMARY

The concept of 'peak minerals' provides a useful paradigm within which to explore the future threats to, and benefits from, the Australian minerals industry.

Peak minerals occurs at the point when mineral production peaks and begins to decline – sometimes occurring at numerous times during the history of production (e.g. gold, which had multiple peaks due to the development of new technologies).

Much of the evidence to date suggests Australian minerals are unlikely to run out in the near future, but it is becoming more difficult to obtain and produce the quantities (and quality) of product demanded by the market, and the consequences of more difficult production (environmental and social impacts) are also increasing. What was once an industry characterised by cheap and easy production, is now more likely to be characterised by difficult and more expensive production.

The peak concept has largely been applied in the context of general resource depletion and physical scarcity (particularly for Peak Oil). However, the concept may hold greater significance in the minerals context when applied in relation to the consequences of continued extractive exploitation up to and post-peak.

With greater environmental and social impacts from mining come greater costs for the mining industry to minimise these impacts. Ultimately, peak production may occur because of the economic scarcity of minerals, rather than physical scarcity alone.

4. THE ECONOMICS OF PEAK PRODUCTION

SECTION FOUR: OUTLINE

This section explores:

- *the economic benefits (4.1) and threats (4.2) that a dependence on mineral resources presents to Australia*
- *the structure of the Australian minerals industry, particularly focussing on the influence of 'economies of scale' and corporate financing and markets (4.3)*
- *how supply (4.4) and demand (4.5) influence production and resource price, and how changing costs as a result of peak minerals may affect the ability to supply product in the future.*

The increased costs associated with mining and processing lower grade ores from more challenging locations has significant economic implications – especially for a country like Australia, which has become increasingly bound to minerals as a source of national wealth. While Australia currently gains considerable economic benefit from its mineral endowment, it is becoming increasingly apparent that without considered and appropriate management, this benefit may fade. Mudd and Ward (2008) demonstrate that although scarcity of mineral resources will theoretically place economic constraints on the mineral industry, it is likely that environmental and social sustainability issues will raise practical impediments to the industry long before issues of scarcity become apparent.

In 2008-09, minerals and fuel exports made up around 56% of Australia's total exports (Table 2). Consequently, minerals play a major role in Australia's capacity to participate in international trade and contribute to the international strength of its currency (AusIMM, 2006). Whether this situation contributes to Australia's economic wealth or weakens its economic position is contested. While those supporting Australia's reliance on minerals cite the theory of comparative advantage, opponents suggest a reliance on resources leads to issues associated with the hypothesised 'resource curse'.

This section will explore the economics of mineral extraction, particularly exploring the benefits and threats associated with reliance on an economically exhaustible resource. It examines the structure of the Australian minerals economy and the key market forces of mineral supply and demand. In understanding mineral supply it explores economic scarcity, and how this may be influenced by the increased internalisation of costs associated with environmental and social neglect or mismanagement. From a demand perspective we examine aspects associated with consumption, transport and the impact of substitution and recycling technologies on traditional extractive production.

4.1. BENEFITS FROM DEPENDENCE ON THE RESOURCE SECTOR

4.1.1. The comparative advantage

In their book *On the Principles of Political Economy and Taxation* Ricardo and Kolthammer (1911) introduce the concept of the comparative advantage as a major driver of international trade and facilitator of national and global welfare. The theory of comparative advantage describes a country's capacity to produce one unit of a commodity more cheaply than another commodity. In other words, it has lower opportunity costs allowing it to produce that specific commodity more cheaply. If all countries focussed on the goods where they held the comparative advantage, a global maximum of goods could then be produced. When considering the possibility of international trade, and when considering no artificial trade barriers (e.g. tariffs), Ricardo hypothesised that all countries would gain greater wealth.

Where minerals can be cheaply and easily extracted mineral reserves often bring a comparative advantage to the national economy of the producer. According to Ricardo and Kolthammer, a nation should fully embrace its comparative advantage to develop maximum of wealth for society. They suggest that after the national resource endowment has been depleted, the economy's focus will shift to other sectors where the comparative advantage can be secured. He indicates that a national economy that has gained a maximum of welfare from the mineral endowment, will transition and diversify more smoothly than if the endowment is not fully exploited. Even though Ricardo's theory is almost 100 years old, it is still considered a key driver in national economic specialisation, development of economies of scale and globalisation.

4.1.2. Australia's benefits from the minerals industry

Throughout Australia's history, the minerals sector has played a major role in the country's prosperity. Historically, mining was considered an activity that pushed back the borders of wilderness, making land accessible for cultivation and civilisation (Mercer, 2000). Through the gold booms (Mercer, 2000), and more recently, during the global economic crisis, Australia has greatly benefited from the economic buffer provided by the mineral industry (Mining Australia, 2009). Most recently this benefit has been rooted in Australia's long-term mineral export contracts with Chinese customers. The Australian economy has effectively been shielded "by a Chinese wall" from the impact of the economic crisis (Mining Australia, 2009).

Australia's mineral production is largely sold on international markets. This production and foreign investment in Australian mining companies strengthens Australia's position in international trade by bolstering its currency value and capacity to import (AusIMM, 2006). Mining contributes indirectly to the national benefit through government revenue collected from royalties, taxes and fees, which are generally used to support the development of infrastructure and public services (MMSD, 2002; Hall, 2009). From a national perspective, it is these two contributions from the minerals sector that are most significant. The share of mining (7.7%) in the national GDP (Table 1) is prominent, but employment (1.5% shown in Figure 4) appears of less importance. However, mining's contribution to Australia's rate of employment may be weighted more, because every mining job is considered to account for 2.5 jobs in other sectors, like in the services sector (Mercer, 2000). This can be attributed primarily to the fact that jobs in the minerals sector usually pay high salaries (average of $78,400) compared to the Australian average ($33,500), thus boosting the importance of mining as a source of employment and generating jobs in sectors which provide inputs to the mining industry.

In the past, mining has changed from a labour intensive to a capital and knowledge intensive activity. This has increased the need for skilled people, mining know-how and specialised services. With a long tradition in mining, Australia has been able to establish education facilities to match this need. Australian now exports this knowledge, along with many specialists, who fill personnel demand in the global minerals sector (AusIMM, 2006). This specific know-how represents tradable goods contributing to Australia's benefit (Wright and Czelusta, 2007).

This last point especially supports the contention that Australia has embraced its mining potential. It has used the economic gains from mining to successfully diversify its economy, enabling it to transform toward a service-based economy (MMSD, 2002; Willett, 2002; AusIMM, 2006; Wright and Czelusta, 2007). Aside from this last point, many of the benefits associated with the mining industry can persist only while minerals are available. This raises the need to consider how the minerals industry (which faces increasing impacts from extracting a finite resource) can most meaningfully contribute to the Australian economy into the future.

4.2. THREATS FROM DEPENDENCE ON THE RESOURCE SECTOR

4.2.1. The Resource Curse and Dutch Disease (or Gregory effect)

Resource Curse

Contrary to the theory of the comparative advantage, many mineral resource rich countries are often outperformed by resource poor countries (Auty and Mikesell, 1998). This paradox, where natural resource abundance actually has a negative impact on the growth of the national economy is termed the 'resource curse' and is illustrated in Figure 18. After an initial economic boost, brought on by the booming minerals economy, negative impacts linked to the boom surpass the positive, causing economic activity to fall below the pre-resource windfall level.

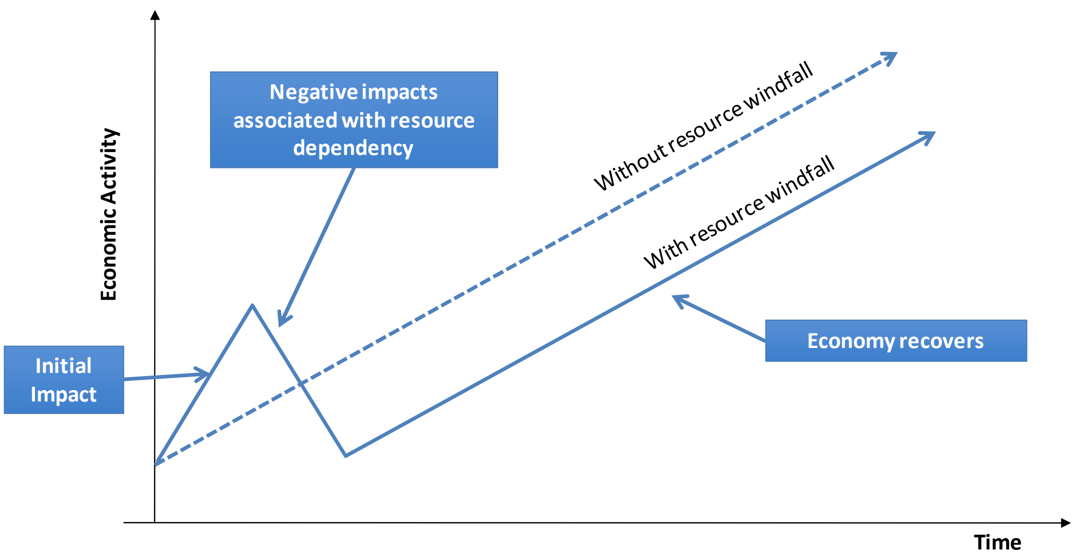

Figure 18: The boom-bust nature of resource dependence (from AusIMM, 2006).

The negative impacts associated with the resource curse are of political, social, environmental and economic nature (Goodman and Worth, 2008). A nation suffering from the resource curse realises huge gains from exporting minerals, which strengthens the local currency (because other nations must buy its currency to obtain the commodity, forcing the price of the currency up). This also means the country's other exports become more expensive, decreasing the competitiveness of other sectors that produce internationally tradable goods. Furthermore, the stronger currency makes importing foreign goods cheaper, increasing the competition for locally produced goods on the national market (Goodman and Worth, 2008; Palma, 2005). While struggling with maintaining its national and international market share, the already weakened non-mining sectors face additional challenges competing with the high salaries paid by the booming resource sector. Ultimately, the point is reached when the sector can no longer attract the workforce required to remain competitive or viable. This effect is worse in countries that are close to full employment and have difficulty supplementing the workforce through migration (Papyrakis and Gerlagh, 2003; Stevens and Dietsche, 2008).

Dutch Disease (or Gregory Effect)

Dutch Disease is a related phenomenon to the Resource Curse, in that both derive from rich resource endowments. It was named following the discovery in the Netherlands in the 1960s of large reservoirs of natural gas which led to appreciation of the currency and a decline in competitiveness of non-resource industries. Larsen (Larsen 2006) distinguishes the Resource Curse from Dutch Disease by noting the former implies stagnant growth, whilst the latter is associated with contracted manufacturing as shown in Table 6: Comparison of Resource Curse and Dutch Disease (after Larsen, 2006).Table 6.

Table 6: Comparison of Resource Curse and Dutch Disease (after Larsen, 2006).

	Resource Curse (reflected by stagnant growth)	
	No	Yes
No Dutch Disease	• Overall growth • Diverse export base	• Stagnant growth • Diverse export base
Dutch Disease Present	• Overall growth • **Strongly contracted manufacturing**	• Stagnant growth • **Strongly contracted manufacturing**

In the Australian context, Dutch Disease is also called the Gregory effect after Professor Robert Gregory from The Australian National University, who described in 1976, the potential burden an expanding mining sector would have on rural and manufacturing sectors (Gregory 1976). Simply suppressing resource-based industries where a nation has the comparative advantage is not the answer (Willett 2002). Craig Emerson (the Australian Federal Minister for Small Business, Independent Contractors and the Service Economy and Minister Assisting on Deregulation) writes that to avoid the Dutch Disease, "Australia needs a new program of productivity-raising reforms" with a focus on the seamless flow of capital, labour and skills across state boundaries, and on education, innovation and wise infrastructure investment (Emerson 2008)

Discussion and implications

Government dependence on income from mining has been shown to contribute to corruption and patronage (Bannon and Collier, 2003). The strength of political institutions in place is also an important variable. Corruption and over-regulation is commonly viewed as an impediment to the operation of market equilibriums, and may further decrease the possibilities of successfully establishing or operating other industry sectors (Goodman and Worth, 2008).

Box 1.
Will Australia face a resource curse in the future?

While few authors argue that Australia's minerals boom is likely to end in the near future, the economic viability of the industry will continue to be challenged by declining ore grades and the increased environmental and social costs associated with the expanded scale of mining that will compensate for this decline (Mudd and Ward, 2008). A failure to anticipate how these added costs may influence the economic viability of the Australian mineral industry may result in adverse impacts associated with the resource curse. In particular, as the internalisation of previously externalised costs (like those from social or environmental impacts of more intensive mining) may constrain the economic reward associated with a resource boom before mineral reserves are exhausted, the necessity to plan for such eventualities with economic, regulatory or technological measures becomes critical.

Even where corruption or patronage are not evident, the resource-dependent government is likely to favour and subsidise the development of the minerals sector (Productivity Commission, 1991), as a booming resource sector not only provides attractive government revenue but also offers employment (Goodman and Worth, 2008). This creates further economic imbalance towards the resource sector.

The consequence of resource dependence is a 'crowding out' of manufacturing and other sectors (Krugman, 1987), and a dependency on export markets that are subject to fluctuations out of the control of the affected country (Palma, 2005; Goodman and Worth, 2008). It also becomes coincidentally dependent on imported goods that are no longer produced locally. Once the resource is depleted, it will be difficult to recover the other sectors of the economy, and the country will be left with a narrow-based and weakened economy (Krugman, 1987). A useful reference on this issue is the *Resource Endowment Toolkit* developed by the ICMM and World Bank[4].

Although studies considering the resource curse phenomenon are supported by many examples, economic underperformance is not necessarily the outcome for countries that embrace their mineral endowment (Hajkowicz *et al.*, 2009; Walker, 2001). Most economists state that if properly managed, the Dutch disease and resource curse can be avoided (Wright and Czelusta, 2003; Papyrakis and Gerlagh, 2003; Walker, 2001), and Australia and Canada are often cited as examples where they have been avoided (AusIMM, 2006). The challenge is to ensure this holds true for the future.

4.2.2. Disadvantages of resource dependence for the Australian economy

Goodman and Worth (2008) indicated that Australia, with an export focus on minerals, is increasingly resource dependent. They found agriculture, once one of the pillars of Australian exporting, was in decline, while the manufacturing sector showed only marginal growth in export output volume. In addition, employment in the manufacturing sector declined despite the slight increase in output volume, and the mining sector (though contributing relatively little to national employment figures) is the only sector showing employment increases in the last five years (Figure 19). These could be seen as indicators of the resource curse, confirming of the view of Gregory (1976) who asserted that our resource dependence would see the resources sector displacing other exporting industries. Further imbalance may result because of the limited extent to which Australia engages in downstream industries like mineral processing and manufacturing. Most of Australia's mineral production is extracted, partly-refined, and exported. Under-developed downstream activities may reflect high labour costs in Australia (Harris, 1980), the lack of established economies of scale for processing and manufacturing (AusIMM, 2006), or minimal local demand to drive local minerals processing or manufacture activities (Harris, 1980). These factors result in a comparative disadvantage for Australia in regard to downstream activities. By comparison, Asian countries like China and Korea have huge markets for end products, lower labour costs, and are situated much closer to other international markets that can absorb minerals and mineral products.

[4] http://commdev.org/content/document/detail/1079/

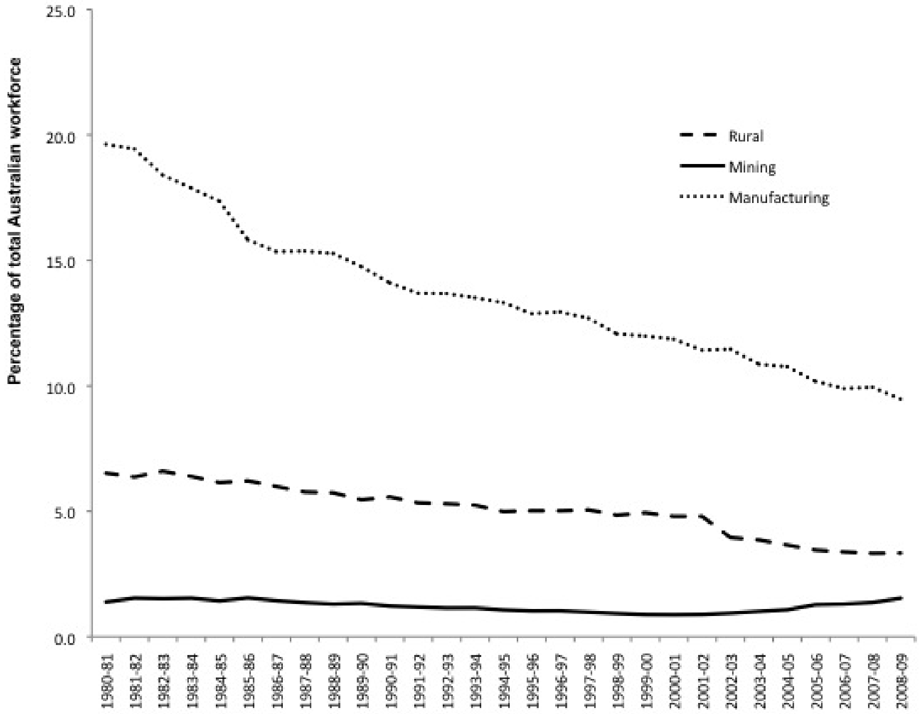

Figure 19: Proportion of the Australian population employed in the rural, mining and manufacturing sectors 1980-2009 (data drawn from ABARE, 2009b).

This situation means the Australian economy only partially capitalises on the ability to value-add to mineral production with downstream activities. It also means a loss in government revenues, as taxes on economic activity are normally relative to the value gained from them.

This loss is particularly apparent when considering the necessity to address social and environmental costs encountered during mine closure and site rehabilitation. Importantly, it is often local governments that must shoulder the financial burden of mine site restoration. Norway for example, another major mineral exporter, has established a specific fund to cover end-of-life mine costs. The absence of such a fund in Australia is heavily criticised and may be a source of future difficulty (Goodman and Worth, 2008). Even today, the local communities most affected by mining may have difficulties gaining enough benefit from mining activity because the current public finance system does not include a mechanism for effectively returning minerals revenues to mining communities (ICMM, 2009; Freudenburg and Wilson, 2002).

Another negative aspect of the focus on mineral extraction and the lack downstream activities in the minerals sector is the strong dependency on the economic conditions in other countries. As these conditions cannot be regulated in the Australian context, this poses an uncontrollable risk from a national perspective. Two main issues can endanger the Australian economy: Australia's capacity to participate in international trade is highly vulnerable to fluctuations of the international demand for its minerals; and, due to its paucity of downstream activities, Australia imports many goods produced from minerals. This conundrum can be observed in the situation where Australia exports crude oil, but at the same time imports fuel and diesel. Clearly the economic conditions associated with these imports depend significantly on the economic situations in other countries. If they are not favourable from an Australian importing sense, Australia may be in danger of not being capable of matching its own import demand for mineral services and goods (Goodman and Worth, 2008).

4.3. THE STRUCTURE OF THE MINERALS ECONOMY

Growing demand for Australian minerals and pressure for increased profitability raise the ‘economies of scale’ of production. Large-scale mines, mechanisation and company mergers increase the size and capital intensity of mining (AusIMM, 2006; Krautkraemer, 1998). In fully exploring how these factors may be impacted by peaking mineral production, it is important to briefly review the structure of the mining industry in Australia and its associated investment flows and trading arrangements.

4.3.1. Multinational, intermediate and junior companies

The global minerals industry is now dominated by a small number of multi-national corporations. Other participants, operating at the national scale, are considerably smaller, and markedly less diversified. Intermediate companies, generally locally owned and operated, may only run a single mine (MMSD, 2002). Smaller companies and an extensive network of consultants generally provide the mine services, primarily exploration and extraction.

The capital intensity of mining means smaller companies with less capital stock must be highly speculative, and are thus more vulnerable to drawbacks such as fluctuations in mineral prices and uncertainties. The need to operate intensively means mergers are common, or small companies are simply bought out by larger ones. This has caused the number of intermediate companies to decline in Australia. If peaking mineral production or increasing costs result in significant mineral market fluctuations, these smaller service oriented companies are likely to be hard hit. Mining service providers are also significant employers in the minerals sector (AusIMM, 2006), and their closure may have considerable employment-related impacts for Australia – particularly in resource rich regions.

Outside Australia, there are more state-owned companies in the mining business (e.g. China, Chile). While the Australian Government operates no mining companies, in the past measures to ensure a majority of Australian shareholders in the Australian mining companies have been introduced. Nevertheless their success varies in an increasingly international mining business. Especially from China, the interest in investing in mining increases internationally (Cohen, 2007).

4.3.2. Corporate financing and economies of scale

As the type and source of financing can greatly influence a company’s behaviour, a closer look at the capital in-flows in the Australian minerals industry is necessary. The Australian government has historically attempted to ensure at least 50% share ownership by Australian stakeholders in Australian mining companies (Mercer, 2000). By contrast, multi-national companies and other geo-economic drivers (like overseas links to downstream markets) favour international investment. These drivers have gradually driven greater foreign investment in the Australian mining industry (Harris, 1980). China, in particular, shows great interest in increasing its involvement in the Australian mining industry (Wallace, 2009). Additionally, low commodity prices, generated by what is now referred to as the ‘Global Financial Crisis’, further favour international investment trends (Williams, 2009). Even though Australian mining welcomes foreign investment from China (Hall, 2009), and highly values its market links, worries are expressed about the current and future levels of foreign investment. BHP Billiton chairman Don Argus expressed his concerns about the internationalisation of Australian mining companies, suggesting that new governance arrangements must be developed to “ensure local investors are not squeezed out of the country's natural resources” markets (Chambers, 2009).

Project financing is also linked to social and environmental impacts from mining. The ‘Equator Principles’ establishes a voluntary set of standards aimed at determining, assessing and mitigating social and environmental risks associated with project financing (Equator Principles, 2009). Signatories to the Equator Principles are largely financial institutions and funding bodies that share the belief that promoting responsible environmental stewardship and socially responsible development can offer significant benefits to themselves, the borrowers and local stakeholders. Such measures encourage greater societal and financial scrutiny of large-scale exploitative operations.

4.3.3. Minerals trading and pricing

The economics of a commodity are generally determined by supply and demand. The framework of the interaction between supply and demand can be understood as the market structure. For Australian minerals, three different markets structures are of interest: Competitive Markets, Oligopolistic Markets and Terminal Markets (AusIMM, 2006). Competitive Markets are transparent and only supply and demand determine commodity price. Some minerals, where there are many suppliers and buyers (such as gold, copper or zinc), are often Competitive Market commodities (AusIMM, 2006). Where only a few suppliers exist, but there are many buyers, the market structure is considered to be Oligopolistic. For oil, lithium or platinum this often is the case (AusIMM, 2006). Oligopolistic markets allow the supplier greater freedom to control the commodity price.

Terminal markets, which include the London Metal Exchange (LME) and the New York Mercantile Exchange (NYME), are organised like a stock exchange for minerals (AusIMM, 2006). They are open to any investor and the prices are set on a daily basis and may be subject to significant short-term price fluctuations. Even though only 5% of world metal supplies are actually traded through the London metal exchange, it has a major influence over global prices because the major share of non-ferrous metal trade (90%) is made in reference to LME prices (AusIMM, 2006; MMSD, 2002). In many cases, longer term contracts are being replaced with shorter contracts closer to the spot price for metals.

Mineral supply and demand will change dramatically as all costs (economic, technological, social and environmental) associated with production, processing and transportation of minerals increases with falling ore grades. These costs will ultimately influence the ability of companies to supply commodities, and the ability of consumers to purchase them. It is likely that social and environmental issues will increasingly drive economic costs associated with supply and demand patterns (Esteves, 2008; Hamann, 2004; Jenkins and Yakovleva, 2006). In these cases, metal exchanges like the LME and NYME (that can significantly influence global commodity prices) may play a growing role as points of trade intervention that price and mitigate the social and environmental consequences of large-scale, intensive mining operations. Market-focussed regulation of socially and environmentally responsible production will ultimately govern supply and demand patterns.

4.4. ECONOMIC SCARCITY AS A CONSTRAINT TO MINERAL SUPPLY

Because minerals are non-renewable resources, the overall stock of a mineral is fixed. Such a perspective might favour physical measures of scarcity to influence future supply. Physical measures of mineral scarcity are applied very broadly. The most prominent example of this approach might be *The Limits to Growth* (LtG) report produced by the Club of Rome (Meadows *et al.*, 1974). The LtG approach generally suggests taking the known stock, sometimes extending it with the probability of successful new explorations, and calculating the total time left to depletion with regard to current consumption or growth in consumption (Yaksic and Tilton, 2009). As neither overall stocks nor future markets are known, most economists do not consider physical scarcity as a good indicator for the availability of a resource for society

(Barnett *et al.*, 1981). Economic scarcity has subsequently been introduced as a more valid approach to assess the supply of minerals.

While physical scarcity occurs through depletion, economic scarcity can have various causes including: war, embargoes, cartels and other market manipulations, natural disasters, accidents, cyclical booms in global demand, inadequate investment in new mines and processing facilities or depletion. Yaksic and Tilton (2009) suggest that factors other than depletion normally do not cause lasting economic scarcity, but do not consider the impact of social and environmental consequences on economic scarcity. Historically, there has rarely been a case of economic scarcity induced by depletion primarily because technologies have improved, offsetting the impacts of depletion and actually causing prices to fall. However, it is worth noting that technological mechanisms, to offset the impacts of social and environmental aspects of mining and processing on economic scarcity, have yet to be found.

There are three commonly accepted measures for economic scarcity: the user costs associated with a resource, the real price of the resource, and the resource's extraction costs. Importantly, these measures have historically externalised impacts of a social or environmental nature – so might be considered inaccurate measures of economic scarcity given increased environmental or social scrutiny in the mining industry. Internalisation of these costs will contribute to economic scarcity by increasing the user costs, the real price of the resource, and its extraction costs.

4.4.1. The User Costs associated with mineral production

The Hotelling model of resource scarcity

The user costs or 'scarcity rent' has been introduced in an economic model developed by Hotelling (1913). His model forms the basis for many economic approaches to mineral resources. He identifies mineral resources as finite, and asserts that the motivation for his model was to define the time during which a finite resource should be extracted to gain the highest possible benefit from it. Based on the work of Ricardo and Kolthammer (1911), Hotelling assumed that the cheapest available resource would always be depleted first. Two opposing forces in his model, the resource rent and the interest rate, determine the speed of extraction and therefore the time of extraction, because the stock is finite.

Clearly, if a resource is finite, extracting and selling it increases its scarcity. Increased scarcity also causes the shadow price of the resource to rise and provides an incentive to extract the resource more slowly, thus waiting for its price to rise further. The shadow price reflects the implicit cost associated with a constraint (in this case scarcity), and represents the maximum price that customers are willing to pay for an extra unit of a limited resource (Smith, 1937). The opportunity cost of extracting a scarce resource, and therefore losing part of an asset with increasing value, is considered a user cost. In the case of finite resources, such user costs are also termed scarcity rent or Hotelling rent. By contrast, the opportunity cost incurred by leaving the resource in the ground and waiting for its value to increase is termed the current interest rate.

Backstop technologies: substitutes driven by economic scarcity

As noted, the mechanism of the scarcity rent causes an increase in price over time. When this price rises too high it stifles the demand, and the scarcity of the resource effectively prices itself out of the market (Solow, 2009). With his concept of the Backstop technology, Nordhaus and co-authors (1973) offer an approach to estimate this 'choking price'. The backstop technology acts as a substitute, giving the finite resource a quasi non-depletable characteristic (Nordhaus *et al.*, 1973). The substitution of fossil fuels with renewable energy resources provides and example of backstop technology in the energy context (Nordhaus *et al.*, 1973).

While the substitute may be available today, it is economically uncompetitive relative to the resource. As the scarcity rent drives up the cost of the finite resource, the backstop technology becomes economically competitive and is taken up (Solow, 2009). There is some disagreement in the literature regarding whether a backstop technology takes over as soon as the price becomes too high (Dasgupta and Heal, 1980), or if the new technology coexists with the finite resource for a period before taking over (Tsur and Zemel, 2003).

Nevertheless the backstop technology also requires research and development effort to become feasible. Increased research and development effort can lower the cost of implementing the backstop technology, and therefore the choking price for the finite resource. To manage an optimal transition to the backstop technology, a rapid approach to the R&D of the backstop technology is recommended by Tsur and Zemel (2003). As suggested by Levy (2000), the availability of a developed backstop technology may also have an impact on the price of the resource and may lead to acceleration in rates of depletion.

However, the practicalities of the operation of backstop technologies present challenges in the context of environmental and social issues. The theory of backstop technologies has largely been applied in the context of technological improvement towards more efficient resource exploitation. With increased social and environmental pressure on the mining industry, it is likely that backstop technologies that overcome issues originating from falling ore grades will become apparent. Material substitution and recycling present potential for backstop technologies that may fill in for traditional mineral extractive production. Both of these potential ‘backstop’ technologies are likely to influence demand for minerals, and are discussed further in section 4.6.4.

4.4.2. The Real Price of resource dependence

Adam Smith (Smith, 1937) introduced the concept of the real price in his classic book *The Wealth of Nations*. The real price of a commodity is what people are willing to give up in order to obtain that commodity. The long-term, deflated development of market prices should reflect the real price of the mineral (Barnett *et al.*, 1981). This is has been a frequently used, and historically well-regarded, approach to assessing economic scarcity (Barnett and Morse, 1965; Tilton, 2002; Yaksic and Tilton, 2009).

To assess physical scarcity, the real price approach builds on the Hotelling hypothesis, but operates it in reverse (Norgaard, 1990). As discussed above, Hotelling suggests that the shadow price of the mineral rises as the resource becomes depleted, thus providing an indicator of the mineral’s scarcity. However, when taking the real price approach to measuring economic scarcity, evaluating the shadow price of the resource directly is seen as too complicated and uncertain (Yaksic and Tilton, 2009). Nevertheless, the shadow price should be reflected in the real price of the mineral, which can be drawn from empirical market data as mentioned above. Many recent empirical studies conclude that resource price does not rise over time (Barnett and Morse, 1965; Barnett *et al.*, 1981; Simon, 1998), contradicting Hotelling’s theory, which suggests an increase in the shadow price if a resource gets extracted (because its scarcity acts as a constraint). They point out that resource price actually fell when examining long-term trends, demonstrating decreased economic scarcity.

Decreased economic scarcity can be explained by the expansion of known mineral reserves (through exploration), the improvement of technological solutions for mining, and the innovation of mineral substitutes (Simon, 1998; Barnett and Morse, 1965). These mechanisms currently outweigh the increase in price caused by the scarcity rent, and therefore the availability of a resource swamps any negative impact that its relatively slower depletion might induce (Barnett *et al.*, 1981; Yaksic and Tilton, 2009). New technologies that have offset the impacts of mineral depletion on price include advances in “hauling techniques in mines, as in the use of trucks and conveyor systems in place of railways, economies of scale in milling, and the replacement of reverberatory furnace smelting by new, energy-efficient techniques" (Gordon *et al.*, 2007b).

According to those in favour of the real price approach, the trend that sees technology and exploration outweighing depletion is likely to continue into the future (Tilton and Lagos, 2007). Some even predict this trend to continue quasi-indefinitely (Simon, 1998).

User Costs and the Real Price: criticism and intersection of the two approaches

It can be argued that neither the real price nor the user costs appear to be direct indicators capable of assessing local resource depletion. Nevertheless global resource scarcity is likely to have an impact on mineral demand/supply equilibriums, and on the dynamics of potential backstop technologies. These two factors will in turn have impacts on the mineral economy (Gordon *et al.*, 2007a). A detailed discussion of mineral demand is presented in section 4.6.

The Hotelling approach has been criticised primarily on a failure of three of its key assumptions.

1. the cheapest available resource does not always get depleted first, simply because it is not necessarily discovered first;
2. for most minerals, the overall stocks are unknown;
3. very few ore bodies exhibit homogenous quality.

The failure of these assumptions in light of empirical data would suggest that Hotelling's model falsely supports decreasing scarcity, where the resource exploiter is tempted to recognise the *in-situ* value expressed by the shadow price of the resource and extract more slowly (Krautkraemer, 1998; Reynolds, 1999).

Reynolds (1999) showed how the dynamics of mineral exploration (principally technological advancement) can keep the resource price low and cause it to peak suddenly. He found that with ongoing exploration, the knowledge about the location of possible resources increases. This contributes to the likeliness of success with every new exploration until the point is reached where there are simply no more stocks. Before that point is reached, the known stock is continually expanded with decreasing effort, falsely indicating decreasing scarcity. Figure 20 shows the relationship between scarcity (as a function of production) and resource price – because actual production can peak beyond a theoretical production peak (in this case the Hubbert peak) with the help of technology, commodity price and resource scarcity can be kept artificially low only until the resource is very close to being completely depleted.

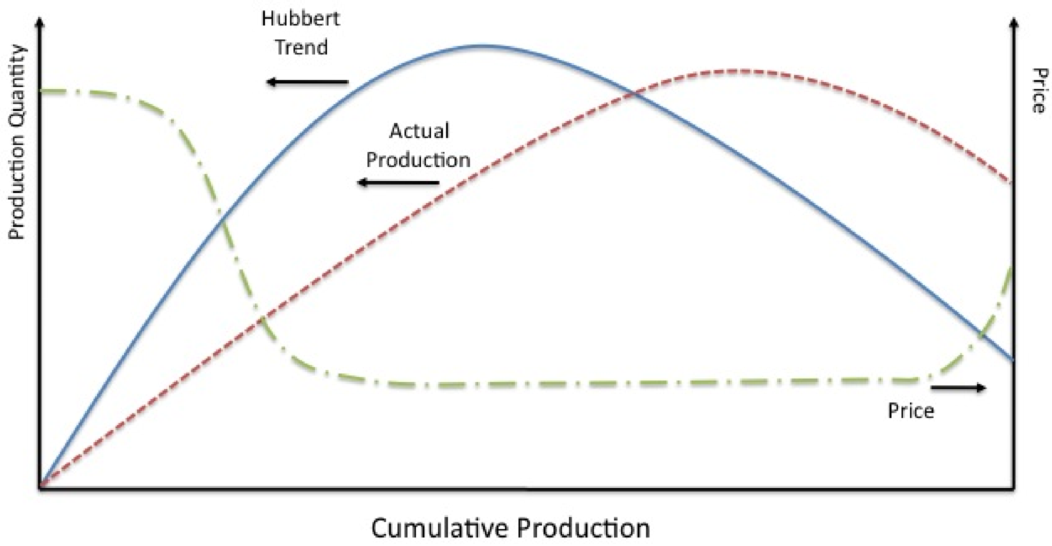

Figure 20: The relationship between the Hubbert supply trend, actual production (where technology can delay the production peak) and commodity price (from Reynolds, 1999).

Even though there have been attempts to extend the Hotelling model to overcome these and other critiques (Reynolds, 1999; Krautkraemer, 1998), a theoretical model will always simplify a complex situation. This is particularly true in the case of 'peak minerals', where many aspects of the problem have not been explored in a theoretical economics sense. The conundrum presented by using economic models to predict resource scarcity was pointed out by Norgaard (1990, p 21) when he identified that "no one has successfully used theory to describe the history of costs, royalties, and prices for any resource industry."

Criticism of the real price approach mostly identifies that on one hand it builds on Hotelling's model and regards a higher price an indicator for scarcity, but on the other hand ignores Hotelling's basic assumption that says (Norgaard, 1990, p 22):

> Major Premise: If resources are scarce, and;
> Minor Premise: If resource allocators are informed of resource scarcity;
> Conclusion: Then economic indicators will reflect this scarcity.

Norgaard subsequently points out that that "it is logically fallacious to try to determine whether resources are scarce by looking at economic indicators" (1991, p 195). As the overall resource stock and its scarcity is not known by allocators (everyone involved in forming the price), then allocation mechanisms, like price, do not reflect the actual scarcity, but the level of information the allocators do have (Norgaard, 1990; Norgaard, 1991). Furthermore, the market price of a resource often does not necessarily reflect all the costs involved in extracting the resource, commonly overlooking the environmental and social costs (Gordon *et al.*, 2007a). Deciding whether to include or exclude these 'externalities' can have a major impact on the price of the resource (Yaksic and Tilton, 2009).

These external costs can be included in the initial Hotelling approach via the marginal extraction costs. Nevertheless it often is assumed that the industry operates under constant costs (Solow, 2009) so they do not have an impact. The inclusion of previously externalised costs into the extraction cost of a resource is seen as a key economic driver in future discussions concerning mineral scarcity (Gordon *et al.*, 2007a; Daly and Farley, 2004; Mudd and Ward, 2008). The activity of internalising these costs is investigated more closely.

4.4.3. The extraction costs

The third approach to measuring economic scarcity, the extraction costs, incorporates the marginal extraction costs (*i.e*. net price) and the fixed costs for the mining operation. The marginal extraction cost defines the expense incurred by extracting one unit of a resource. The fixed costs describe the initial costs in establishing a mining operation including exploration and the installation of the operational infrastructure. If these costs exceed the benefit gained by selling the resource unit, production becomes uneconomic (Daly and Farley, 2004).

Additionally, resource production has other hidden costs that should be included in the overall cost of producing the resource. Many of the environmental and social costs are either overlooked or passed on to society after mine site abandonment (Gordon *et al.*, 2007a). In the future, it is likely for these to increasing become sustainability constraints in accordance with heightened demand for the internalisation of costs. Gordon and colleagues (2007a, p 27) specifically cite that "potential constraints on traditional mining … could result from the availability of energy sources, from water limitations or fluctuations related to climate change, or from legal restrictions related to environmental protection or social disruption" will play a significant role in future mineral production.

This section provides a brief overview over some of these constraints to production. Close inspection is required to make specific predictions about future production for particular resources, and this section covers only the broad aspects of extraction costs across the whole spectrum of minerals. The extraction cost as a limitation to production will also be influenced by whether the mineral is mined as a by-product, a co-products or a main product (AusIMM, 2006).

Decreasing accessibility of minerals

The most accessible of known reserves are normally depleted first (Daly and Farley, 2004; Hotelling, 1913). This mechanism leads to the extraction of increasingly lower grades of ore in increasingly inaccessible areas (Daly and Farley, 2004). The cut-off point that determines when the extraction of energy resources remains economically viable may be easier to evaluate than in the case of other minerals. As soon as the energy required for getting a unit of the resource out of the ground and transported to its final purpose exceeds its embodied energy, the resource will no longer be economically viable to extract (Daly and Farley, 2004). However, determining this cut-off point for minerals is difficult because of the diversity of benefits provided by minerals (which broaden their benefit and value to society) over those of energy resources.

Declining ore grades

With continuing production, most ores decrease in quality. Consequently, to obtain the same amount of mineral, an increasing quantity of the ore has to be mined and processed. This increased effort also requires greater energy and water use and results in increased waste production (Norgate *et al.*, 2007; Mudd, 2007a, c; 2009a, 2010). Increased consumption contributes to rising extraction costs (Mudd and Ward, 2008). Also, an increase in mine waste will lead to higher landfill costs. Some authors, like Daly (Daly and Farley, 2004) see these costs as the most critical for mining, predicting that their impact may overshadow the effect of physical depletion on the economic viability of a mineral.

Rising oil prices

A rise of the fuel price causes a major increase in the overall costs of mineral exploration, production and processing. The oil shock of the 1970s was a case in point. The artificially high oil prices caused by OPEC's supply restrictions were reflected in heightened mineral prices

(Barnett *et al.*, 1981). Notwithstanding the Global Financial Crisis, a return to rising prices as a result of peak oil will also have a big impact.

Greenhouse gas emission constraints

The issue of climate change urgently calls for green house gas emission constraints. Industrialised countries like Australia are put under pressure to set goals for cutting back their emissions. Reaching those goals, using mechanisms like carbon trading, is likely to cause increased downstream costs for mining production. Because much of our energy comes from burning fossil fuels that emit green house gases, the increased costs brought on by carbon trading are also likely to cause the energy price to rise. This will have a significant impact on energy intense industries like mining (Mudd and Ward, 2008). Increasing energy prices become an even greater pressure on the costs of mining when considering the growing energy need prompted by declining ore grades and greater difficulty accessing reserves (Mudd and Ward, 2008). Even though there have been major improvements in mining energy use, it is likely that this trend may become very difficult to maintain (Gordon *et al.*, 2007a).

The timing of emission constraints is a highly political issue. In Australia, emission trading has been delayed to now start in 2011 and many GHG emitting industries have been granted free permits.

Other environmental costs

From an economic perspective, emission constraints are an effort to internalise major global environmental costs. But especially for mining, there are also environmental costs at a local level. These costs include mine site closure and storing of waste rock. Together with the discussion regarding greenhouse gas emission also other environmental considerations may gain more momentum. Nevertheless measuring these environmental costs and allocating them properly can be quite difficult (Mercer, 2000). Such costs are normally addressed through obligations for the industry established by governments; including prohibiting certain mining techniques, demanding shut down plans or charging higher taxes and royalties (to cover environmental remediation costs for example). In the US and Europe, stricter environmental regulations and greater difficulty obtaining mining permits has made open cut mining economically unattractive (AusIMM, 2006).

Fees, levies, taxes and royalties

Fees, levies, taxes and royalties represent further costs to the industry. Especially under politically unstable conditions, which are often encountered in developing countries, these costs can represent a huge uncertainty for the mining industry (Humphreys, 2001). It should be noted that Australia has a decentralised tax system for mining. The states own the resources and therefore each state has its own mining acts and regulations (ICMM, 2009). Therefore the costs for mining associated with fees, levies, taxes and royalties can differ widely between different mines and between states (Mercer, 2000). The current Henry Tax Review is in deliberation at the time of writing and will also impact the industry (Stevens, 2009).

Capital costs

Due to the huge investments necessary for establishing today's large scale and highly automated mining operations, mining has become a capital intense industry. As it partly depends on debt financing, it is vulnerable to fluctuations on the capital market (AusIMM, 2006) and extraction costs rise and fall with interest rate changes.

Output constraints

Costs at the production facility often determine the quantity and quality of the mined output and form a technical boundary for reacting to changes in demand. This can handicap the mining industry's ability to seize economic opportunities like growing demand, but can also limit their capacity to decrease production when it becomes economically appropriate (Krautkraemer, 1998). This issue is caused by the need for a mine to operate at its most economically efficient level, which occurs close to their maximum output (AusIMM, 2006)

Opportunity costs of different land use

Mine sites that are close to agricultural areas (e.g. the Hunter valley and Liverpool Plains) or in regions that attract tourism (e.g. catchments adjacent to the Great Barrier Reef) can cause a conflict in land use, linked to amenity and the potential impact on surface or ground water. Toxic emissions from mining can also be detrimental to human settlements and the natural environment. Opportunity costs, resulting where mining hinders or causes economic losses for other industries, must also be considered because they are likely to increase extraction costs.

Exploration costs

Reserves are finite, but the overall stock of the resource is generally unknown. Consequently, exploration plays a major role in the minerals industry. Exploration costs for most mineral commodities have increased over time. For example, in the 1950s on the US mainland, one barrel of oil invested in exploration lead to the discovery of 50 new barrels. By 1999 this ratio of discovery cost had declined to 1 to 5 (Daly and Farley, 2004), meaning the relative cost of discovery has increased ten times.

For most minerals, successful exploration has not kept up with growing demand for the commodity. Gordon and colleagues (2007a` , p 27) argue that "discovery of new sources of copper ore has not kept pace with the amount of ore extracted to supply the increase in the copper stock-in-use and make up for losses arising in the disposal of end-of-life products". This means that copper is being used faster than it can be produced, and that without adequate use management, the supply will ultimately be exhausted. Similar findings show that successful exploration for gold has not kept pace with extraction and the growing demand for the metal (Hill, 2009; Fitzgerald, 2009).

4.5. DEMAND FOR MINERALS

While the ability to supply a commodity determines its availability as has been demonstrated, demand for minerals can also influence their availability. The use of and demand for minerals is as diverse as their specific properties. The majority of minerals are inputs for various goods and services, fewer are traded as final goods. How minerals are used, where they are distributed, and how trade barriers, downstream use industries, substitution and recycling can potentially influence demand for minerals and, ultimately, their availability. These drivers of mineral demand are discussed in the following section.

Economists are cognisant of the role of demand as an availability driver, but many do not regard factors besides depletion as having a long-term impact on mineral availability (Yaksic and Tilton, 2009). Those who do not agree with this hypothesis state that several other factors may also have a lasting impact on mineral availability (Norgaard, 1990; Daly and Farley, 2004; Gordon *et al.*, 2007a). For example, greenhouse gas emission regulations, where political decisions with a long-term impact may significantly limit future mineral production capability.

4.5.1. Cheap transport facilitates international trade

Mining is ultimately a local activity because it is bound to areas where the resource is in the ground: rarely are minerals found close to their markets. Consequently, minerals must be transported to their final market, incurring transport costs that often add significantly to the overall cost of mining. Whether the demand for a mineral is global, national or regional usually depends on their value relative to transport costs (MMSD, 2002). The high value of Australian gold allows it to find buyers all around the world, whereas Australian Iron ore is primarily distributed to the closer markets of China, Korea and Taiwan (AusIMM, 2006). The lower the value of the mineral, the more likely it will be that transportation costs will limit its movement and, hence, the mineral's ability to meet demand. While historically cheap transportation costs (especially in shipping since the Second World War) has established an international market for many minerals (AusIMM, 2006), future developments in transport costs and technology may have a major effect on the competitiveness of minerals (AusIMM, 2006). Increases in the costs for transportation, due to rising fuel prices, may constrain the demand for lower value minerals, as fossil fuels remain the major source of energy for transport. The dynamics of oil price increases and volatility, as well as emission constraints, are increasingly likely to present restrictions on the spatial extension of markets for Australian minerals in the future. Considering its remote location, this is particularly significant for Australian mineral exporters.

4.5.2. International trade barriers

The most common international trade barriers are import taxes, monetary exchange rates and protectionist government policies. Globalisation and the establishment of free markets have seen these barriers lessened or removed in the past (AusIMM, 2006). Whether or not this trend continues will have a major influence on the minerals supply/demand equilibrium. For example, China has recently introduced protectionist politics that limit its export of rare earth elements (China currently produces 95% of the world's rare earth elements) and other minerals (Lorenz, 2009; Boreham, 2009). This did not only lead to a price rise for those commodities, but also facilitated the re-opening of some formally abandoned mine sites in other countries (Lorenz, 2009; Boreham, 2009).

4.5.3. Downstream industries

As most minerals serve as inputs for other economic activities (AusIMM, 2006), they are embedded in a complex framework of downstream industries. This may be especially true for minerals that are traded internationally (MMSD, 2002). One example of this complexity is exhibited in the Chinese steel industry, where the demand for iron is closely linked to the demand for coking coal. Even though China has extensive iron and coal reserves, it imports both in addition to extracting them locally because its own production cannot match the vast throughput of its steel industry (Brown, 2001). Furthermore Chinese coal is not appropriate for coking steel (Williams, 2009). Therefore, a rise in the demand for Chinese steel will also result in an increased need for coking coal imports in China.

4.5.4. Substitution and Recycling

Substitution or recycling may act as a backstop technology (introduced in section 4.4.1) as mineral resources become increasingly depleted. As mentioned earlier, a key driver of mineral demand is the diversity of goods and services for which the minerals are required. Consequently, the demand for minerals is directly linked to the demand for the goods and services (AusIMM, 2006). The discovery of mineral substitutes, or development of capacity in recycling technology may cause significant shifts in demand for those minerals affected by these changes.

The development of substitutes for all minerals is seen as quite unlikely (Daly and Farley, 2004). Furthermore, peak oil raises the necessity to establish technological or other solutions to fossil fuel use in mining by providing renewable energy alternatives (Diederen, 2009). Even so, many minerals, especially metals, are recyclable, raising the question of whether recycling might be a backstop technology for mining.

There are diverse opinions regarding whether recycling can substitute for mineral extraction (Ayres, 1999). The overall stock of recyclable material is rising (MMSD, 2002), but the availability of various metals for recycling differs widely. As long as the infrastructure or product, they are embedded in, is still in use, they cannot be recycled. Other barriers to recycling include the technical effort to gain the materials back from the specific product or infrastructure, and the logistic effort required to effectively transport products to recycling institutions. The more diverse the use of the mineral, the harder it will be to overcome these recycling barriers (MMSD, 2002). Legislation and product stewardship schemes like the end of life vehicle legislation often result in improved recycling rates (MMSD, 2002).

Furthermore there is an ongoing discussion concerning how the second law of thermodynamics affects materials cycling (Ayres, 1999). It suggests 100% recycling is not feasible, because with every recycling process a certain amount of material will inevitably be lost. This causes the overall stock to decline and gives rise to the need for new, virgin material if the demand remains constant. The impact of this loss on the amount of recycled material leads to further discussion concerning the need to manage in-ground resources so that they can complement those resources in-product (Georgesçu-Roegen, 1977; Georgesçu-Roegen, 1979; Daly and Farley, 2004). However, this idea is contested by others, including Ayres (Ayres, 1999), who suggests that the Earth is a closed system where no material is lost. So with enough effort and energy, every material loss can be retained.

An economic driver supporting recycling is the ratio of the prices for recycled and virgin material (Mudd, 2007c). It already requires less energy (and therefore less capital) to gain steel or aluminium from scrap, than from virgin material (MMSD, 2002). Other factors such as reduced landfill costs and the structural advantages of the recycling industry will play a major role. Recycling a mineral from scrap is not as locally bound as mining, and so the transport costs can be reduced. Recycling's main inputs of secondary waste, energy and labour allow the industry to be positioned close to densely populated areas where there is a workforce, a constant input of material goods abandoned by society, and at the same time a market for the recycled material (MMSD, 2002; Daly and Farley, 2004). However, depending on how concentrated or dispersed the metal is and the transport required, recycling may not always have lower energy requirements. The competitiveness of recycling will also increase as the production costs associated with the social and environmental impact from traditional mining rise, and which are likely to contribute significantly more cost pressure in the future as ore grades continue to fall.

Nevertheless, as long as the worldwide demand for minerals rises, the need for obtaining new, virgin material from the ground will continue. Consequently, with the expectation that the future need for minerals will not decline or to level out, recycling cannot solely fulfil the criteria of a backstop technology. Still, recycling certainly has a major effect on the overall availability of minerals and their prices, and therefore also on the speed at which they are produced.

Australia should consider what role it wishes to play with regard to recycling technology development and how its competitiveness will be affected by its increased uptake in other countries like Japan (UK Department of Trade and Industry, 2005) and China (Yu *et al.*, 2008) It is also interesting to note that in the second half of last century, ageing secondary copper smelters in the USA closed due to poor environmental controls (Biswas and Davenport, 1994).

4.5.5. Mineral demand varies between nations

Overall, worldwide demand for minerals is increasing (MMSD, 2002). But different economies around the world are demanding different materials, which raises the distinction between minerals mainly used for high technology like lithium (which are necessary for many new innovative technologies such as batteries for electric cars), and minerals mainly used for classical, well known purposes like iron (for example static purposes in construction) or copper (for its conductivity).

The latter group of well known, structural metals are especially important in emerging and developing countries like China and India, which both present huge, and growing, markets for mineral and metal producing countries like Australia (MMSD, 2002). In these developing countries, structural minerals and metals are required to support infrastructure development, which is a highly material intense phase of the industrialisation process (MMSD, 2002; Dinda, 2004). Cheaper, non-value added resources are these countries' key requirements because financial capital is often limited (Kesler and Laznicka, 1994).

By contrast, in developed countries, demand for structural minerals and metals has largely levelled out (admittedly at a high level), causing the market for basic minerals to be quite stable (Dinda, 2004). However, the strong consumer society in developed countries, and mechanisms like product 'creative destruction' (a mechanism employed by leading companies to keep and extend their market share by constantly developing new innovative products, which invariably require more or different technical minerals or metals) continue to push the overall material throughput, and lead to a growing need for minerals used for technological goods (Brown, 2001). Even though the overall material efficiency has increased significantly, the throughput of goods and materials has increased even more quickly (Brown, 2001).

The demand for high tech minerals (e.g. rare earth elements) also spreads to emerging countries like China, causing a highly competitive market for these goods (Boreham, 2009). The close link between the mineral market and the mineral's end use can cause huge fluctuations as a result of changes in the final use (Brown, 2001). One example is the increasing demand for aluminium in the car industry accompanied by a decrease of demand for steel in that area. Rises in the oil price made fuel more expensive raising demand for smaller, lighter, more fuel efficient cars (MMSD, 2002). As less steel is required to build a smaller car, the demand for steel decreased. Furthermore aluminium replaced steel in many parts of the car causing the need for steel to decrease even further whereas the demand for aluminium increased dramatically (MMSD, 2002).

Also, the minerals used in rechargeable batteries are likely be in higher demand as plans to decentralise electricity are realised, causing demand for batteries to rise (MMSD, 2002). Current developments like the shift towards electric vehicles are likely to have similar impacts (Yaksic and Tilton, 2009). Especially expected growth in demand over the coming century for lithium batteries to power hybrid and fully electric automobiles has raised some concern about the future availability of lithium (Tahil, 2007).

As Australia exports a huge share of its minerals to China, India, Korea and the US, developments in those markets should be of major interest for the Australian mining economy.

SECTION FOUR: SUMMARY

Minerals represent a significant source of national wealth for Australia. However, peak minerals introduces important economic implications for Australia's long-term mineral wealth – especially because our economy is becoming increasingly bound to minerals as a source of national wealth. While there is no evidence to suggest Australia's economic prosperity has suffered as a result of this close bond to mineral resources, there is also no certainty that continued dependence will not bring consequences in the future. Considered macro-economic policy to rectify sectoral imbalance and patronage towards the mineral industry should be a key goal to ensure long-term national benefit from the minerals industry. Such a policy focus may also influence the way mineral resources are valued in a national sense, and consequently influence their demand and supply – where the actual costs of mineral production (economic, environmental and social) are factored into the resource's production costs and market price.

5. TECHNOLOGY IN THE MINING INDUSTRY

SECTION FIVE: OUTLINE

This section explores:

- *a conceptual overview of the role of technology in being able to access resources and create valuable products from minerals and how this affects peak minerals (5.1)*
- *an overview of existing technological developments along the supply chain, highlighting breakthroughs and inertia, both relevant for future uptake of more sustainable technology (5.2).*

5.1. ACCESSING RESOURES, CREATING PRODUCTS

Technology has always been, and remains, a fundamental part of the mining industry and its ability to transform mineral resources into mineral wealth and useful end-products. The technology of mineral or metal extraction evolved relatively slowly until the onset of the Industrial Revolution, which rapidly drove growing demand for key commodities such as coal, iron and copper – meeting this demand required ever greater technological advances. This led to the development of crucial technologies that still form the basis of the industry today: such as flotation, the blast furnace, railways, geophysics, drilling, trucks and transport, and a wide variety of others.

In the 21st century, technology forms the basis of a very capital and machine intensive mining industry, with a labour force considerably lower than manufacturing (Figure 19), but which contributes much more significantly to Australia's export revenues (Table 2). The technological advances in the industry also have social and environmental implications, both positive and negative, and how we apply future effort towards further advancement in these spheres will play a significant role in the future of the industry's sustainable development.

The role of technology in creating mineral wealth will be analysed and discussed with respect to the typical life cycle stages of mining and minerals, shown in Figure 21.

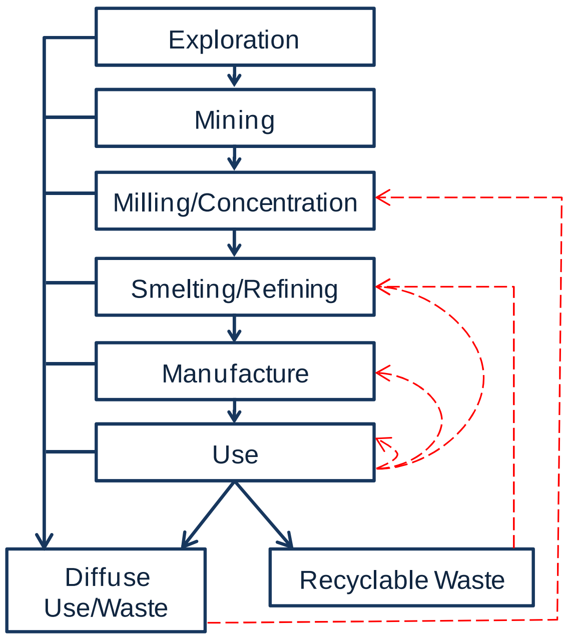

Figure 21: The typical life cycle of mining and mineral products (Stewart *et al.*, 2004, adapted)

A range of existing and potential future technologies within each major stage of mineral wealth production process were discussed by Giurco and colleagues (2009). Improved technological performance has allowed the industry to:

- extend the resource base through improved exploration capabilities (especially in geophysics and drilling);
- extend the resource base through new processes that reduce costs or improve yields when processing complex ores (e.g. development of flotation and carbon-in-pulp; hydrometallurgical copper processing for oxides);
- limit the costs associated with regulatory compliance for a range of environmental impacts on air, water, or land; (e.g. lower sulphur dioxide outputs of flash smelting superseding reverberatory copper smelting)
- reduce costs associated with labour, such as lost labour due to injury (i.e. technology to improve safety) or increasing productivity through growing mechanisation (e.g. Long-wall mining, automated and remotely controlled vehicles);
- reduce major input costs, such as energy or chemicals (e.g. conversion from oil to natural gas, substitution of pyrolusite for Caro's acid at the former Nabarlek uranium project);
- recover resources from wastes (e.g. precious metals from electronic wastes).

As evidenced by the past two centuries of mineral production, the development and widespread use of new technologies has enabled a strong growth in supply to meet rising market demands. This technological success has, to date, been the main argument against treating minerals as 'exhaustible' – because rates of mineral discovery and technological development kept pace with production and demand. However, this historic pattern relied on working easier, more accessible mineral deposits. As deposits continue to decline in ore grade and quality (with rising impurities), mines become deeper, and waste burdens and environmental costs grow, it is uncertain whether future technological success can continue to keep pace with mineral demand. This is the foundation for peak minerals – in contrast to peak oil, which is largely governed by geologic factors and physical resource exhaustion (see section 3 on page 19).

Technology has historically focussed on winning economic gains from the first four phases of the typical mining life cycle (i.e. exploration, mining, milling/concentration, smelting/refining; see Figure 21). These advances have been characteristic of a mining industry whose production was primarily limited by the ability to get the resource out of the ground and get it to market as cheaply as possible. However, with the onset of peak minerals, and the consequences these changes could bring, the industry must also focus technological advancement efforts towards those processes that circumvent these traditional lifecycle phases (Figure 21 in red dashed lines), and promote alternative technologies while at the same time minimising the social and environmental consequences of any ongoing mining activities that do continue (Figure 22). Most importantly, addressing these 'new' costs (new because these costs are only now being incorporated into the full costs of a mining operation) will contribute significantly to the industry's ability to remain economically viable.

Figure 22 depicts the incremental influence of technology on the ability to increase production. For example, technology allowed economical processing of lower grade ores, thus expanding the ore resources available and delaying peak production. By contrast, more radical technological developments would give rise to a new peak (such as was the case with carbon-in-pulp and gold described in Figure 16 and in Figure 22, which shows the potential development of ocean resources and recycling).

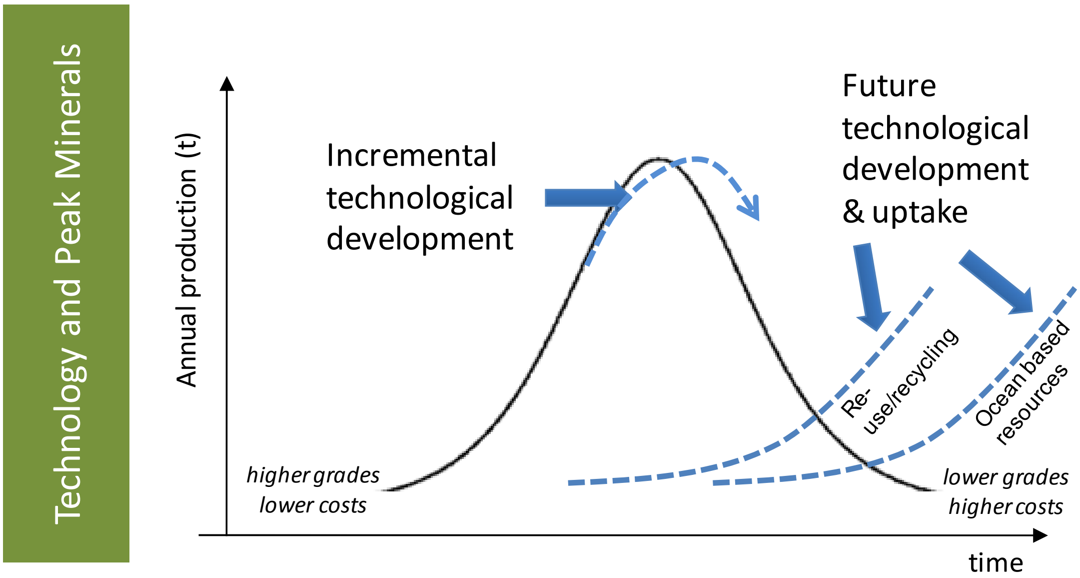

Figure 22: Incremental and next generation roles of technology in relation to the peak minerals paradigm.

New technologies also create opportunities to explore new paradigms of mineral wealth. In addition to permitting new mechanisms for bringing metals to market, new technologies will change end-uses and demand for metals. For example, shifts to electric cars will increase demand for lithium, currently used in batteries, and as research and development increasingly shows re-use and recycling to be economically advantageous, the opportunities they present will continue to grow in importance.

Each principal stage of the mining cycle is now briefly reviewed to gauge the historical importance and current status of their respective technologies.

5.2. EVOLUTION IN TECHNOLOGY IN THE MINERALS INDUSTRY

5.2.1. Exploration

The role of technology in mineral exploration has grown enormously. In the 19th century, amateur prospectors or even pastoral station workers made almost all major mineral discoveries in Australia. For example, shepherds discovered the rich Burra copper deposit, north of Adelaide in 1845; amateur prospectors discovered gold in Eastern Australia in 1851; and, a pastoral station boundary rider discovered Broken Hill's lead-zinc-silver deposits in 1883.

By the mid-20th century, however, science and technology had begun to dominate mineral exploration. The emergence of geophysics was also a major breakthrough, since it allowed wide-ranging surveys of natural gravity, magnetic and radiometric intensity, thereby providing indicators of geology, mineralised rocks and potential mineral deposits. In addition, numerous field survey methods also evolved for particular minerals, such as examining gold in superficial materials to identify anomalous zones and potential deposits (this approach was crucial in underpinning the 1980s gold boom), tracking natural mineral concentrations in fluvial systems to identify potential mineralised terrains and target source rocks (the giant Argyle diamond deposit was discovered this way).

One of Australia's most important mineral deposit discoveries of the past 30 years has been the super-giant Olympic Dam mineral deposit in northern South Australia. The Olympic Dam deposit contains economic concentrations of copper, uranium, gold and silver (all currently produced), as well as uneconomic but significant concentrations of rare earth minerals (not extracted). The deposit lies at some 350 m depth and has no physical surface expression. The discovery in 1975 was made by theoretical work targeting coincident gravity and magnetic anomalies as mineralised systems – with the most spectacular results, since the Olympic Dam deposit is now ranked as one of the super-giant ore bodies of the mining world. The theory also led to a revolution in exploration, and was later applied to help discover the Ernest Henry (1991) and Prominent Hill Cu-Au deposits (2000).

The Alligator Rivers region of the Northern Territory, now mostly part of the Kakadu National Park world heritage area, hosts a range of major uranium deposits. From 1969 to 1973, the Ranger, Nabarlek, Jabiluka and Koongarra deposits were first indicated by aerial radiometric surveys and later explored through drilling. This geophysical exploration technique was initially developed after World War 2 to help discover uranium for the nuclear weapons race of the Cold War, but evolved rapidly and is now a widespread tool as part of general mineral exploration work to differentiate rock and soil types or geologic structures.

Another major area of exploration technology is drilling. Led largely by the needs of the global oil industry, drilling technology has evolved significantly over recent decades to allow faster, more efficient and lower cost exploration. This evolution in drilling capability has been pivotal to the emergence of 'hot dry rock' geothermal prospects, which rely on deep drilling technology to tap into hot granites at three to four kilometres depth to extract energy and produce electricity[5]. Given the need to drill deeper for future mineral discoveries, the role of drilling technology will continue to be an important pillar of the mining industry and subsequently of mineral wealth.

There are a range of other technologies and methodologies used in mineral exploration, such as remote sensing, bio-prospecting, complex geological modelling tools (e.g. fluid flows), field analysis instruments (e.g. metal concentrations, mineralogy), and so on. Increasingly, many of these tools and technologies are being combined in large, complex databases and visualisation systems to facilitate more targeted exploration, lowering the costs of exploration and, ideally, increasing success rates.

The cross-linking of information over time as exploration work progresses, especially with respect to critical environmental aspects such as sulfidic content or ore mineralogy, will also be more important. The widespread use of existing technology, as well as the potential for new technology, will continue to be critical in mineral exploration.

5.2.2. Mining

The principal methods of mining remain the same – underground, open cut or through extraction of fluids (e.g. oil-gas, solution mining). Over the past several decades, however, all three types have undergone change as technology has evolved.

[5] Although no commercial scale hot dry rock geothermal project is operating as of early 2010, Geodynamics Ltd are developing the world's first such project in north-eastern South Australia and plan to reach commercial scale within the next few years.

Underground mining

For underground mining, a wide variety of methods are now used, depending on ore and rock types, as well as the geometry of the deposit and its strength characteristics. In underground coal mining, the vast majority of coal is now extracted through longwall mining, which extracts more of the coal resource but leads to significant surface subsidence. Conversely, in hard rock mining, large scale block caving is possible when conditions are suitable (e.g. strong rock, large orebody). Overall, a variety of different methods are employed to extract ore in hard rock underground mines. Increasing mechanisation is also a key factor in continued underground mining.

At some major mining projects or fields, underground mining is now regularly reaching depths of more than 1 km, such as the Sudbury district of Ontario, Canada, now mining at around 2.5 km depths, or the gold mines of the Witwatersrand field in South Africa now at 4.3 km depth. Given South Africa's long-term decline in gold production over the past decade(Mudd, 2007a), it would appear that present technology is no longer able to compensate for the increasing depth of their gold mines – again showing the importance of understanding the key drivers and factors which might give rise to peak minerals.

Open cut mining

There are perhaps three major factors which have facilitated the long-term growth in open cut mining: firstly, increasing truck sizes; secondly, safer and cheaper explosives; and lastly, cheap diesel fuel. The size of dump trucks used to transport ore and waste rock has grown from a 25 t payload to now being capable of some 400 t. Over this same time period their energy efficiency has improved dramatically (Koellner *et al.*, 2004) due in part to turbo diesel engine technology. The vast scale of open cut mines, such as those in the Pilbara, Kalgoorlie or the Darling Ranges, would simply not be feasible without such trucks.

Another important, but perhaps lesser-known breakthrough for open cut mining, has been the development of ammonia-nitrate fuel oil (ANFO) explosives technology. The introduction of ANFO in the 1960s allowed a step change in the scale of open cut mines due to its considerable safety advantages and much lower costs (O'Malley, 1988; Oliver, 1979).

The issue of peak oil is of fundamental importance for open cut mining, since diesel can often constitute a major portion of the energy costs for a mining project. For example, in gold mining, diesel energy for mining can often reach half or more of total energy consumption (based on data from Mudd, 2007a,b, 2010). The continual rise in the price of crude oil, which creates higher diesel prices, presents a major strategic challenge to open cut mining. Whether this leads to increased underground mining (which is generally more electricity dependent), a switch to biodiesel sources, or the electrification of mining fleets (Koellner *et al.*, 2004) is very hard to predict. Open cut mining is more diesel-reliant than underground mining, which uses more electricity per tonne of ore, but is still a reasonably significant consumer of diesel.

Solution mining

The third type of mining involves fluid movements only, and encompasses mainly the oil and gas sector but also minor sectors or mines such as potash, uranium or even salt production. Another term used for this broad category is 'solution mining'. For oil and gas, this involves drilling a series of bores into the prospective layer of rock or sediment and pumping out the desired product. A re-injection bore may also be used, to maintain fluid pressures within the reservoir and optimise extraction rates and efficiency (water is most commonly used, but carbon dioxide is used in certain fields to enhance production). Analogous to deep underground mining, part of the driving force behind peak oil is the increasing depth of oil and gas fields, now reaching several kilometres, and including deep oceans (e.g. the recent Tiber discovery in the Gulf of Mexico is in 1,260 m of water depth with a further 9,430 m underground to the oil field[6]).

When uranium is being mined with solution mining techniques, a dense network of groundwater bores are drilled, and the acid or alkali chemicals are injected into the uranium ore zone through one bore, and the resulting uranium-rich solution is extracted from an adjacent bore. Over a large area this leads to hundreds of injection and extraction bores. On the surface, the uranium is extracted and purified through conventional chemical processing techniques, with the barren solution then re-injected after the addition of more chemicals. This type of mining is also referred to as '*in-situ* leaching' (ISL), since the uranium is chemically leached from the ore body. Although ISL removes the tailings and waste rock from a mining project, there are major concerns about the extent of groundwater impacts from operations, especially the legacy impacts after mine closure (see Mudd, 2001). However, Taylor *et al.* (2004, p iii) report that "as this groundwater has no apparent beneficial use other than by the mining industry, this method of disposal is preferable to surface disposal". Although not yet proven, it is widely believed and accepted that natural attenuation will result in the contaminated water chemistry returning to pre-mining conditions within a timeframe of over several years to decades." It also concludes that "ISL mining of uranium has considerably less environmental impact than other conventional mining techniques". The only operating uranium ISL mine in Australia is at Beverley, in north-eastern South Australia, with two nearby projects at Beverley Four Mile and Honeymoon expected to start production soon.

It is possible to apply ISL methods to other minerals, or in combination with conventional mining. Small trials of ISL for copper were conducted in the Mt Isa-Clonclurry province in the late 1960s to mid-1970s, such as Wee MacGregor, but very little is known about these projects (Bell, 1984). At Eastville, west of Bendigo in central Victoria, Australia's first ISL gold mine was proposed but failed to proceed (Hore-Lacy, 1982). Alternately, the ore in an underground stope can be blasted and fractured, and left in place, with solutions then circulated through it to extract the mineral of interest (e.g. copper, gold, uranium). Although underground stope leaching has been used in Australia, most notably at the Gunpowder-Mt Gordon copper mine in western Queensland (see Landmark, 1992; Middlin and Meka, 1993) and trialled at the former Mutooroo copper mine in South Australia (see Bampton and others, 1983), the extent of production has been very small (Gunpowder probably produced <75 kt Cu by stope-based ISL; see Mudd, 2009a). One promising research focus is the use of *in-place* leaching to recover stranded gold deposits (Roberts *et al.*, 2009).

There is certainly merit and active interest in developing and improving ISL mining methods, especially the restoration of impacted groundwater, but since ISL mines tend to be small low-grade deposits, whether the technology can expand to meet expected future demand is debateable.

5.2.3. Processing

A critical step in most mining projects is the milling or concentration stage. Many base metal ores have low grades at per cent levels (e.g. copper, nickel, lead, zinc), meaning the ratio of ore smelted to product retrieved is high. Smelting raw ore is therefore very energy intensive. To reduce energy intensity and improve metals recovery when smelting polymetallic ores, such as lead-zinc, the separation of pure metals is more complicated still. To overcome these problems, a variety of milling technologies have been developed, the most important of which is flotation. Other separation methods include gravity and dense media separation, and

[6] Source: http://www.mirror.co.uk/news/top-stories/2009/09/03/that-s-well-deep-115875-21643992/, Accessed 18 December 2009.

magnetic or radiometric sorting, though the latter two are not widely used (except in specific sectors, like magnetic sorting in iron ore).

The method of froth flotation was first developed at Broken Hill, in order to separate the Pb from Zn and facilitate improved lead smelting (since zinc was considered a contaminant) (Mudd, 2007c, 2009a). Froth flotation involves mixing ore with specific chemicals (e.g. oils or bespoke flotation polymers) in water and aerating the mixture. The sulfide minerals stick to the oil or polymer, which are forced to the surface by aeration, thereby separating the metal-rich sulfides from the gangue or remaining rock. The method was first applied to the extensive tailings at Broken Hill and then to new ore (after further process improvements). The use of flotation to produce metal-rich concentrates can reduce the amount being fed to a smelter by up to 50-fold, leading to significant improvement in the economics of smelting as well as enabling larger quantities of low grade sulfide ores to be milled (especially copper). The use of froth flotation went on to revolutionise the milling of sulfide ores around the world (Bear *et al.*, 2001; Newnham and Worner, 1983; O'Malley, 1988).

A limitation of the flotation technique was the associated need to grind the ore to a fine powder to improve extraction rates during flotation. As such, there has been a continual evolution in ore grinding technology over the past century. A major trend is progressively smaller average particle sizes to facilitate higher extraction rates and liberate metal sulfides from more complex ores (e.g. McArthur River lead-zinc-silver project in the Northern Territory).

A very recent example of the risks of impurities affecting processability is the Armstrong nickel mine in the Kambalda field of Western Australia. The Armstrong nickel deposit was never developed by WMC due to the high arsenic content and low iron to magnesium oxide ratio of the ore. Junior miner Titan Resources began open cut mining in mid-2004, only to find that the ore exceeded agreed tolerances for sale to the Kambalda mill – and (then) WMC promptly rejected all Armstrong ore. The collapse of the project almost sent Titan Resources bankrupt – and the mine still remains in mothballs in 2010 .

For the gold sector, the ongoing development of extraction technologies has been crucial to its long-term success. The original development of cyanide methods to extract gold in the 1880s was a substantial improvement on previous mercury-based (amalgam) methods, since it was faster and achieved higher extraction rates. In the 1970s, the US Bureau of Mines developed carbon-in-pulp (CIP) cyanide process technology for gold, which was significantly more efficient than traditional cyanide technologies and allowed very low-grade ores to be processed using any level of water quality (critical in arid central Western Australia). At the same time, the gold price was deregulated by government and it rose from ~US$30/ounce in the early 1970s to reach a stable range of ~US$300-500/ounce. These two factors combined have allowed a massive global gold boom (see Mudd, 2007a), led by the USA and Australia. Even so, both countries have shown a production decline over the past decade.

It can be observed that milling or concentration technologies are critical for all commodities. The future of this area of development remains of paramount importanc, since the challenge of declining ore grades, and more complex ores, must be met by continued improvements in milling and concentration technologies. Significant research to develop processing technologies is currently being undertaken within the CSIRO Minerals Down Under Flagship. This research is focussing on developing technologies to, for example, remove phosphorus and other impurities from iron ore to enable lower grade ores to be economically processed (Treadgold, 2009). Having begun to exhaust our higher quality ores, such technological development is important for Australia, should it wish to maintain its competitive export position relative to countries that have higher-grade deposits. Other areas of research include bioflotation and bioflocculation.

5.2.4. Smelting and Refining

Smelting of copper sulfide ores in the past decades has seen the phasing out of blast furnace technology and the dominance of flash smelting technology (Biswas and Davenport, 1994). Technology developments in smelting and refining have seen an increased use of AusMELT/ISASMELT™ technology for lead and copper smelting. Lower grade copper ores are also being processed by heap leach solvent extraction electrowinning (see section 5.2.5 below).

Smelting research within CSIRO is focussed within Minerals Down Under and the Light Metals Flagship (Aluminium, Titanium, Magnesium). Part of this work is looking at reducing greenhouse gases (GHGs) by using renewable carbon as a fuel and reductant (e.g. in the form of char as a processed biomass), but also the ability to capture and utilise heat from processing activities (Jahanshahi, 2008). While aiming to reduce GHG emissions, these technologies also have the potential to significantly reduce water consumption during processing.

Over time, the grades of metal-rich concentrates have increased, especially for copper, such as through improved grinding technology or more efficient flotation reagents. Thus whilst the overall volume of concentrate to smelters is generally declining over time, the volume of ore fed to flotation mills is increasing substantially due to declining ore grades, the grade/recovery trade-off and increasing production scales.

Opportunities for reduced impact in refining include the efficient use and recovery of heat. Where an electro-refining stage occurs, cleaner electricity sources (than coal) can be used to reduce impact.

A final comment to note is the potential for future smelting and refining to receive a greater proportion of recycled and scrap feed stocks (discussed later in section 5.2.7).

5.2.5. Heap Leaching and Refining

A major variant of solution mining is heap leaching. The mined ore is placed in large piles or heaps, with chemical solutions sprinkled through irrigation on the surface and the resulting metal-rich solutions captured at the base and processed. Heap leaching works well for low-grade gold and copper mines in particular, where strong production growth has been shown over the past three decades. The extraction of minerals by heap leaching-solvent extraction-electrowinning (SX-EW) may be more or less energy intensive than conventional milling and smelting (see Norgate and Jahanshahi, 2010), but recoveries are lower and given the typically low ore grades, heap leach projects can often be economically marginal. At large scales, however, some projects have been very profitable (e.g. Morenci copper mine in Arizona). There is significant scope for improvement in heap leaching, mainly through higher recoveries and faster leach times. While not the dominant source of overall mineral production, the importance of heap leaching is growing (particularly for copper and nickel).

The CSIRO is also developing technology that uses lower impact lixiviants to enable gold leaching.

Box 2.
New Technology and Adoption Inertia: High Pressure Acid Leach for Nickel Laterite Ores

Major new processing breakthroughs that fundamentally change a commodity's production are relatively rare (e.g. flotation, CIP). In the mid-1990s, a major new class of processing technology was promoted for extracting nickel from recalcitrant laterite ores. The technology, called high pressure acid leaching (or 'HPAL'), used titanium-lined autoclaves at high temperature (245 to 270°C) and pressure (up to 5.4 MPa) to liberate the diffuse nickel from the ore. The metal-rich solutions are then processed through conventional hydrometallurgical techniques.

On a global scale, the only major nickel project that had used HPAL technology was the Moa Bay mine in Cuba, originally built in World War 2 to supply military needs and later modified and re-opened in the 1960's. Moa Bay had a troubled start and took several years to reach full production capacity. However, it is still in operation today.

The emergence of improved HPAL technology in the mid-1990s was promoted as a robust, reliable and lower cost alternative to traditional nickel sulfide pyrometallurgical technology. A major attraction of the technology was its application for production from nickel laterite ore resources, which are considerably more abundant than sulfide deposits. Larger scales of production were believed to push down unit costs of production. A minor nickel laterite boom occurred as a consequence, and three new projects were quickly developed at Cawse, Bulong and Murrin Murrin. The Cawse and Bulong projects lasted 1-2 years and became complete financial and technical failures. The Murrin Murrin project survived, but production must be monitored constantly to ensure financial viability because Ni production is considerably more difficult and expensive than expected.

Curiously, the dominant nickel miner in Australia, Western Mining Corporation (then WMC, now owned by BHP Billiton), chose to stay out of the nickel laterite boom – which in hindsight was a wise move given the large investments that failed at Cawse and Bulong. This highlights the issue of technological inertia – the difficulty in developing and then successfully employing new technology. Although HPAL certainly failed at Cawse and Bulong, it is now operating effectively at Murrin Murrin (after severe financial and corporate turbulence in its early years), where production is ~30 kt Ni/year.

A more recent HPAL example is the Ravensthorpe nickel laterite mine in Western Australia, recently developed by BHP Billiton Ltd. Despite some $2.5 billion of investment, the project was terminated during the commissioning stage. While the main reason cited was the collapse in the price of nickel (again showing the high cost of laterite nickel, although several sulfide mines have also closed in Western Australia recently), there has been speculation about whether Ravensthorpe was achieving its design parameters and operating effectively.

Even with such a chequered history there are a number of new nickel laterite projects around the world that are looking to utilise HPAL technology. These include the Goro and Koniambo mines in New Caledonia, and Ambatovy mine in Madagascar.

It is important to note that production from nickel laterite is more costly in terms of energy and chemicals. It also generates larger pollution outputs, like greenhouse gas emissions (depending on the electricity source) (Jessup & Mudd, 2008) when compared to sulfide production. Laterite-derived nickel is up to five times more energy intensive than production from sulfides.

As such, the implementation and uptake of new HPAL technology has been shown to be a complex endeavour, and although it works, it comes at a higher financial and environmental cost than traditional sulfide-derived nickel. These are important factors to consider with respect to peak minerals, particularly if the example described here becomes indicative of production-associated difficulties with other commodities in the future.

5.2.6. Manufacturing and Use

The application of new technologies in manufacturing and use is important in terms of both demand for metals and their end-of-life impact. The way in which metals are used in manufacturing affects their ultimate impact in several ways. If the metal is used in a dissipative application (e.g. copper in pesticides or phosphorus in fertilisers) then the dilute quantities not only have direct toxic effects on the environment, but recovery of the metal is much less economic, or completely impossible (Giurco, 2009; Cordell *et al.*, 2009). Also, combining a number of metals into one product in small quantities (e.g. in electronic printed circuit boards) makes the process of metal recovery difficult and further research is required for processing technology development (Reuter, 2005). However, the use of a metal combination for making specific alloys with unique properties may enable longer use (e.g. nickel in stainless steel).

One promising approach in manufacturing is to further use 'light-weighting', which can reduce the metal used in manufacturing the same product, however the rebound effect must also be considered (see Berkhout et al. 2000).

5.2.7. Recyclable Waste

Recycling metals often uses much less energy than production from virgin ores (Henstock, 1996). However, the total cost of recycling depends on factors including the concentration of the product stream and the distance it must travel to be reprocessed. Also, the relative investment required to establish recycling facilities will be significant, and considering facilities for primary production are already in place. Other pressures, like peak minerals or influences from other countries already recycling, will drive the development and uptake of recycling technology in Australia in the future. This will depend on the economic costs of and the differences between primary production from conventional mining versus those of existing and new secondary production from recycling (for example, some old secondary copper smelters in the USA had poor environmental controls and were closed (Biswas and Davenport, 1994). Over time, this paper argues that peak minerals will mean a greater need to incorporate recycling into mineral and material flows to continue providing goods and services.

Some research is exploring ways of improving the manufacture and use of minerals and metals to make end-of-life products more readily recyclable. Gerst and Graedel (2008, p 7038) review estimations of the in-use stocks of metals, suggesting that there has been a "substantial shift in metal stocks from the lithosphere to the anthroposphere", which now represent a huge, and largely untapped resource. For this reason, Kapur and Graedel (2006) speak of cities particularly as 'mines of the future'. They introduce the concept of 'employed stocks', the mineral stocks already in active (in-use) or inactive (hibernating, i.e. gold in old mobile phones in peoples' drawers at home) use. They identify that employed stocks are growing relative to 'geochemical stocks' (distributed or as ore in the lithosphere), to the point that they will become the most significant stocks of some commodities in particular countries (Elshkaki *et al.*, 2004) within a relatively short timeframe. As such, finding ways to realise value from end-of-use stocks, particularly within the context of peak minerals (geochemically speaking), will become increasingly important.

Establishing efficient recycling technology poses challenges, but the rewards can be significant. "Recycling of electronic waste is an important subject not only from the point of waste treatment but also from the recovery of valuable metals" like gold (Cui and Zhang, 2008). Recycling mobile phones presents an interesting example. Using current recycling technology (Hagelüken, 2005), between 100 and 400 grams of gold can be obtained from one tonne of electrical circuit boards (depending on their quality). Gold is currently mined at ore grades as low one to five grams per tonne of ore (Mudd, 2007c), so recycling end-of-life electrical products presents an immensely promising possibility. Reuter (2005), offers useful insights into the technological challenges of processing end of life vehicles and electronic products, noting that the metallurgy of processing naturally occurring ores is very different to the processes needed for processing recycled electronic equipment.

Research exploring the possibilities of recycling is limited in Australia, where technological development focuses on improving primary production. However, in Europe (Theo, 1998), Japan and Taiwan end-of-life product return legislation is much stricter and the quantity of recyclable goods is considerably larger because of the larger population base (which is the source for recycled goods and metals). These countries consequently invest more into the development of efficient recycling technologies. Driven by its Department of Innovation (not waste), Japan is actively seeking to 'close the loop' to avoid environmental problems associated with end-of-life products (Department of Trade and Industry (UK), 2005) by recycling and reusing these materials in new products. Manufacturers in these locations are also stockpiling a range of mineral inputs to supplement their future production cycles.

The Swedish mining company, Boliden, promotes their recycling business and innovative use of smelting technology in their recent sustainability reporting by showing the contained metals in mobile phone scrap versus copper-gold ore, shown in Figure 23. The clear message is the potential business value in metal scrap recycling. The lack of Australian research in this area is partly attributable to the limited population base and limited recycling industry – with the notable exception of Sims Metal Management who are the world's largest metals and electronic waste recycler (SIMS, 2009). This represents an area of future technology development that should be capitalised on.

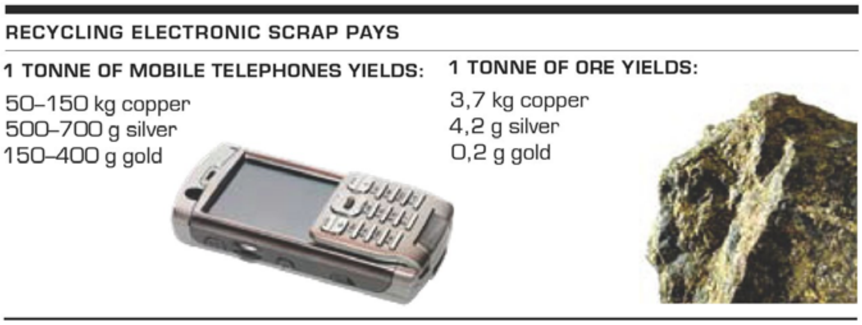

Figure 23: Contained metals in mobile phone scrap versus copper-gold ore (Boliden, 2008).

SECTION FIVE: SUMMARY

Technological advancement has fundamentally influenced the Australian mineral industry's ability to find, access and produce minerals and metals. Technology has therefore played a central role in Australia's ability to create wealth from minerals. In the absence of peak minerals, technology has focussed on winning economic gains from the early stages of the typical mining life cycle. As production has moved from 'cheap and easy' to more 'difficult and expensive', technological development is increasingly needed to solve economic and production problems. However, technology is also being used more to solve the environmental problems that add to the costs of production. Continuing difficulties associated with production from lower ore grades in less accessible locations (under the shadow of peak minerals) will mean technology is increasingly directed towards addressing and mitigating the growing environmental and social costs, and will also begin to focus more on the later stages of the minerals production chain.

6. ENVIRONMENTAL CONSTRAINTS & IMPACTS

SECTION SIX: OUTLINE

This section explores:

- *environmental factors which will affect mineral production (6.1)*
- *environmental impacts arising from mining and minerals processing (6.2); with illustrative examples with respect to peak minerals at the local, national and global scales*
- *the intersection between technology and environmental issues in response to peak minerals (6.3).*

The peak minerals paradigm used throughout this document splits access and utilisation of resources into 'cheap and easy', located at one end of a time/production continuum, and 'expensive and difficult' which is located at the other end. Economic, social and environmental costs change occurring at different points along this continuum, and the impact of these changes on mineral production will be of paramount importance.

This section gives an overview of the challenges and opportunities associated with the sustainable management of minerals resources in Australia, with regard to the changing environmental costs associated with the peak minerals paradigm. Its focus is in two distinct areas, firstly, how environmental factors may affect future production and consumption of minerals and metals; and second, how environmental impacts of minerals processing affects the long-term competitiveness of Australia's mineral industry.

6.1. ENVIRONMENTAL FACTORS AFFECTING PRODUCTION

This section illustrates that future mining and minerals processing activities will be affected by environmental factors both caused by, and external to the minerals industry.

6.1.1. Climate change

The effects of climate change are anticipated to hinder Australian mining operations as a result of changed water availability, and increased frequency and intensity of storms, cyclones and floods (McInnes, 2008). Climate change-induced severe weather events will mainly interrupt transport services linked to the export of minerals (Stevens, 2008).

Climate change may also cause mineral and metal supply and demand fluctuations. Increased demand for minerals may be linked to climate change adaptation, and the necessary infrastructure development that will aid mitigation efforts. Reduced demand may result as markets become increasingly carbon sensitive – choosing products and processing routes with a low carbon footprint. For example, Iceland is developing its hydro and geothermal power to allow expansion of aluminium refining (Krater and Rose, 2009).

6.1.2. Input costs and constraints – oil, water and energy

Environmental factors will also affect inputs to mining, in particular water and energy, which themselves are affected by climate change and policy responses. Despite a decline in oil prices in 2008, linked with the global financial crisis, the International Energy Outlook foresees a return to higher oil prices of $130 per barrel (2007 dollars) by 2030 (Energy Information Administration, 2009). Transport fuels in use today will become more expensive as a result of peak oil, affecting competitiveness ahead of a transition to other transportation energy sources.

Water constraints, from climate change or competition with other users (urban and rural), will reduce overall water *availability* and/or *quality* in some areas. Anticipating and adapting to these pressures will require the application of potential response options including using less water through better efficiency, installing desalinisation or water recycling facilities (McInnes, 2008).

In the context of the peak minerals framework, a move from easy to more difficult production will reflect increasing water and energy requirements post-peak. Those mineral resources, which are harder to access because of their remoteness, depth underground, lower grade or higher impurities, or more complex mineralogy, may become less economically viable (and move from viable reserve to a more general resource stock). This also exacerbates the impacts of input constraints post-peak production.

6.1.3. Land use competition

"The loss of food and water security is one of the most immediate threats posed by global warming" (Rajendra Pachauri, IPCC, 2007). The manifestation of this includes continuing conflicts over the quantity and quality of water resources between coal mining and agricultural land use in the Liverpool Plains and Darling Downs of NSW. A Senate inquiry into the 'Impacts of mining in the Murray Darling Basin' makes a series of recommendations including, "the prevention of new mines or extractive industries in the Murray Darling Basin if their impacts on water resources are inconsistent with the Basin plan", and also highlights the need to coordinate research to "better understand the cumulative impacts of mining" (Australian Senate, 2009), which is becoming an increasingly prominent concern throughout the mining sector (Franks *et al.*, 2009).

6.1.4. Legacy impacts of mined land and technology

Legacy impacts from previous mining operations – together with a range of drivers explored further by Giurco and colleagues (2009) – affect the ability of mineral extraction and processing operations to obtain what is often referred to as 'a social licence to operate'. In seeking to address this challenge, sustainability criteria have recently been developed, together with an indicator framework to assess the impact of legacy mined land (Worrall *et al.*, 2009). The extent to which mined land rehabilitation will affect the viability of operations varies, but social, environmental and economic costs pose significant and tangible obstacles. Where operations impinge on established communities in developed areas, it is more likely that direct intervention from members of affected communities will be more common.

Additionally, the impacts of historical technology use can affect the deployment of current technology (e.g. *in-situ* leaching). Within Australia, the use of *in-situ* leaching for uranium extraction, the development of oil shale, and use of by-products like Alkaloam®, have been the focus of public opposition. In one case, public opposition halted mining development using these technologies altogether (Barclay *et al.*, 2009).

Perhaps the greatest part of the challenge presented by legacy impacts relates to mine wastes – the tailings and waste rock remaining after completion of a project. Given declining ore grades, deeper mines and higher quantities of waste rock (especially sulfidic material), mine waste management is a growing strategic issue and challenge for the mining industry (Mudd, 20092, 2010). The exposure of sulfidic materials to the surface environment leads to major risks of acid and metalliferous drainage (or 'AMD'), requiring very pro-active assessment and management (Taylor and Pape, 2007). Although technology has improved to address these issues, such as soil covers, pre-mine assessment of AMD risks, improved tailings dam designs, as well as more holistic risk management, the sheer and escalating scale of annual mine wastes in Australia will continue to make legacy impacts an issue of growing strategic importance with respect to peak minerals (Mudd, 2009a, 2010).

As production becomes more difficult and more expensive, post-peak, legacy impacts of mined land are likely to broaden and intensify. Mining companies will face greater challenges in managing and mitigating these impacts. While self-regulation, improved reporting structures, and demonstrated corporate responsibility have moved the minerals industry a long way toward addressing these issues, continued development and application of sustainability initiatives will be required. Companies that anticipate these challenges and demonstrate investment in technologies (mechanical and conceptual) that can mitigate social or environmental issues will be rewarded by public and consumer support into the future.

6.2. ENVIRONMENTAL IMPACTS OF MINERAL AND METAL PRODUCTION AND CONSUMPTION

Having reviewed the impact of environmental factors and their impact on the future of mining 'easier' and 'harder' ores, this section turns its focus to describing the different impacts associated with minerals and metals production along the production consumption chain and across local, national and global scales. The aim is to identify which areas will be more affected by increasing environmental costs of mining lower grade ores.

6.2.1. Impacts along production-consumption chain

Understanding the environmental impacts associated with production and consumption of metals is imperative, as highlighted by the Mining Minerals and Sustainable Development project:

> *Connecting the production and use of mineral-related materials is critical to ensuring that the minerals sector contributes optimally to sustainable development* (MMSD, 2002, p 286)

The relationship between the economic value and environmental impact of stages in the mining production chain is illustrated in Figure 24. This shows that the initial stages are characterised by low value, but high environmental cost: resource extraction and then processing/refining have the highest impacts. By contrast, later stages like forming and assembly are attributed less environmental impact, but generate the majority of the economic value. While this example is drawn from a production chain associated with a mobile phone, the convex nature of the impact/value curve also applies more generally to other products. As the environmental impacts of resource extraction increase, due to declining ore grades and increased waste, the environmental impact curves associated with the first two stages of the production chain become even steeper. This increase prompts the question of what business models could harness more economic value from extraction and processing, whilst reflecting the true costs of these production stages.

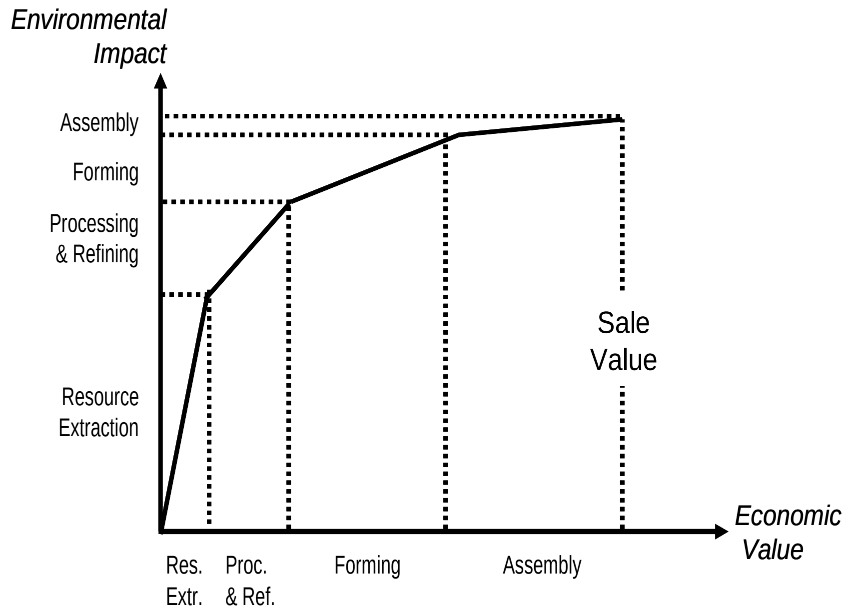

Figure 24: Relationship between added economic value and environmental impact at resource processing stages (after Clift and Wright, 2000)

Life Cycle Assessment (LCA) has also been used to understand and examine environmental impacts along the production chain. In the metals context, cradle to gate studies (see for example, Giurco and Petrie, 2007; Norgate *et al.*, 2007; Norgate and Rankin, 2000; Mudd, 2007a,b; Ecobalance, 2000) have been more prominent than cradle to grave studies because of the complexity of end-uses to which metals are put. Yellishetty and co-authors (2009) offer a review of issues relating to the application of LCA to minerals and metals.

6.2.2. Local impacts

Potential environmental impacts at the local scale are illustrated in Figure 25. This figure identifies that some environmental impacts of mining persist throughout all phases of mining production (e.g. surface degradation and contamination, watercourse contamination), but that others arise variably during or after production (e.g. air pollution and cultural site disturbance). Many of these issues result in cumulative consequences for mining communities and the ecosystems in which mining operations are situated (Franks *et al.*, 2009).

POSSIBLE TYPES OF ENVIRONMENTAL DAMAGE	PHASES OF MINING PROCESS					
	Geological Exploration	Establish Pilot Mine Site	Establish Mine	Operate Mine	Close Mine	Post-Closure
Surface degradation and contamination	●	●	●	●	●	●
Flora and Fauna (e.g. Die back)	●	●	●	●	●	●
Damage to historical or sacred sites	●	●	●	●	●	–
Contamination of streams and rivers	●	●	●	●	●	●
Contamination of dams	–	–	●	●	●	●
Underground Water	–	●	●	●	●	●
Change in water table	–	–	–	●	●	●
Soil Erosion	–	–	●	●	●	–
Local air pollution	–	–	–	●	●	●
Regional air pollution (e.g. acid rain)	–	–	–	–	–	–

Figure 25: Possible environmental impacts (indicated by dots) at phases of mining process (adapted from Frost and Mensik, 1991)

With declining ore grades comes the necessity to intensify operations in order to produce one unit of product. Deepening environmental consequences will mirror this production intensification. These consequences will be particularly significant in the early stages of mine site establishment, when greater effort is directed to exploring larger areas for better mineral deposits, or when an operation must expand to support the greater ore through-put requirements.

Declining ore grades may also be important toward the end of a mine's productive life (Laurence, 2006). Falling ore grades and the associated intensification of environmental impacts may cause a mine to close prematurely (because of the resource's economic scarcity). Aside from the social and economic development implications of closure (explored in more detail in section 8.2.1), corporations that do not anticipate these changes may also be unable to conduct the required mine-site remediation activities required of them.

At the local scale, all phases of production have locally significant environmental impacts, which vary during the life of the operation (Figure 26). Pre-peak minerals impacts are primarily associated with mine establishment, which are replaced by remediation and closure impacts post-peak. Importantly, the localised nature of extractive operation means these impacts are spatially concentrated and often borne by a relatively small number of stakeholders.

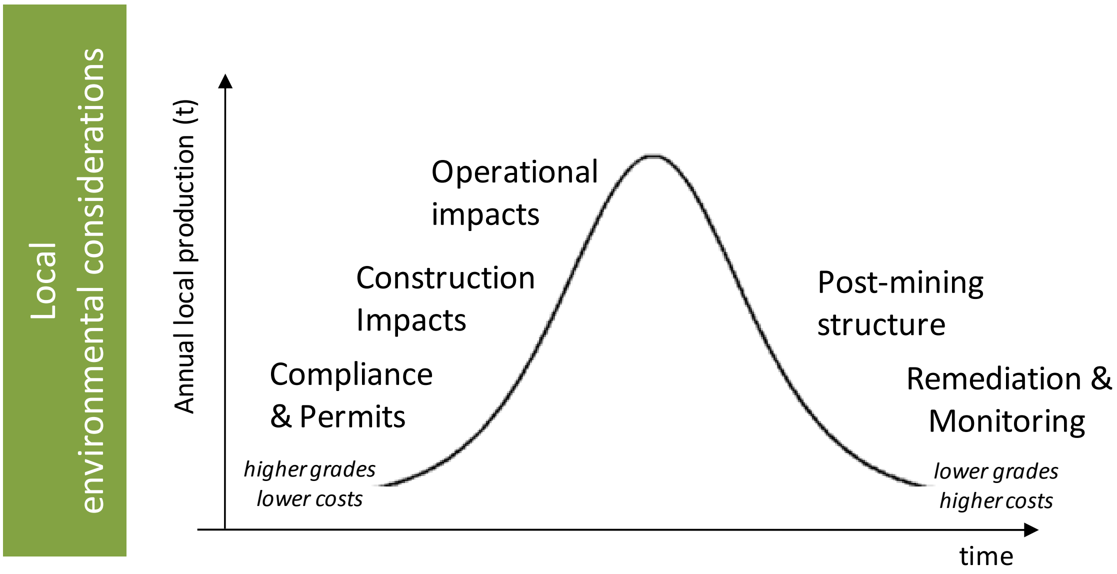

Figure 26: Illustrative environmental impacts of peak minerals at the local scale

6.2.3. National impacts

National environmental issues are considered in the context of the productive life of the resource (Figure 27). While permitting issues are a common feature of early production stages, as production continues, governance and national reporting processes become a focus. As production of resources continue to decline (e.g. as a result of changes in economic viability or declines in reserve size) then structural adjustment of the economy becomes imperative.

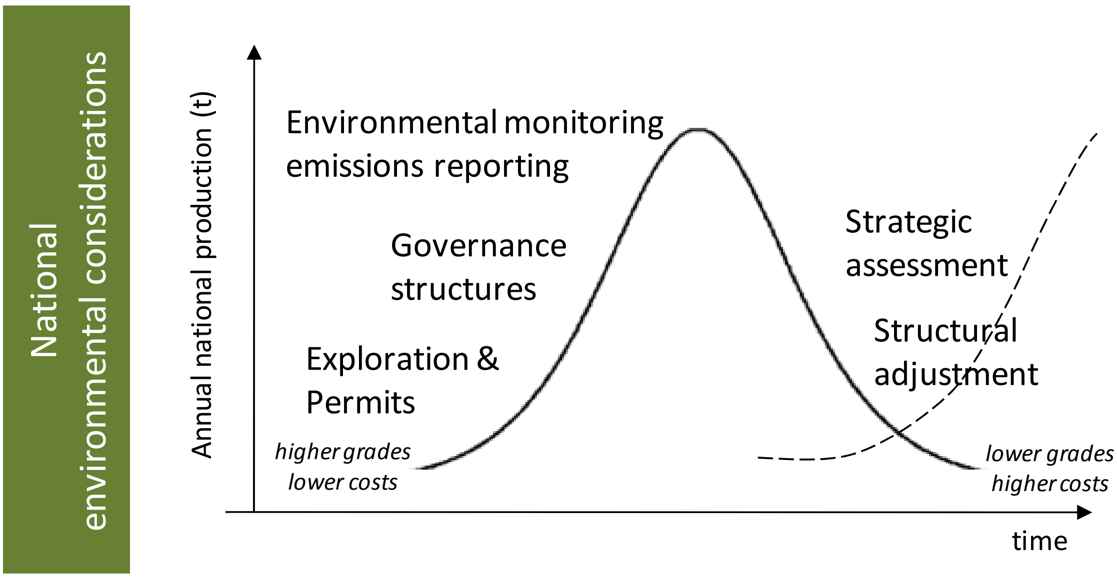

Figure 27: Illustrative environmental impacts of peak minerals at a national scale.

Social and regulatory pressure, and the growing influence of corporate environmental responsibility has contributed to significant improvements in standard environmental reporting conducted by the Australian minerals industry (Brereton, 2003; Brereton and Forbes, 2004; MCA, 2000). These advancements in self-governance demonstrate the industry's transparency, need to display high environmental sustainability credentials, and desire to meet national and global sustainable development goals (ICMM, 2009; IIED and WBCSD, 2002;

MCA, 2005). The operational changes that are required to ensure these measures are incorporated into day-to-day production and process will provide a stable foundation for further improvement as production become more difficult and more expensive, and as the environmental consequences of continued production (under these pressures) intensifies the existing environmental problems the sector faces.

Where a resource is approaching exhaustion (e.g. local oil), a strategic assessment must either identify how the country can access the resource or how the resource (or an alternative) can provide the same service in a different way. At the national scale, declining viability of terrestrial ores may be a cue for diversification that allows traditional production to be compensated by increased production from deep-sea reserves, from landfill or from recycled scrap (depicted by the dotted line in Figure 27). However, realising these alternatives may bring more significant environmental consequences, which may be largely unknown and difficult to anticipate and plan for (see for example Littleboy and Boughen, 2007).

The time-scale of this diagram must be viewed relatively, and is not to scale. The early stages of production may represent considerably longer time-spans than later stages. Impacts over time at the national and global scales will be dramatically longer than those examined at the local scale.

6.2.4. Global impacts

Environmental issues that can be considered globally important are illustrated in Figure 28. Issues like cross-border pollution, the consequences of exploitation, trade and use of minerals or metals (particularly hazardous minerals like uranium) are likely to be important as production increases while ore grades are favourable and production costs are low.

Increasing environmental pressure will coincide with falling ore grades and increased production costs, which characterise the resource’s growing economic scarcity (and ultimate depletion). Issues of geo-political tension and the need to establish adequate global plans for transition will accompany the changes in production post-peak. Phosphorous provides a relevant example of a mineral resource whose production, and future depletion has significant global environmental and social consequences (Cordell *et al.*, 2009).

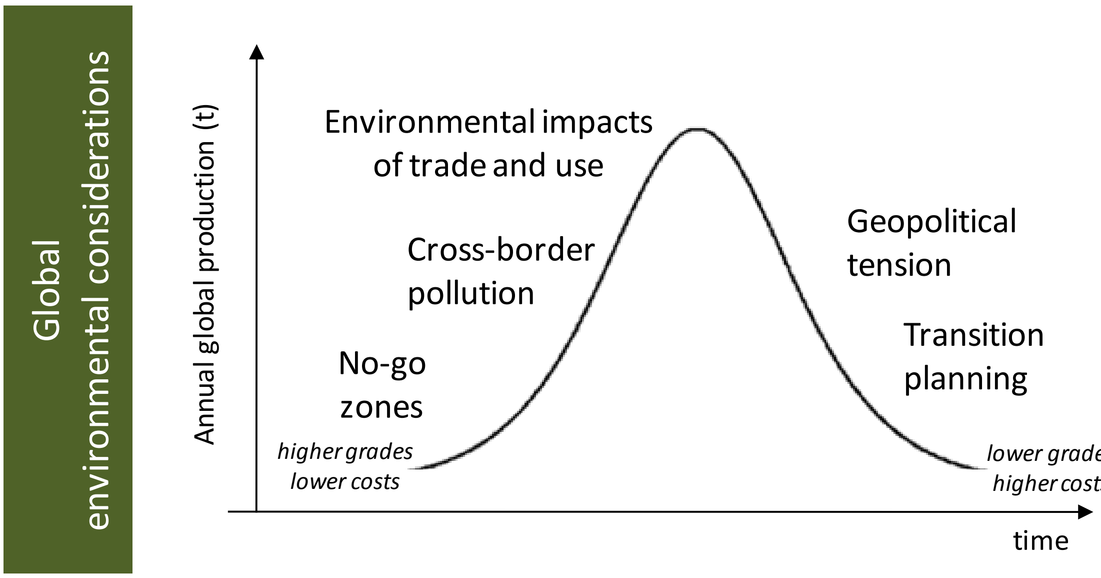

Figure 28: Illustrative environmental impacts of peak minerals at the global scale

Declining global production of many important minerals also increases pressure to allow exploration of traditionally ‘no-go’ mining areas. Environmentally sensitive and globally important locations like World Heritage Sites (the Great Barrier Reef and Antarctica) and RAMSAR wetlands (Kakadu National Park) are generally sensitive to resource extraction, which can contradict the environmental values of these wilderness areas. These environmental value these important environments provide (aesthetically, culturally, and for environmental services) are considered the heritage of humanity, and consequently, their exploitation must attract global discussion and agreement.

As a carbon intensive sector, the minerals industry also has a duty to mitigate the consequences of global climate change. The carbon intensity of the industry is likely to mirror the production peak (assuming the industry remains dependent on fossil fuels through the peak). However, as the environmental cost of mining increases relative to the price of minerals post-peak, the global minerals industry will be required to find energy alternatives (such as linking to geothermal sites for example), or contend with the cost-price squeeze brought about by the need to reduce the carbon footprint (through an Emission Trading Scheme or Carbon Tax).

Global patterns, particularly global trade, ultimately drive environmental issues at national and local scales (Dinda, 2004). Global trade in Australian minerals leads to the expansion of mining operations, and the environmental consequences these expansions bring (which have been discussed in this section). Such trade also increases the size of the national economy, and GDP. However, environmental pressure (and degradation) often rises more quickly than income (Dasgupta *et al.*, 2002; Dinda, 2004), slowing down only when higher incomes permit social or technological intervention to solve the environmental issues – a pattern described by the Environmental Kuznet’s curve (Figure 29).

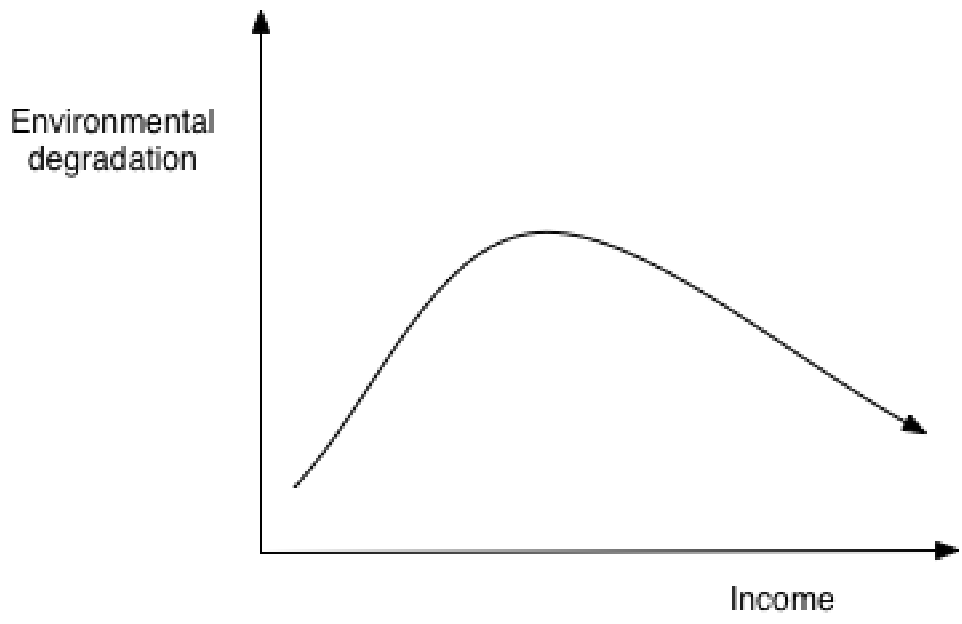

Figure 29: The Environmental Kurznet’s Curve showing the relationship between increasing income and environmental degradation (from Dinda, 2004)

6.3. LINKING ENVIRONMENTAL ISSUES AND TECHNOLOGICAL SOLUTIONS

Technology will increasingly play a key role in addressing the environmental impacts from mining (Giurco *et al.*, 2009; Dinda, 2004). To date, the environmental costs associated with mining have been addressed in an indirect manner, externalised as side effects of production, rather than included as real costs in an operation (e.g. when addressing climate change by imposing an emissions trading scheme). Increasing wealth from resources (in conjunction with the environmental issues this wealth carries with it) should mean part of that wealth is used to mitigate the resulting environmental problems encountered generating this wealth – as is hypothesised by the Environmental Kuznet's Curve. Technological development (both mechanical and conceptual) is an important instrument that should contribute to levelling off the environmental degradation that comes with economic development of mineral resources.

Some historical examples of technological approaches to minimise environmental issues from mining and smelting include:

- Sulfur dioxide – implementing scrubber systems to capture sulfur dioxide emissions from smelters and converting this to sulfuric acid (e.g. Mt Isa, Kalgoorlie, Olympic Dam);
- Broken Hill, Port Pirie, Mt Isa – implementing tall stacks from smelters to ensure adequate dispersion of atmospheric pollutants (especially particulate-bound lead);
- Coal seam methane – building methane gas extraction systems prior to coal mining to both reduce safety risks as well as effective greenhouse emissions (e.g. Hunter Valley and Illawarra coal fields);
- Sulfidic mine waste and acid and metalliferous drainage (AMD) – use of engineered soil covers to rehabilitate and mitigate potential long-term pollution problems from sulfidic mine wastes (e.g. Rum Jungle, Kidston and numerous others).

While there are many more examples that could be cited, this shows that significant issues can be minimised, or even effectively eliminated, by the appropriate use of technology. However, it must also be pointed out that many new technologies adopted in the mining industry have not always led to lower environmental costs. For example, the development of flotation allowed the processing of low grade sulfide ores, including copper, lead-zinc, nickel and even some gold ores – but at the cost of significantly greater tailings and, when combined with open cut mining, also waste rock. The emergence and rapid deployment of carbon-in-pulp (CIP) technology for the gold industry allowed the massive 1980s gold boom to occur (combined with the sustained rise in the gold price) – but also created a massive mine waste burden, including cyanide-contaminated tailings. Given that the carbon intensity of gold mining is inversely related to ore grade, and that ore grades are in seemingly terminal decline (Mudd, 2007a,b), this also means that sustaining future gold production will result in even greater greenhouse gas emissions per tonne of product in the future, unless a move is made to renewable energy sources.

Thus, although many new technologies across the mining industry have enabled economic production to be sustained or even boom, these have invariably addressed financial costs only and rarely have they reduced external environmental costs. Future technologies in the mining industry will clearly need to reduce not only financial operating costs, but also tangibly reduce environmental costs as they are increasingly internalised in the economic system.

SECTION SIX: SUMMARY

The environmental costs associated with mining increase, approaching and then beyond the year of peak mineral production. As access to high-grade mineral ore deposits becomes more difficult, the environmental consequences of mining also increase: greater waste, larger tailings ponds and greater landscape disturbance. Future mining and minerals processing activities will increasingly be affected by environmental factors both caused by, and external to the minerals industry, including: climate change, input constraints like water and energy, competition for arable land, and legacy impacts from previous mining operations. The environmental consequences of mining can be characterised based on their impact at various scales, and along the mining production-consumption chain. How these impacts change as a result of peak minerals will influence the economic viability of many mining and minerals processing operations. Identifying where greater value can be drawn from all stages of the production-consumption chain will ensure the changing (increasing) environmental costs at these stages can be covered by the financial gains such advances yield. Finding technological solutions for environmentally-driven costs to the minerals industry will contribute to the long-term viability of the sector, and Australia's national benefit.

7. A CHANGING SOCIAL LANDSCAPE

SECTION SEVEN: OUTLINE

This section explores:

- *how social issues and the environmental consequences of mining are tied together, and how society is increasingly driving substantive changes in the minerals industry (7.1)*
- *how social impacts vary across scales (local, regional/national and global), and the influence peak minerals has in this context (7.2).*

The social landscape surrounding the mining and minerals industry is steadily changing. With increasing environmental awareness during the 1970s and 80s, fortified by several significant environmental incidents (Erikson, 1976; Warhurst and Mitchell, 2000; Hamann, 2003), public concerns about mining operations have broadened and increased (Hamann, 2003; Jenkins and Yakovleva, 2006; Kumah, 2006; Sarin, 2006; Warhurst and Mitchell, 2000; Earthworks and Oxfam America, 2004). Changing social perceptions, and solidified social will has also encouraged greater regulatory scrutiny concerning improved corporate behaviour and responsibility (Mtegha *et al.*, 2006; Solomon *et al.*, 2008; Warhurst and Mitchell, 2000; Worrall *et al.*, 2009), much of which has been through the mining industry's self-regulation (Brereton, 2003; Warhurst and Mitchell, 2000; Hamann, 2003) instead of formal governance arrangements. This pattern of increased, socially-aware, regulation will continue to shape the economic capacity of the minerals industry into the future (ICMM, 2008).

Increasing social pressure has consequently been translated into greater corporate social and environmental disclosure in the last two decades (Jenkins and Yakovleva, 2006; Warhurst and Mitchell, 2000). This pressure has come to influence the operation of an industry where social and environmental costs have traditionally been externalised (Bridge, 2000; Jenkins and Yakovleva, 2006). As Jenkins and Yankova (Jenkins and Yakovleva, 2006, p 272) observe, a sustainable mineral industry now "requires a commitment to continuous environmental and socio-economic improvement, from mineral exploration, through operation, to closure."

Importantly, many of the environmental drivers now influencing society's perceptions of the sustainability of the minerals industry are connected to the consequences of peak production. As ore grades and mineral reserves decline, the environmental impacts of mining increase (Mudd, 2007c; Mudd, 2009a; Mudd and Ward, 2008). Despite significant technological developments in the industry aimed at maintaining economically viable production from falling ore grades, this progress has been largely ineffective in preventing environmental consequences and the social flow-on effects. This section presents a review of the social implications of peak minerals in the context of local, national and global societies, and explores how these impacts overlap with the mining lifecycle (exploration, production and mine closure).

7.1. RESPONDING TO SOCIAL IMPACTS

Environmental and social criticism, and changing public perceptions regarding the sustainability of mining practices is changing the way mining companies operate and interact with the community (Bridge, 2000; Esteves, 2008; Hamann, 2003; Hamann, 2004; Jenkins and Yakovleva, 2006; Solomon *et al.*, 2008; Jenkins, 2004; Hilson and Murck, 2000). In an industry increasingly scrutinised on its sustainable business credentials, concepts like 'corporate social responsibility' and 'social license to operate' are drawing serious consideration – from companies and communities alike.

7.1.1. Corporate Social Responsibility

Corporate social responsibility (CSR) describes the obligation of corporations to maximise the positive and minimise the negative social or environmental impacts associated with their mining operations (Hamann, 2004; Jenkins and Yakovleva, 2006; Solomon *et al.*, 2008). Yet, being profit driven, managing this obligation requires a keen eye to maintaining profit (Esteves, 2008; Garvin *et al.*, 2009; Hilson and Murck, 2000; Jenkins, 2004). It encapsulates the need to demonstrate corporate sustainability credentials (Solomon *et al.*, 2008), not only to shareholders, but also "to other stakeholders, including employees, customers, affected communities and the general public, on issues such as human rights, employee welfare and climate change" (Hamann, 2004, p 238).

7.1.2. Social License to Operate

Establishing sustainable development goals that incorporate the concept of corporate social responsibility requires substantive operational changes. But in implementing these changes, corporations are investing in an operational reputation bound to the concept of a 'social license to operate' (Solomon *et al.*, 2008). Like the outcomes of CSR, social license to operate (SLO) acts like a complementary piece of legislation to the normal regulatory licenses to mine. Unlike CSR, SLO is informal and unwritten, but can still act as a powerful form of regulation. Most often, it has encouraged companies to maintain their operations in a way that does not contradict the values and attitudes of the community members living in proximity to the mine's operations.

7.1.3. Corporate self-regulation

CSR and SLO are ultimately self-regulatory responses to the negative public perceptions and attitudes about mining as an extractive industry. These informal regulatory arrangements have primarily arisen out of the industry's realisation that community demands (and should be given) some recourse to influence the behaviour of companies operating in their midst. The reputational investment in CSR or SLO made by a company (through greater internalisation of environmental and social costs) may offset the possible short-term reductions in profit, caused by low public confidence in their operations, by ensuring future long-term public consumer support (ICMM, 2009; MCA, 2005).

Internalising social and environmental costs into mining operations has impacts at the regional/national level and on the global scale (Earthworks and Oxfam America, 2004; ICMM, 2008; MMSD, 2002). As mine operators become increasingly concerned about how to address social and environmental sustainability issues, they also face a less economically stable future. However, the impact of these social pressures is most directly experienced at the local level, where landholders, consumers, activists and the general public seek the change they feel is due. Consequently, examining the social impacts of peak mineral production within a framework of a changing social landscape is useful when conducted in the context of especially local, but also regional/national and global contexts.

7.2. PEAK MINERALS AND SOCIAL ISSUES ACROSS SCALES

When examining the influence of peak minerals on society, it is clear that impacts vary at different scales: local, regional/national and global. At an international scale, Clark and Clark (1999) identified tenure and social issues as the two most important factors that would impact on global mining operations in the future. More locally, in a survey of mining industry representatives (members of the Australian Institute of Mining and Metallurgy), Moffat *et al.* (2009) demonstrated that although social issues were not considered of primary importance as future drivers in the Australian industry (with economic and environmental drivers rated more highly), they were nonetheless considered significant. That these concerns vary merely demonstrates the variability inherent in the social dynamics of the minerals industry.

Clearly, the minerals industry is dependent on a vast network of mines, transporters, processing sites, ports and markets around the world. Each of these network focal points operates on a local or regional scale, but their operation has global implications. Society also plays a key role in this mineral network, driving consumption – for example, 80% of mined gold becomes jewellery (Kumah, 2006), so the individual can have a substantial influence over its production (Sarin, 2006). However, although the social dimensions of mining are increasingly influencing the minerals industry, it is still the least well-understood aspect of sustainable development (Solomon *et al.*, 2008).

Box 3.
Baia Mare: from Global to Local impacts

On January 30, 2000 around 100,000 cubic metres of water containing 50-100 tonnes of cyanide, as well as cooper and other heavy metals spilled into the Danube catchment after a tailings dam of a vat leaching gold mining operation broke in north-western Romania.

No human life was lost as a direct result of the disaster, but it destroyed the livelihoods of many people engaged in the fishing and agriculture sectors in Romania, Hungary, Yugoslavia and Bulgaria. Regional water supplies were contaminated and significant biodiversity loss was recorded throughout the affected area of the Danube catchment – a listed World Heritage and RAMSAR site.

While the disaster had substantial local and regional/national environmental and social impacts, it also had international political ramifications and resulted in the resignation of the mining company's CEO, and the delisting of Esmeralda Exploration (an Australian company holding a 50% share in the miner) from the Australian Stock Exchange. (Csagoly, 2000; Cunningham, 2005).

7.2.1. Local issues

The high spatial concentration of mining or processing operations means social impacts on a local scale are not homogeneous. Indeed, many communities become established around mines, coalescing in response to employment, service or support requirements associated with the mine (Rollwagen, 2007; Sharma, 2009). In other cases, established communities are fundamentally changed as a result of the establishment of a mining operation nearby (Whitmore, 2006). Either way, the mining operation becomes a key element in the community, which is in turn directly, or slowly bound to the operation's fate (Brereton and Forbes, 2004).

Recognising the social implications of mining operations, international and regional mining industry representative groups are increasingly advocating ways to minimise or avoid the social impacts from mining at the local scale (ICMM, 2008; MCA, 2005). These organisations are primarily promoting greater industry engagement with affected and interested stakeholders, because more significant engagement is viewed as the best way of identifying and addressing the diversity of social impacts mining precipitates at the local level. While the social impacts of mining are considered the most difficult to address in sustainable development (Solomon *et al.*, 2008; Esteves, 2008), engagement is perceived to demonstrate that the industry is actively attempting to manage and mitigate these impacts (Ivanova *et al.*, 2005; Brereton and Forbes, 2004; Kapelus, 2002).

In relation to stages through time related to peak minerals, the impacts change as represented conceptually in Figure 30.

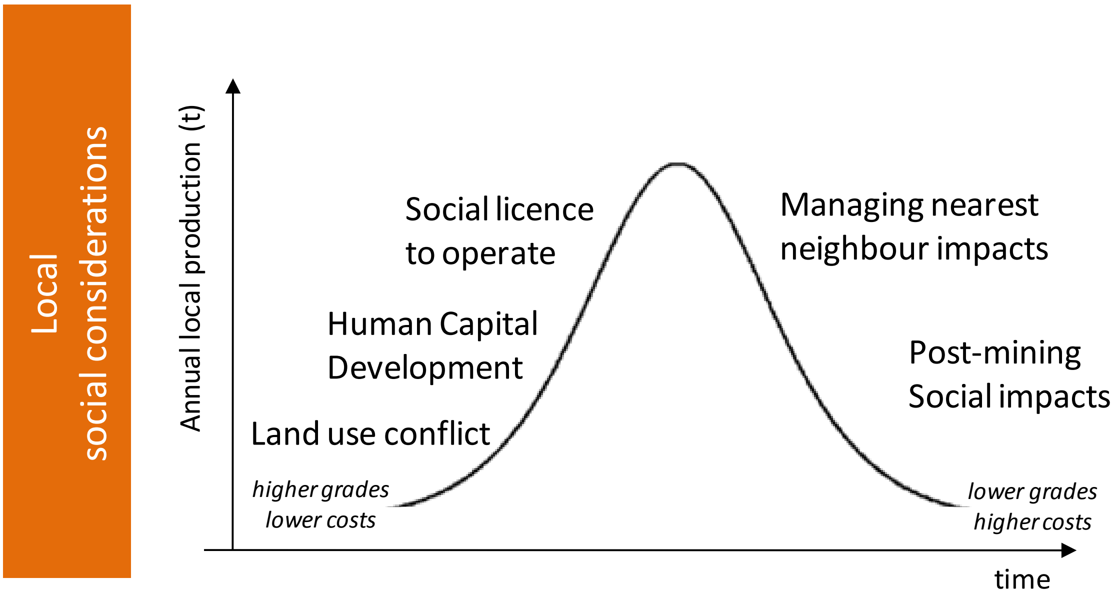

Figure 30: Illustrative social impacts of peak minerals at the local scale

Local impacts associated with the minerals industry can be loosely grouped into four categories: those associated with land use conflicts; impacts on social capital; 'nearest neighbour' impacts; and mine closure and post-mining impacts. Identifying and addressing these social impacts has added importance when considering that the industry is largely self-regulated from a social perspective (Brereton, 2003; Warhurst and Mitchell, 2000; Hamann, 2003), and few mandatory arrangements exist to monitor or evaluate the nature of the social impacts from mining (Lockie *et al.*, 2009).

Land use conflicts

Land use conflict has been a consistent issue for the mining sector, but was traditionally overlooked because the economic benefits of mining overshadowed the social and land tenure consequences (Hilson, 2002; O'Faircheallaigh, 2005). Many of the land tenure-related conflicts arising from mining have resulted from the historic exclusion of indigenous peoples and traditional owners from discussions regarding mine exploration, planning and production (Clark and Cook Clark, 1999; Mudd, 2008; Garvin *et al.*, 2009). More meaningful engagement between corporations and local communities in the last decade has begun to address these tenure and conflict issues. This issue was also discussed in section 4.4.3.

Social and Human Capital

The previous section assumes that the development of mining within communities brings benefits, and that without effective planning, the removal of those benefits has a detrimental impact on the sustainability of those communities. Indeed, community dependence on mining (Stedman *et al.*, 2004) also raises particular issues in the context of the cultural and social well-being of those communities. The level of dependence can vary dramatically between communities, in relation to the mined commodities (Stedman *et al.*, 2004), and as a result of the way mining companies operate in different localities (Solomon *et al.*, 2008; Stedman *et al.*, 2004; Warhurst and Mitchell, 2000). Understanding the dynamics of social and human capital in relation to the dynamics and exploitation of natural capital must be a key consideration in exploring the localised impacts of peak mineral production on mining communities. Many of these impacts cannot be addressed by the development of infrastructure, schools, health centres, or other contributions that are commonly associated with progressive socio-economic development (Bury, 2004; Esteves, 2008).

Social Capital

Social capital describes the ability of members in a community to secure benefits from that membership (Portes, 1998). As a theory it conceptualises the way individuals interact to form communities (Putnam, 2000; Forrest and Kearns, 2001) and "captures the idea that social bonds and norms are critical for sustainability" (Pretty, 2003, p 1912). Following from this, a sustainable local mining industry is reliant on the existence of social capital within the community, and between the community and mine operator (Bell, 2009; Bury, 2004). Social capital is recognised to lower the 'transaction costs' between individuals, facilitating cooperation by giving individuals (and community partners in mining operations) the confidence to trust each other (Pretty, 2003). There is a further differentiation between 'bonding' (within the group) and 'bridging' capital (linking to other groups). The former without the latter can inhibit community development, particularly in modern society.

Human Capital

The mine operator can play a significant role in the development and maintenance of social capital by investing in human capital, but also in the degradation of human capital (Bell, 2009). This is particularly important where a negative relationship between community resource dependence and human capital exists (Stedman *et al.*, 2004). Building human capital is important given the significant impact mine operations can have on new or established communities (Azapagic, 2004). Companies can invest in human capital by ensuring their employees have access to education, training career development opportunities – which also increase the competitiveness of the company (Ayres *et al.*, 1996; Azapagic, 2004), as well as supporting education and health initiatives in the wider community. These opportunities provide community members with a valuable legacy from the company, and contribute to strong labour-management relationships (Azapagic, 2004), which in turn build social capital within the community and between the community and the company. This social capital is based on trust, reciprocity and connectedness (Bell, 2009; Forrest and Kearns, 2001; Portes, 1998; Pretty, 2003; Putnam, 2000).

However, the positive relationship between increasing human and social capital is not always clear (Bell, 2009; Bury, 2004). Actions by mining companies that erode trust, reciprocity and connectedness detrimentally influence within-community and community-company social capital. Fruedenburg (Freudenburg, 1992) demonstrates that negative social capital is often associated with commodity price volatility and the company's cost-price squeeze. This is important in the context of peak minerals, where increasing difficulty and expense in mine production will surely contribute to declining economic viability in mineral and metal production.

Specifically, there are a variety of social issues that can be brought to communities where mining companies operate, which are listed in Table 7. Many of these issues interact to produce considerable cumulative impacts on communities and community members, but all can be addressed or mitigated by effective and collaborative mine planning and operation (ICMM, 2008; MMSD, 2002; Queensland Government, 2007). Of particular interest with respect to Australia, is the prevalence of Fly-In-Fly-Out (FIFO) operations.

Table 7: Issues and impacts associated with mining on the local scale (at the mine site)

Issue	Impact	Author
Failure to deliver economic benefits to community	• Lack of anticipated community development • Loss of trust in mining company, and community groups advocating mining • Inability to weather mine closure and post-closure impacts	(Artobolevskiy, 2003; Freudenburg and Wilson, 2002; Garvin *et al.*, 2009; Lockie *et al.*, 2009; Stedman *et al.*, 2004)
Income disparity	• Greater divide between mine workers and those from other sectors • Skilled labour shortages in other sectors • Disruption of social and culture structures within the community	(Artobolevskiy, 2003; Azapagic, 2004; Bury, 2004; Freudenburg and Wilson, 2002; Stedman *et al.*, 2004)
Inequality in employment	• Traditionally male-dominated • Less opportunity for women, Indigenous and other minority employees • Non-mine related service sectors suffer from an employee-drain	(Azapagic, 2004; Bell, 2009; Bury, 2004; Lockie *et al.*, 2009; Jones *et al.*, 2007)
"Fly-in/fly-out" and contractual employment	• Non community contractors filling jobs of local people • No investment in human capital within the community – implications for employment post mine closure • Loss of "sense of community" and community acquaintanceship • Male-dominated communities – anti-social behaviour attached to single male, high-income lifestyles	(Azapagic, 2004; Beach *et al.*, 2003; Ivanova *et al.*, 2005; Lockie *et al.*, 2009; Storey, 2001)
Land tenure	• Overtaking/destruction of arable land • Increased land/dwelling price	(Bury, 2004; Garvin *et al.*, 2009)
Health and welfare	• Health concerns during production or processing operations, and following closure due to local pollution • Social distress associated with exposure to dust, landscape changes, vibrations, loss of flora and fauna, and building damage • Disintegration of the connection between human health and ecosystem health • Preventable accidents and injuries reduce productivity	(Aron and Patz, 2001; Avery *et al.*, 1998; Conner *et al.*, 2004; Higginbotham *et al.*, 2007; Laurence, 2005)
Engagement in decision-making	• Loss of trust in decision-making processes • No participation in decision making – a key objective in sustainable development • Inability for community members to express community visions/goals	(Azapagic, 2004; Bell, 2009; Clark and Cook Clark, 1999; Esteves, 2008; Garvin *et al.*, 2009; Hamann, 2003; ICMM, 2009; Ivanova *et al.*, 2005; MCA, 2005; MMSD, 2002)
Psycho-social issues	• Loss of "social psyche" • Loss of sense of community • Loss of identity – connected to loss of employment, or relocation/closure of mining activities	(Bell, 2009; Lockie *et al.*, 2009; Smith *et al.*, 2008; Sharma, 2009; Avery *et al.*, 1998)

Lastly, protection of human rights is an extremely important social concern that must be considered in the sustainability of the minerals industry (Azapagic, 2004). Of all community groups, indigenous people have perhaps suffered most significantly from mining operations because their social and cultural structures and lifestyles are so different from those perceived to demonstrate wealth and well-being in non-indigenous society (Clark and Cook Clark, 1999; Hilson, 2002; O'Faircheallaigh, 2005). This is particularly true in the context of land tenure and unequal employment (Bury, 2004; Clark and Cook Clark, 1999; Smith *et al.*, 2008; Hilson, 2002). However, indigenous participation in the environmental management of mining projects on their traditional lands is increasingly considered an imperative in governance arrangements (Centre for Aboriginal Economic Policy Research, 2008; ICMM, 2008; MCA, 2005; MMSD, 2002; Mudd, 2008; O'Faircheallaigh, 2005; Brereton, 2003).

Nearest Neighbour Impacts

The resource rich nature of some localities means they are likely to experience the cumulative impacts of several mining operations (Franks *et al.*, 2009; Brereton, 2003). Whilst impacts to 'nearest neighbours' of mining operations usually refer to those near the fence line, impacts are also felt by nearby communities. How the communities subject to these cumulative, near neighbour impacts react has implications relating to the ability of the mining company to obtain their social license to operate (Stehlik, 2008).

Nearest neighbour impacts vary with the mining operation. In interviews and workshops with community members in a high-density mining locality, Brereton and Forbes (Brereton and Forbes, 2004) demonstrated that noise pollution, dust, water source pollution or conflict over water use, visual pollution (particularly in open-cut mining locations), and conflict over land use were the most important near neighbour impacts (Franks, 2007). While the community members recognised their dependence on mining as a foundation in the local economy, the cumulative impact of these mining side effects were sources of concern. The prospect of multiple mine closures would also cause considerable social and cultural upheaval in high-density mining areas (Franks *et al.*, 2009).

Recognising the importance of cumulative near neighbour impacts on changes in community attitudes and public perception towards mining operations is advantageous for mining companies (Franks *et al.*, 2009). By understanding and assessing these impacts "in the context of the interactions between the environment and society and all of the human-generated stresses" (Franks *et al.*, 2009, p 351), mining companies can ensure the impacts remain within acceptable levels. Where the mining industry does not take appropriate action to manage or mitigate these impacts, obtaining regulatory or community approval for mine expansion will be more difficult (Brereton and Forbes, 2004).

Mine or facility closure

Mines close for economic, geologic, geotechnical, and regulatory reasons, but also because of mechanical or infrastructure failure, or even community opposition (Laurence, 2006). As production moves from being cheap and easy to more expensive and difficult because of falling ore grades and reserves of minerals, economic reasons for closure will become more apparent. The negative consequences of mine closure will be felt first, and most significantly by those communities (of *place* and of *interest*) that have developed around them (Laurence, 2006; Rollwagen, 2007). Australia is littered with mining towns that have been abandoned following mine closure: Farina (South Australia), Cassilis (Victoria), Newnes (New South Wales), and Gwalia, Goldsworthy, Cossack and Wittenoom (Western Australia). However, this outcome need not be inevitable (for example, Newcastle following the closure of BHP's steel plants).

Economic implications

The establishment of mining activities generally brings many positive opportunities to a town – infrastructure, investment, jobs and population expansion (Laurence, 2006). However, these localised benefits are largely withdrawn when a mine closes (Jenkins and Yakovleva, 2006; Peck and Sinding, 2009; Warhurst and Mitchell, 2000; Rollwagen, 2007). Laurence (Laurence, 2006) identifies a range of social issues (for the individual, community and company) associated with mine closure including: job losses, loss of community support and company credibility, discord among community members, media headlines (public perceptions shift), loss of shareholder interest/investment, and delisting of the company from the share market.

Addressing issues associated with mine closure has not traditionally been a high priority for companies – there is little financial incentive. But with socially cognisant operations that address corporate social responsibility and fulfil the social license to operate, the closure phase is becoming more important (Peck and Sinding, 2009). Planning for mine closure has been increasingly incorporated into initial mine planning (Azapagic, 2004), but although these plans often address the environmental consequences of closure, fewer have considered the socio-economic impacts (PWC, 2001; Peck and Sinding, 2009). The incentive to adequately manage the mine closure phase comes in the form of positive public perception.

Planning for Closure

Meaningful planning for the environmental and social consequences of mine closure can lower closure and post-closure costs (Azapagic, 2004; Peck and Sinding, 2009). Companies that consider the ecological rehabilitation and ongoing social implications of closure in the mine's establishment and planning are better placed to cope with the financial burden these measures bring at the end of their operations (Wright and Vleggaar, 2006; Azapagic, 2004). Carefully planned and well-managed closure processes also demonstrate to surrounding community members that mining companies are operating as responsible corporate partners (Cesare and Maxwell, 2003).

Closure of mining or processing operations, at the local level, need not be entirely negative (Otchere *et al.*, 2004; Warhurst and Mitchell, 2000). In particular, where possible social, economic or environmental value is identified and added during the mine closure phase, the well-being of the community can be sustainably managed (Otchere *et al.*, 2004). However, this requires a corporate strategy that is both anticipative and pro-active (Warhurst and Mitchell, 2000). Otchere and colleagues (2004) note that while direct investment from mining companies in the communities where they operate may be limited, instituting mechanisms for local economic development during mine planning can allow the local community to benefit from new investment and growth.

In order to meet sustainable development goals mining companies are increasingly integrating social and economic aspects into mine closure plans (ICMM, 2009; MCA, 2005; MMSD, 2002). This is considered to be a key step in "transform[ing] mining investment into sustainable development" (MMSD, 2002, p xxi). Stakeholder involvement in these planning processes is seen an imperative, helping to identify and capture the requirements of the community (ANZMEC and MCA, 2000; Laurence, 2006; Otchere *et al.*, 2004; Peck and Sinding, 2009; Warhurst and Mitchell, 2000; Azapagic, 2004). It also helps to counteract the historically strained relationships between stakeholders and mining companies that have been characteristic of the (different, but slowly changing) past (Warhurst and Mitchell, 2000).

7.2.2. National issues

The contribution of the minerals industry to Australia's economic performance (measured using Gross Domestic Product) is significant, and our national mineral dependence extends beyond the monetary. Our political systems are closely tied to mining success (Pearse, 2009; Birrell *et al.*, 1982), possibly because the mining industry provides our most significant foreign trade opportunities (ABARE, 2009a; Access Economics, 2008; Willett, 2002). Australia's ability to exploit its vast mineral endowment has ensured strong growth in a neo-classical economic model sense (AusIMM, 2006). But while some consider the exploitation of natural capital to ensure the foundations of a thriving economy (Walker, 2001), others consider this dependence dangerous (Freudenburg and Wilson, 2002; Daly, 1996) – particularly from a wellbeing perspective (Costanza and Daly, 1992; Jackson, 2005; Sharma, 2009).

Illustrative social issues for peak minerals at the national scale are shown in Figure 31.

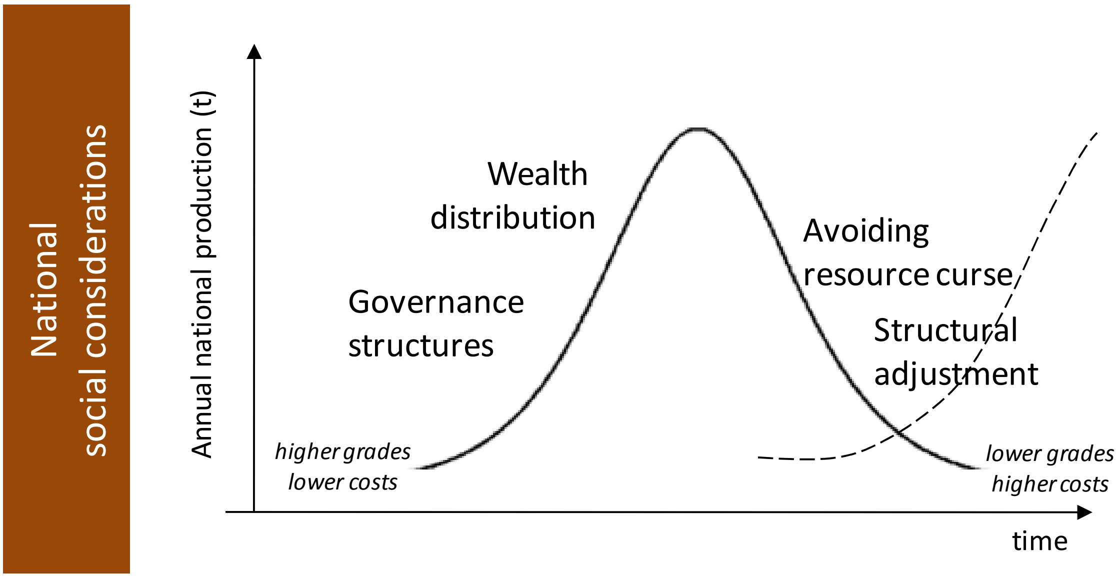

Figure 31: Illustrative social impacts of peak minerals at the national scale

Governance structures, permits and taxes

The stable governance structures in place in Australia reduce the uncertainty associated with developing new mining operations, relative to less stable overseas locations. The present situation Australia is however, complication by different laws and taxation arrangements in each state (AusIMM, 2006). Taxes in particular are the subject of current review (Henry Review).

Wealth distribution - how do regions benefit from mining?

Increasingly, society is questioning whether unchecked resource extraction is in the national interest (Clark and Cook Clark, 1999; Hamann, 2003; Jenkins and Yakovleva, 2006; Littleboy and Boughen, 2007; Sharma, 2009; Stedman *et al.*, 2004). If regions are experiencing fewer benefits, at a time when the mining industry is ever more dominated by large multi-national corporations (Brereton, 2003), with less direct connections within our society (through local investment or ownership), will the public continue to support mining expansion? Peak mining production is likely to intensify these issues, particularly if inadequate mine closure and post-closure planning means these costs are transferred to the wider society (Jenkins and Yakovleva, 2006; Laurence, 2006). More difficult and expensive production (because of regulation, environmental or social constraints) will likely result in increased economic protection for a struggling export industry competing on the world market. The costs of protecting an industry, which may no longer hold a comparative advantage, are also likely to be borne indirectly by society (Productivity Commission, 1991).

Moffat and colleagues (2009) showed that environmental and economic issues were perceived to be the key future drivers of the minerals industry through a survey of mining industry representatives. Given the connection between environmental concerns and increasing social pressure as a result of increased negative perceptions of the industry (Brereton, 2003), it is likely that public support for (perceived) unsustainable extraction activities is likely to fade.

Avoiding the resource curse

Avoiding the societal pitfalls that may follow resource dependence requires careful planning and macroeconomic management on the part of national governments (Larsen, 2006). The question of whether Australia may be suffering from 'dutch disease' or the 'resource curse' is the subject of some debate (Goodman and Worth, 2008; Hajkowicz *et al.*, 2009; Stevens, 2003). The potential threat that the resource curse poses to our economy, and society, makes it worth of further investigation and study. However, proposed remedies must be carefully considered: (Sachs & Warner, 1999) ask "which is worse: the natural resource curse, or the policy errors made as countries attempt to avoid the curse?"

Perhaps the clearest example of a single country avoiding the resource curse is that of Norway (Larsen, 2006; Stevens, 2003; Stevens and Dietsche, 2008; Wright and Czelusta, 2007). Larsen (Larsen, 2006) argues that Norway effectively avoided the resource curse through government regulation (wage centralisation, fiscal discipline and foreign investment, efficient industrial policy, transparent democracy and adequate monitoring) that effectively minimised rent-seeking activities – where resource-related interests attempt to realise benefit (legitimate and otherwise) from a resource endowment. The forethought that saw the establishment of these mechanisms has ensured Norway's national wealth from its oil production has been well managed.

Unlike Norway, Australian governments have consistently refrained from establishing mechanisms to avoid the resource curse. Indeed, governments have historically operated in a rent-seeking capacity by supporting the national minerals industry, often at the expense of other less competitive industries (Productivity Commission, 1991). Importantly, there may be evidence to suggest that Australia's historical escape from the resource curse may only be temporary, a pattern also observed in Norway (Larsen, 2006). Such patterns suggest a need to implement more significant or longer-term strategies that improve our chances of avoiding the economic and social consequences of resource dependence.

Structural adjustment and transition

Once mineral resources are exhausted, the national economy must find other income sources.

When looking to future transitions, Australia should consider that consumers are no longer willing to simply choose the least expensive option, where greater 'expense' (from a public perception point of view) is attributed to unethical or unjust corporate behaviour (Earthworks and Oxfam America, 2004; Sarin, 2006). While consumers traditionally chose on the basis of obtaining goods and services that provide 'utility' at the best price (Jackson, 2005), they are increasingly turning to products they know to be of ethical provenance (Pearce, 2002) – regardless of cost. Australia has the opportunity to position itself, not only with existing technology – but for embracing new technologies to unlock the next peak – as a country operating with high standards to meet the demands of a more discerning market by becoming more socially and environmentally responsible.

7.2.3. Global issues

Historically, the global mineral industry's capacity to produce minerals was largely based on economic capacity. Many of the most important decisions concerning exploration, production and mine closure were made through negotiations between governments and mining corporations, and centred around the key economic 'trade-offs' that determined the viability of an operation (Clark and Cook Clark, 1999). However, increasing social awareness of the importance of environmental and human rights issues is influencing global minerals operations and markets.

In contrast to Australian work (Moffat *et al.*, 2009), studies within the international mining industry have identified tenure and social issues as the two most important global drivers facing the industry at present (Clark and Cook Clark, 1999). Many of the issues occurring at the local or regional/national scales have implications on the global scale. As already noted, environmental disasters as a result of mining operations create international political incidents (Csagoly, 2000; Cunningham, 2005); poor labour relations between mine workers and their employers cause strikes and can halt production (Bell, 2009; Jones *et al.*, 2007); questionable corporate behaviour that result in human rights or social justice violations may influence the ability of a mine operator obtaining a social license to operate (Clark and Cook Clark, 1999; Hilson, 2002; Mudd, 2008; O'Faircheallaigh, 2005).At the global scale these impacts can result in negative public perception about mining and its products (Sarin, 2006).

Global social issues associated with differing stages of peak minerals are illustrated conceptually in Figure 32.

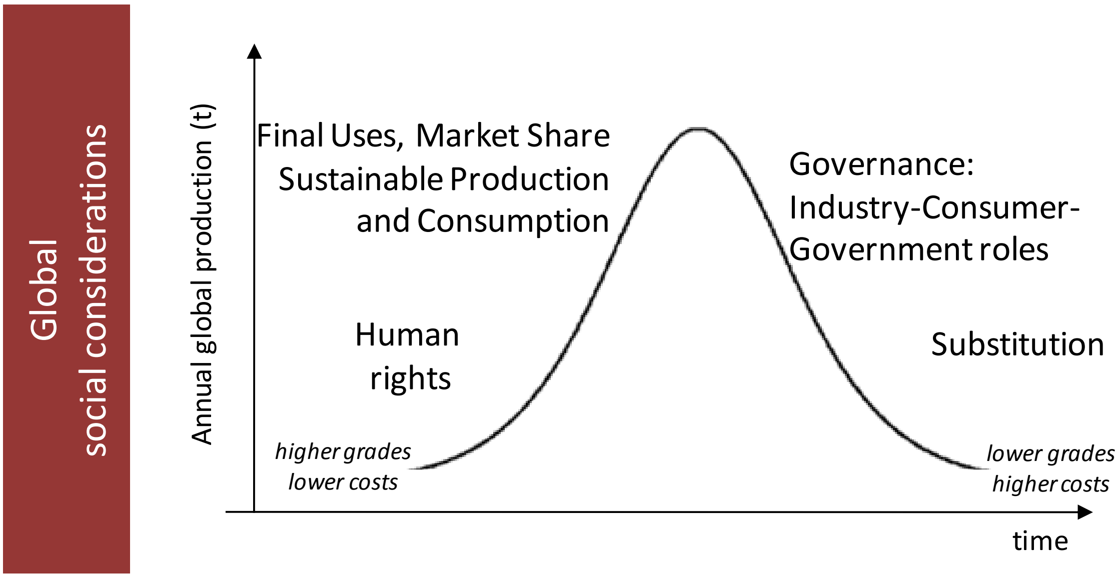

Figure 32: Illustrative social impacts of peak minerals at the global scale

Human rights

While many authors associate economic development with mine establishment and operation, there are many examples where the opposite has been the case (Freudenburg and Wilson, 2002; Bridge, 2008). Particularly in developing countries (Earthworks and Oxfam America, 2004; Hilson, 2002), but also in developed countries (Mudd, 2008), the mining sector lives with a history that has largely overlooked the cultures and values of the peoples its activities has sought to 'develop'. Indigenous and non-indigenous communities often have little recourse to challenge the mantra of economic development when it contradicts those cultures and values (Earthworks and Oxfam America, 2004).

In many parts of the world indigenous communities often do not hold legal title to the lands they live on. These people are vulnerable to eviction when mining is permitted by a central government: "eviction may be imposed without prior consultation, meaningful compensation, or the offer of equivalent lands elsewhere" (Earthworks and Oxfam America, 2004 , p 18). Land tenure conflict and violence can be exaggerated in countries where national wealth is tied to resource dependence, and where the wealthy minority exclude the poorer majority from gaining benefit from a resource existing in lands with contested ownership (Earthworks and Oxfam America, 2004; Papyrakis and Gerlagh, 2003; Shaxson, 2007; Stevens, 2003; Stevens and Dietsche, 2008).

National and international initiatives, like Enduring Value: The Australian Minerals Industry Framework for Sustainable Development (MCA, 2005), seek to address these past injustices by advocating stronger and more meaningful engagement with communities impacted by mining operations. In Australia, one benefit of greater engagement is the propensity to develop mine plans that benefit communities and corporations. While legislative pathways like the Native Title Act (1993) provide a means by which indigenous Traditional Owners can claim title to their traditional lands, and regulate land use, these outcomes are not guaranteed, and are often not mutually beneficial.

Sustainable production and consumption

Globally, there are initiatives aimed at fostering more sustainable patterns of production and consumption. For example, import regulations like the European Commissions Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation means minerals exporters must increasingly meet importers requirements, or find alternative markets for their goods. The ability of the minerals industry to anticipate and positively address these changing market requirements will determine their ability to remain competitive internationally.

Final uses, market share

The changes in what metals are ultimately used for globally and its link to technological product development in is also important. Where two competing metals can be used for the same application (e.g. copper or aluminium for carrying electricity), industry and industry associations compete to maintain market share.

Industry-consumer-government roles

Consumer activism and increased public scrutiny of the mining industry is beginning to influence the way the public purchases their TVs, mobile phones or cars (Walker and Howard, 2002; Esteves, 2008). Traditionally it has been very difficult for citizens (particularly from the developed countries) to connect minerals production with the products that make their lives possible and easy. In many ways, an awareness of the provenance of the minerals contained in their possessions has been thrust on them through the media – largely a result of environmental NGO activism (Hamann, 2003; Earthworks and Oxfam America, 2004; IUCN, 2003) and active community dissent (MAC, 2001).

The global minerals industry is by no means a stationary bystander watching as public perceptions, markets and regulation move around them. Industry initiatives (ICMM, 2008; MCA, 2005; NMA, 1998; The Chamber of Minerals and Energy of Western Australia, 2009; WAIAC, 2000) and corporate self-regulation (Brereton, 2003; Hamann, 2003; Hilson and Murck, 2000; Jenkins and Yakovleva, 2006; Welker, 2009) attest to their dynamic responses to global supply and demand of minerals.

The role of corporations in the development of activities like corporate sustainability reporting, and concepts like corporate social responsibility over the last twenty years has "encouraged increasingly comprehensive disclosure of the integrated environmental, social and health impacts of mining" (Giurco *et al.*, 2009 , p 20). The growing need to satisfy the corporation's social license to operate has encouraged both mandatory and voluntary regulation and reporting that is open and transparent (Jenkins and Yakovleva, 2006; Sampat and Cardiff, 2009).

Substitution

The idea that globally, we may run out of specific mineral and metals with particular uses which are more or less easily substitutable is framed around 'critical materials (for example tantalum in mobile telephones) (Graedel, 2009). The implications for Australia are twofold:

- **where Australia has** significant resources of globally critical material (e.g tantalum for which we account for half the world's production)
    - in what ways do we manage this resource differently from others which are non-critical?
    - how do geopolitical factors balance economic and other factors
- **where Australia demands** critical or non-substitutable minerals (such as phosphate for food production (Cordell *et al*., 2009) to assist our low phosphorus soils)
    - in what ways do we seek to manage this resource from others which are non-critical
    - again, how do geopolitical factors balance economic and other factors linked to long term national benefit.

SECTION SEVEN: SUMMARY

The social landscape in which the present-day minerals industry exists is changing. Past environmental incidents, human rights abuses and land tenure conflicts have meant that communities in Australia are becoming more concerned about amenity issues and less likely to accept at face value claims about the benefits of mining.

More significant social scrutiny also comes at a time when the mineral industry must manage the impacts of falling ore grades, increased waste, and the cost-price squeeze these pressures elicit. Although considered to be among the most complicated issues facing the sector at present, mining companies are responding through greater corporate responsibility, more transparent sustainability reporting, and self-regulation. Maintaining a social license to operate while addressing these environmental, social and production issues will remain a persistent driver for the industry into the future.

8. UNDERSTANDING AUSTRALIA'S LONG-TERM MINERAL WEALTH

This document has explored the concept of peak minerals in relation to Australia's dependence on its mineral endowment. In doing this it has examined the economic, technological, environmental and social implications and opportunities that will increasingly be presented to the mining industry in Australia. Ultimately, minerals will remain a key source of national wealth into the future. However, it will become more difficult to tie the mineral endowment to our national wealth without a significant re-conceptualisation of the ways in which we cost, value, sustain and manage resources that could conceivably ensure our wealth and prosperity into the future.

8.1. LINKING NATIONAL WEALTH TO MINERAL ENDOWMENT

Australia's future wealth from minerals can be understood within the framework provided in Figure 33. Our ability to realise persistent national wealth from minerals hinges on our ability to recognise that the **future drivers** of the industry are changing, and will present **new constraints and opportunities** for those organisations that plan for the consequences of **peak minerals**. Adequate planning can ensure the **benefits** from resource dependence are maximised, while the **impacts** are minimised.

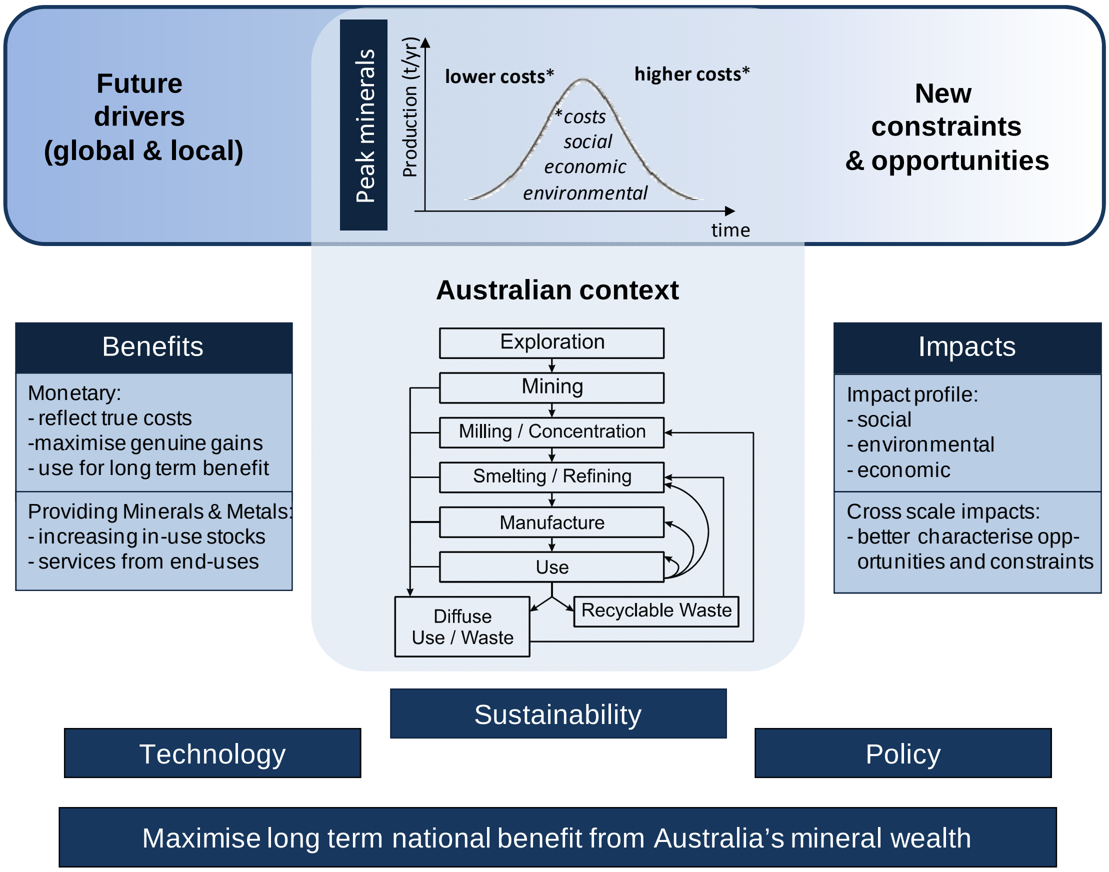

Figure 33: Maximising long-term benefit from Australia's mineral endowment by recognising the benefits and impacts associated with unmanaged resource dependence.

8.1.1. Benefits for the national economy

True cost and economic value

Realising monetary benefits from our mineral endowment into the future requires a re-appraisal of what resource value means, and how cost is characterised within this meaning. Re-valued resources must **reflect the true costs** of production. For example, early stages in the mineral production chain (extraction and processing) have significantly higher environmental and social costs than later stages. Addressing this disparity through technological, operational or managerial advancement to minimise these costs will yield both environmental and social benefits, but will also **create economic value** from these hitherto undervalued stages.

Genuine gains for long-term benefit

Properly characterising the true costs of production will ensure an understanding of how these costs arise, and what impact they have on the economic viability of the minerals industry. **Maximising genuine gains** from minerals will become a key indicator of the industry's economic performance. **Declines in national stocks of mineral ores must also be accounted for more thoroughly.** Where profit-loss statements and healthy dividends have traditionally demonstrated wealth from minerals, future returns must also cover the expenses incurred while creating this form of wealth. Internalising the non-economic costs of mineral production attributes *new value* to these resources, and increases the likelihood that these resources are **utilised for long-term national benefit**.

Valuing In-use stocks and end-use services

Understanding the true costs of mineral production, and re-valuing our mineral wealth ultimately influences our capacity to provide minerals and metals to market. As the economic, environmental and social costs of traditional minerals and metal production increase with peak minerals, **in-use stocks will become more valuable**. Our ability to realise this value through investment in recycling and re-processing technologies for existing products will yield significant national benefit: both in the contexts of ethical consumption and international competition from countries already acting to realise the value of in-use stocks. Re-valuing these product-bound resources will also promote the necessity to **realise end-use services** for providing long-term access to minerals *and* national wealth without relying solely on traditional resource extraction.

8.1.2. The implications of mineral resource dependence

The changing impact profile

The need to acknowledge the triple bottom line paradigm (economic, environmental and social pressure) has long dominated discussions concerning sustainable development. However, the relative importance of the factors identified within this paradigm are changing as we approach peak mineral production. **Mining is becoming more expensive** as we mine deeper, lower grade ores, in new, sensitive or remote areas. These changes are accompanied by **growing environmental impacts** and the costs associated with these impacts. More expensive mining, and more intense environmental impacts result in **significant social flow-on effects**. Peak minerals is changing the environmental and social impact profiles of traditional mining, and these changes will drive production costs higher still.

Characterising cross-scale impacts

The Australian mining industry is dominated by multi-national organisations trading commodities on international markets. Our state governments administer the operations of these companies, and federal macro-economic policies largely promote mineral exploitation.

Yet all mining operations are conducted at the local scale. Our mineral industry is strongly demarcated in the context of scale. Acknowledging and characterising the cross-scale impacts of mining provides an avenue to **identify the opportunities and constraints** peak minerals will pose at each of these scales. This is extremely important given that the onset of peak minerals is likely to have a dramatic influence on the actual impacts of mining at particular scales, but also on the intensity of these impacts. Characterising these impacts will ultimately contribute to our ability to **manage and mitigate their consequences**.

8.2. MAXIMISING LONG-TERM NATIONAL BENEFIT FROM AUSTRALIA'S MINERAL ENDOWMENT

The concept of 'Peak Minerals' describes a paradigm that parallels most of Australia's mineral production: from easy and cheap in the industry's infancy, to harder and more expensive now and into the future. The concept helps to frame a discussion concerning the management of Australia's mineral endowment, and the wealth it provides to our society. This review paper has explored the concept of peak minerals in the context of Australia's mineral industry. It has examined the implications of peak mineral production by exploring its economic, technological, environmental and social implications for the industry and for Australia's long-term wealth. Maximising long-term benefit from mineral wealth will require a three-pronged solution: resource management for sustainability; investment in new technology; and, new policy direction.

8.2.1. Seeking sustainability

Mineral production is currently unsustainable, not primarily because of resources being finite, but **because of impacts associated with processing and use**. The concept of peak minerals raises the spectre of resource depletion, and the necessity to begin to plan for transition in the way we produce (through recycling) and use and reuse (sustainable design and extended producer responsibility) minerals in our society. Supplementing traditional production with alternative mineral and metal sources will contribute our ability to maximise long-term wealth from minerals by:

- Reducing our national economic dependence on in-ground mineral resources and boosting the activity and competitiveness of secondary (and tertiary) sectors that establish to realise value from in-use stocks and end-use mineral services.

- Avoiding or minimising many of the environmental and social implications of traditional mining that are reducing the nation's genuine gains from exploitation of our mineral endowment.

8.2.2. Diversifying technological solutions

The consequences of peak minerals will intensify the social/environmental cost-price squeeze. **Economic pressure drives technological advancement**, so finding technological solutions (mechanical and conceptual) to social and environmental issues will become increasingly important in the context of long-term national benefit from the mining sector. Rather than being constrained by social, environmental and economic pressure, investment in technology that addresses or mitigates the social or environmental costs of mining will begin to **yield profitable outcomes** for mining companies.

8.2.3. Establishing a renewed vision and appropriate policy

Australia's mineral endowment has contributed significantly to our national wealth and development, and should continue to do so into the foreseeable future. However, heavy dependence on natural resources presents benefits and threats for national wealth.

In this context, **Australia must renew its vision for the minerals industry and associated technologies which underpin its performance**.

Effective macro-economic policy that simultaneously ensures **long-term productivity** from our mineral endowment, while encouraging mineral **exploitation from alternative sources** will be necessary contribute to maximising Australia's long-term national benefit.

The challenge is summarised in a 2009 speech entitled *The Shape of Things to Come: Long Run Forces Affecting the Australian Economy in Coming Decades,* by Secretary to the Treasury, Dr Ken Henry. He stated:

> *"...the re-emergence of China and India which, because of its implications for global commodities demand, has conferred on Australia a large boost to its real wealth; but, at the same time, set up a set of structural adjustments that will challenge policy makers for decades. And it, too, implies a very substantial increase in our rate of investment.*
>
> *Had these forces hit the Australian economy of the 1960s, 1970s or 1980s, the prospects of our finding a sustainable growth path would have been remote. In particular, the current account would quickly have emerged as a binding constraint on our capacity to access the higher levels of investment capital needed to adjust. But these forces are hitting now; at a time when we have implemented 25 years of economic reforms; when the Australian economy has just demonstrated to the rest of the world that, for some time now, it has quite possibly been the best governed, most flexible, most resilient of all industrialised economies; when there is unprecedented global interest in us; and when there is, domestically, a strong appetite for further policy change.*
>
> *Yet all of these changes will test the limits of sustainability; economic, social and environmental. It will only be by recognising those limits and adjusting policy accordingly that this generation will be able to say with confidence that it will hand to its children and grandchildren an even higher level of wellbeing; an even greater capability to choose lives of value".*

GLOSSARY

Term	Definition
AusIMM	The Australasian Institute of Mining and Metallurgy
Balance of payments	The balance of a nation's exports, imports, income and capital flows in a given period.
By-product	A product so unimportant that its price has no influence on a mine's output (cf. co-product).
Comparative advantage	An economic theory, first developed by 19th-century English economist David Ricardo, that attributed the cause and benefits of international trade to the differences among countries in the relative opportunity costs of producing the same commodities.
Consumption	The process of individuals, households, business and government using up goods and services.
Corporate social responsibility	A corporate obligation to society to conduct their mining operations in a socially, environmentally and economically sustainable way.
Cost-price squeeze	The narrowing of profit margins as production costs increase relative to commodity price.
Cumulative impact	The combined impacts from mining on society, and particularly near-neighbours
Cut-off grade	The lowest grade, or quality, of mineralised material that qualifies as economically mineable and available in a given deposit. May be defined on the basis of economic evaluation, or on physical or chemical attributes that define an acceptable product specification.
Depletion	The act of exhausting a resource's abundance
Dutch Disease	The effects arising from the co-existence of booming and lagging sectors in an economy, which often brings significant structural adjustment, typically following the discovery and initial exploitation of major new resources.
Economic growth	The growth in total production over a given period or in *per capita* production of the average citizen over a given time period.
Economic scarcity	As a resource becomes depleted the costs associated with its production increase. When these cost become too high, the resource can no longer be obtained profitably.
Economic sustainability	Sustaining improvements in human living standards or human material well-being.
Final product	A product that is produced for its final user and not as a component of another good or service.
Financial capital	Those assets of an organisation that exist in a form of currency that can be owned or traded, including (but not limited to) shares, bonds and banknotes. Financial capital (shares, bonds, notes and coin) reflects the productive power of the other types of capital.
Fly-in, fly out (FIFO)	A working pattern in mining operations involving working travelling long distances from their normal residences to remote locations, working several days at the site where food and accommodation are provided, and then travelling home for several days of leave.
Grade	Any physical or chemical measurement of the characteristics of the Analysis (Value) material of interest in samples or product. Note that the term quality has special meaning for diamonds and other gemstones. The units of measurement should be stated when figures are reported.

Gregory Effect	Occurs when international demand for a commodity causes the value of the trader's currency to rise, which ultimately makes imports cheaper, but reduces the competitiveness of other exporting sectors.
Hotelling Rent	Hotelling rent is defined as the rent that exists on the marginal quantity of an exhaustible resource (price minus marginal cost) and it is considered a measure of the inter-temporal scarcity of that resource. It is interpreted as the portion of profit that accrues to extractive firms because they are mining an exhaustible resource.
Human capital	Human capital incorporates the health, knowledge, skills, intellectual outputs, motivation and capacity for relationships of the individual. Human Capital is also about joy, passion, empathy and spirituality.
***In-situ* price**	see Nett Imputed Value *in-situ*
Intergenerational equity	Concern about whether depletion of mineral resources leaves future generations without the ability to earn comparable levels of income because the asset stock inherited by future generations is diminished.
JORC Code	Australasian code for standardised reporting of mineral resources and ore reserves which is prepared by the Joint Ore Reserve committee (JORC)
Laterite	A rock product forming in response to a set of physiochemical conditions, which include among other things iron-containing parent rock and a well-drained terrain.
Long run	The period within which all the market conditions facing a mining firm can change).
Main product	A product so important to the economic viability of a mine that its price alone determines a mine's output. (see also **by-product**).
Manufactured capital	Manufactured capital is material goods and infrastructure owned, leased or controlled by an organisation that contribute to production or service provision, but do not become part of its output.
Market share	Obtaining and holding a nominated percentage of a mineral market, a common corporate objective of many large and small mineral producers.
MCA	Minerals Council of Australia
Mineral Reserves	Subsurface mineral deposits that are known and profitable to exploit, given existing technologies and prices.
Mineral Resources	Mineral reserves; together with deposits that are: economic but not yet discovered; or expected to become economic as a result of new technology or other developments within the foreseeable future.
Natural capital	The stock of environmentally provided assets such as the soil, minerals, the atmosphere, the forests, wildlife and water.
Non-renewable resource	A resource with a rate of natural replenishment that is so low that it does not provide any hope of replenishment within a reasonable time period.
Secondary scrap	Products that have reached the end of the useful lives from which metal can be recovered.
Opportunity cost	In economic terms, the opportunities forgone in the choice of one expenditure over others. The concept of opportunity cost allows economists to examine the relative monetary values of various goods and services.
Ore	A natural aggregation of one or more minerals that can be mined, processed, and sold at a profit.
Ore reserves	'Ore Reserves' is preferred under the JORC Code but 'Mineral Reserves' is in common use in other countries and is generally accepted.

	Other descriptors can be used to clarify the meaning e.g. coal reserves, diamond reserves etc.
Peak minerals	A framework in which geological and non-geological constraints on mineral production are considered in terms of their effect on economic, social and environmental systems.
Production	The process of converting economic resources to useful final goods and services.
Real Price	As with many other economic terms, the use of the word 'real' indicates that the effects of inflation have been considered.
Renewable resource	A resource that can be replenished naturally with the passage of time.
Resource Curse	The situation where natural resource abundance is negatively related to an economy's economic performance.
Resource Rent	A tax that seeks to identify economic rents by allowing the deduction of all costs of production from revenue, including normal profit, and then taking a share of any resulting rents (see also resource rent tax).
Self-regulation	The propensity of corporations to adopt informal regulatory actions aside from formal regulations imposed by government.
Services	In most countries, the share of economic activity accounted for by services rose steadily during the 20th century at the expense of agriculture and manufacturing. More than two-thirds of output in OECD countries, and up to four-fifths of employment, is now in the services sector.
Shadow price	The true economic price of an activity. Shadow prices can be calculated for those goods and SERVICES that do not have a market price, and are often used in cost-benefit analysis, where the whole purpose of the analysis is to capture all the variables involved in a decision, not merely those for which market prices exist. (see also **opportunity cost**)
Social and cultural sustainability	Fairness in the distribution of benefits and burdens associated with economic activities to all participating interest groups.
Social capital	The ability of members in a group to secure benefits from that membership. For example networks, communication channels, families, communities, businesses, trade unions, schools and voluntary organisations as well as social norms, values and trust.
Social license to operate	Corporately responsible miners are permitted to operate through informal social regulation (by local communities, interested citizens and shareholders). Corporations invest in an operational reputation bound to the concept of a social license to operate.
Substitute good	A good that can be used as an alternative to another good because it possesses a similar range of attributes.
Sulfides (or Sulphides)	Any member of a group of compounds of sulfur with one or more metals. Most … sulfides are simple structurally, exhibit high symmetry in their crystal forms, and have many of the properties of metals, including metallic lustre and electrical conductivity. They often are strikingly coloured and have a low hardness and a high specific gravity. Sulfides are the ore minerals of most metals used by industry, as for example antimony, bismuth, copper, lead, nickel, and zinc. Other industrially important metals such as cadmium and selenium occur in trace amounts in numerous common sulfides and are recovered in refining processes.
Terms of trade	The ratio of the prices of the goods and services that a nation exports to the price of the goods and services that it imports.

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APPENDIX A

To be consistent with the Australian mining industry, this report adopts the specific Joint Ore Reserves Committee (or 'JORC') Code definitions. Based on the JORC Code, the analysis and reporting of ore reserves and mineral resources for the mining industry have very specific and statutory meanings:

Mineral Resources

A 'Mineral Resource' is a concentration or occurrence of material of intrinsic economic interest in or on the Earth's crust in such form, quality and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade, geological characteristics and continuity of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge. Mineral Resources are subdivided, in order of increasing geological confidence, into 'Inferred', 'Indicated' and 'Measured' categories.

- *Inferred Mineral Resource* – that part of a Mineral Resource for which tonnage, grade and mineral content can be estimated with a low level of confidence. It is inferred from geological evidence and assumed but not verified geological and/or grade continuity. It is based on information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes which may be limited or of uncertain quality and reliability.

- *Indicated Mineral Resource* – that part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a reasonable level of confidence. It is based on exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. The locations are too widely or inappropriately spaced to confirm geological and/or grade continuity but are spaced closely enough for continuity to be assumed.

- *Measured Mineral Resource* – that part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a high level of confidence. It is based on detailed and reliable exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. The locations are spaced closely enough to confirm geological and grade continuity.

Ore Reserves

An 'Ore Reserve' is the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined. Appropriate assessments and studies have been carried out, and include consideration of, and modification by, realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting, extraction could reasonably be justified. Ore Reserves are subdivided in order of increasing confidence into 'Probable Ore Reserves' and 'Proved Ore Reserves'.

- *Probable Ore Reserve* – the economically mineable part of an Indicated, and in some circumstances, a Measured Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined. Appropriate assessments and studies have been carried out, and include consideration of and modification by realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors These assessments demonstrate at the time of reporting that extraction could reasonably be justified.

- *Proved Ore Reserve* – the economically mineable part of a Measured Mineral Resource. It includes diluting materials and allowances for losses that may occur when the material is mined. Appropriate assessments and studies have been carried out, and include consideration of and modification by realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting that extraction could reasonably be justified.

In concept, the relationship between resources and reserves and the level of confidence in the estimates are shown in Figure 34 (see also a recent article by Lambert *et al.*, 2009))

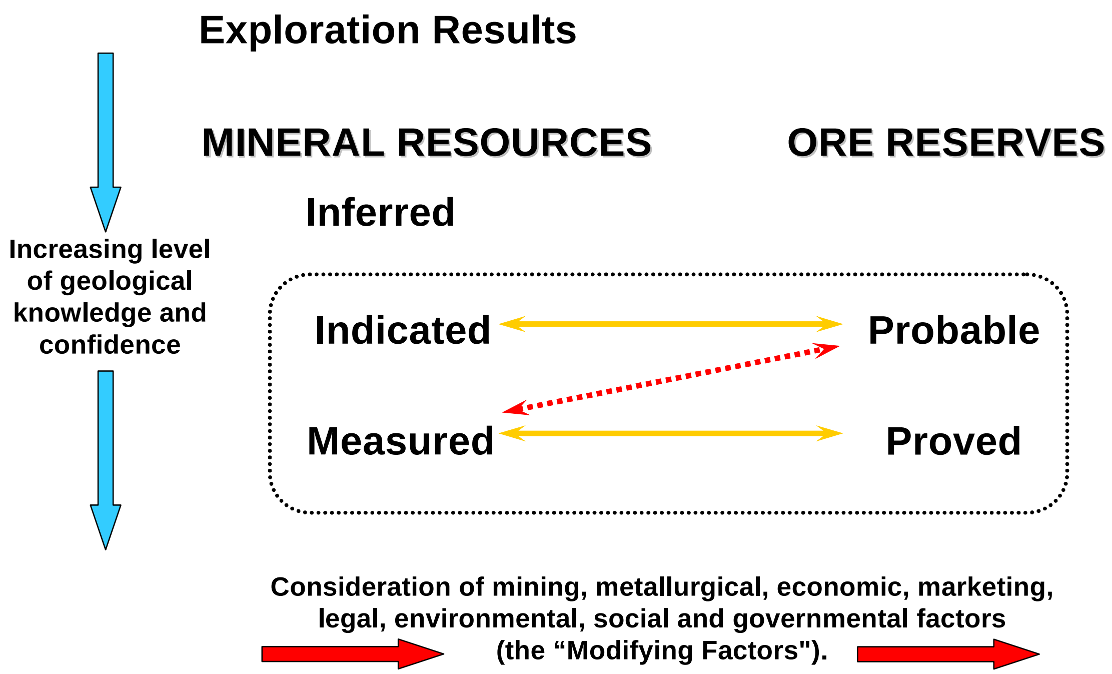

Figure 34: The relationship between mineral resources and ore reserves under the JORC Code (AusIMM *et al.*, 2004)

The USGS 'McKelvey' System

The US Geological Survey classifies minerals based on a very broad concept of economic, marginal and sub-economic resources. Their system is based on the early work of McKelvey, and has different meanings to those used by the JORC Code. The USGS system is explained in their annual reports, such as the Mineral Commodity Summaries (USGS, var.-a) or Minerals Yearbook (USGS, var.-b). The main categories used are 'reserves' and 'reserves base':

- *Reserves* – that part of the reserve base that could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system.

- *Reserves Base* – That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently sub-economic (sub-economic resources). The term 'geologic reserve' has been applied generally to the reserve-base category, but it also may include the inferred-reserve-base category; it is not a part of this classification system.

Note on Terminology for Reserves & Resources

As stated earlier, to be consistent with the Australian mining industry, this report adopts JORC Code definitions. However, given a broad audience for this report and the fundamental role of resources with respect to 'Peak Minerals', we note the following:

- specific reference to ***reserves*** are not used in this report– as this is too close to 'ore reserves' and could create confusion. The USGS system is noted, but only discussed with reference to the JORC system.
- all mentions of ***resources*** are left as a generic use of the word 'resources'. When required, the specific term of *mineral resources* is used when discussing potentially mineable deposits and ores – provided it is line with the JORC definition.