INNOVATION AND GROWTH – KEEPING PACE IN A VIRTUOUS CYCLE

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ABSTRACT

The first decade of the 21st century was one of fundamentally changed dynamics for the minerals industry. Following intense globalization commencing in the late 20th century production is now concentrated into large businesses that can compete across geography in diverse commodities. Asian industrialization and urbanization is now the main driver of growth in demand for energy and materials. Demand for the output of these industries has risen sharply, reversing decade long trends to reduced real commodity prices. Supply responded with expansions of existing mining and processing operations, and large investment in new resource development. Development of new, lower grade or more remote resources was stimulated.

Resource development by global entities in frontier environments reinforced the importance of effective forms of social contract, and of stronger environmental performance. The worst economic shock in decades provoked no significant pause despite large impacts on corporate ownership. State owned enterprises commenced unprecedented foreign direct investment in minerals and energy resources. A thrust towards resource nationalism re-emerged as governments sought to ensure that the export of state owned resources contributes more strongly to government revenue, reducing the burden of trade in scarce resources on other trade-exposed sectors.

The unprecedented combination of forces at work has made future predictions difficult, with day-by-day volatility in anticipated corporate fortunes, and investment plans.

The challenge for process innovation (and for exploration) has been to keep up, maintaining a lid on costs as lower grade and more challenging ore bodies are brought on quickly in a context of competition for land use, community expectations and continued care for natural and living environments. While new projects have provided the necessary platforms for implementation of innovative approaches, there is evidence that a gap may have emerged between the pace of growth and the pace of innovation.

The history of a century of process innovation in the context of growth of output, declining resource grades and commodity prices is presented. The necessary conditions for accelerated process innovation are considered, and future needs and approaches are discussed.

Keywords: process innovation, resource development

INTRODUCTION: INNOVATION IN THE MINERALS INDUSTRY

The minerals industry has a unique combination of characteristics that differentiate it from most other industries. Generalizing from keys to success in other industries into the minerals industry is difficult, other than at the broadest and least useful level of detail.

There is no other industry that has the following combination of characteristics:

- very long product lifecycles (with some mineral and metal commodities having been traded for millennia),

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- high capital intensity, (with capital, finance, and energy related costs typically dominating net cash outflows for production),
- a finite resource base underlying each investment, with high asset redundancy at depletion,
- very long capital cycles (typically from 8 to more than 20 years), relative to business cycles
- relatively short business cycles, and
- fixed costs that are high relative to movements in revenue (high Beta).

These characteristics imprint a particular complexion onto the march of innovation in the minerals industry (refer Figure 1).

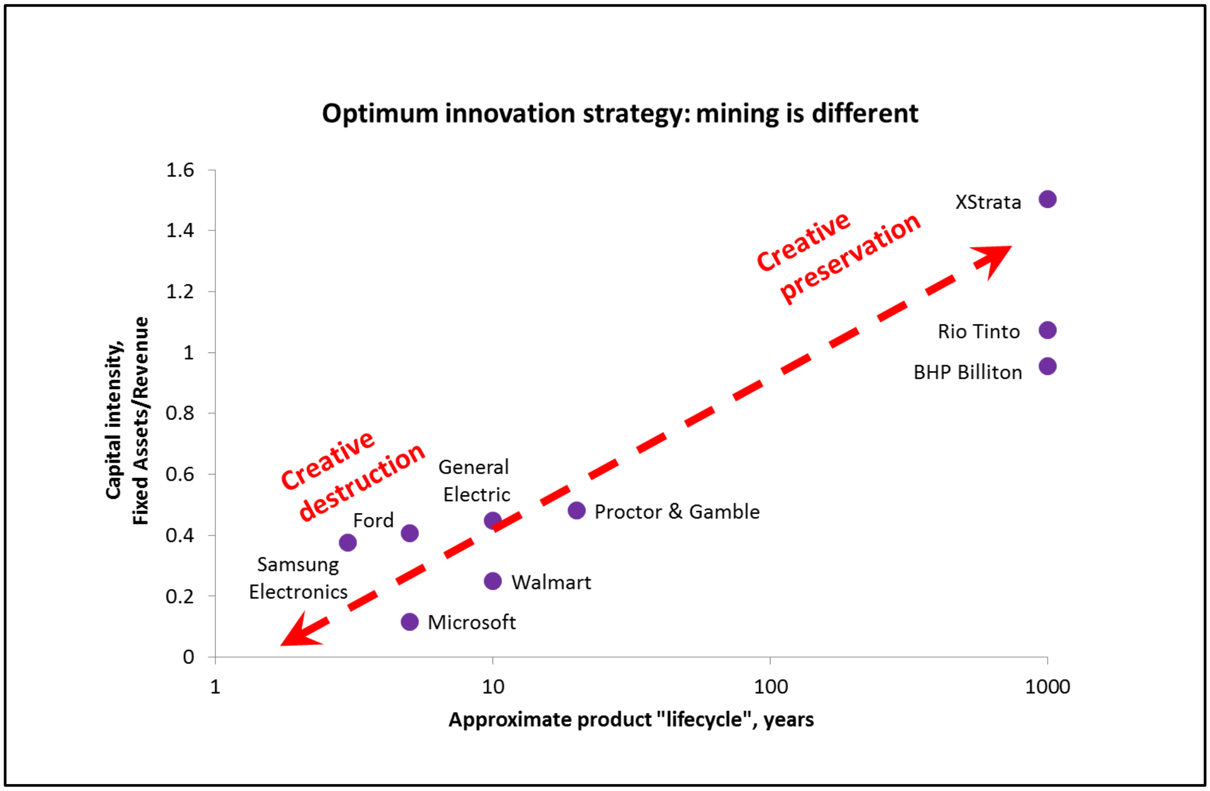

Figure 1. Capital intensity and product lifecycle impact innovation strategy (Co. annual reports, 2011)

Surviving mining companies don't exhibit the short cycle "creative destructionist" approaches that characterize successful manufacturing, electronics, communications, and software industries. The unique characteristics of the minerals industry better support "creative preservation" approaches. Short cycles to capital replacement aren't rewarded with a revenue premium. Smarter ways to lengthen asset life, reduce fixed costs and increase production rate at low incremental capital invested work to create shareholder value in a mining company in the same way that reinvention works in other industries. For successful mining companies, this approach to shareholder value is instinctive.

Where the innovation that seems to strongly drive the fortunes of other industries is product, function, and service related, innovation in the minerals industry is focused on better planning, materials movement, and processing, and is mainly characterized by incremental improvements, occasionally punctuated by development of significant new platforms (Peterson et al., 2001). Where significant new platforms are developed, the requirement for large-scale prototyping and unavoidable risk in final implementation associated with process innovations results in high costs and long lead times from concept to first full scale implementation, and even longer for industry penetration to mature.

It was only just over twenty years ago, after decades of annually declining real commodity prices and low growth in profits that investors in post-industrial societies considered that mining may have permanently lost its sheen (Houston et al, 1984). At the growth rates that were available at that time, coupled with increased recycling and emerging substitution by new materials, it wasn't seriously considered that the supply of primary materials could be materially limited by scarcity of natural resource projects, production capacity of developed mines, overtaxed infrastructure, or shortage of skills.

By the mid 1990s, reduced impediments to international movement of capital, coupled with technological advances enabling fast communication, resulted in a major shift in corporate focus from particular geographic concentration with organic growth via greenfields exploration and project development, to geographical diversification with growth by acquisition and brownfields expansion. Industry rationalization occurred at a fast pace, for the most part without regard to national borders. Local or regional companies that were once household names were subsumed. Efficiencies of scale and the exigencies of competition replaced a former diversity of industry participants with large, diversified global enterprises. It was understood that a successful mining company would be based on "new competencies" that enabled it to be welcomed by individual communities and governments globally (Harvey, 2002).It is no coincidence that the International Council on Mining and Metals (ICMM) was first established at about this time (in 2001) with the aim of improving the sustainable development performance of the mining and metals industries (ICMM).

Industry rationalization in the context of ongoing pressure on margins from declining commodity prices, and opportunities for growth by acquisition and brownfields expansions in global markets caused a fundamental shift in the way mining companies managed sustaining activities like greenfields exploration and research and development. Investment in both greenfields exploration and research and development fell sharply, in what was seen by some to create a risk of slowed improvement and renewal for established resource companies.

- A well-researched summary of minerals industry economic context at the time (Humphreys, 2002) concluded with some "present realities":
- fewer, bigger, more focused companies
- better returns for acquisition than exploration
- better capacity management through the down-cycle
- greater geopolitical risks
- need for more rigorous assessment of investments
- declining long run prices.

The legacy of this relatively recent history has not all been overwritten by events since. For example, effective strategies based on acquisition and progressive brownfields expansion of large, long life, competitive resources supporting large sector positions are consistent with this world view.

Greenfields exploration (with research and development) remains largely "outsourced" by now more concentrated global mine operators and developers (Australian government, 2010), while the principles of sustainable development, especially including social development, have been globalised and internalized. However, those who may have quite reasonably accepted that the multi-decade trend of declining long run prices and cautious investment would continue were soon to be caught short.

Just over ten years later it is sometimes difficult to imagine that these were only recently the dominant forces at work in the mining industry. Since 2003 growth in demand for primary materials has transformed markets, pushing up real commodity prices to levels not seen in 40 years, and creating a boom in capital projects for supply of minerals and primary energy that was largely unexpected, at most pausing briefly through the largest economic shock since the great depression.

Rapid and centrally planned urbanization and industrialization of highly populous, previously agrarian economies, primarily China, has changed the dynamics of the minerals industry. Even where Chinese imports represent only a small proportion of total global consumption there has been a fundamental shift in industry fortunes as growth in demand-outstripped growth in supply in most commodities. An example of this shift is the move to market clearing price mechanisms for rationing supply to demand in bulk commodities (in place of "capacity management").

The power of this shift has been sufficient to create a "two speed economy," not just internationally, but nationally and regionally. Changing terms of trade and capital inflows in resource rich economies, coupled with skills shortages, have pushed up the costs of supply to importer economies, and reduced the competitiveness of other trade-exposed industries. It can seem ironic that countries having the largest relative economic contributions from minerals and energy exports become less cost competitive even in those industries, as a result of their strong competitive endowment.

It's sobering to see "the curse of the mine" becoming a nationally debated phenomenon, with increased direct and indirect moves towards "resource nationalism", for redistribution of benefits. For global mining companies, sustainable development has a new "national economy" focus. While mineral and energy resource development has long been demonstrated to have impacts on the competitiveness and stability of national economies, this is perhaps the first time, with high growth coinciding with an already globalised and concentrated industry, that individual "stateless" mining companies are identified as having those impacts, even in developed economies.

Maintaining a "welcome and invited" status for minerals and energy developments becomes more difficult when it is perceived that gains in one part of the economy are offset by losses in others.

It is clear that the minerals industry was "geared up" for low growth in output, with competition for low cost positions based on acquisition and progressive brownfields growth that crowded out greenfields opportunities. It then experienced a "black swan" shock, as trends diverged from the industry's normal volatility.

Opportunistic greenfields entrants with bullish views on pricing and ready access to capital based on a resource endowment challenged positioning strategies based on the superior cost base of brownfields expansions. For existing producers brownfields and nearby resource potential that underwrote cost-based advantage now became an opportunity to compete for growth. Ready availability of cash supported by inflating asset values fuelled large capital expenditures. Competition for strategic positions having large, long life resources from which fast growth could be launched produced an unrealistic market in acquisitions that eventually resulted in large write-downs, sometimes with changes in corporate ownership, when the next "black swan" shock of the global financial crisis arrived.

It seems that in the last decade the pace of change and growth, with its overlay of both volatility and unpredictability, has frequently outstripped the ability of the mining industry to adjust effectively. Nevertheless, growth in industry output has occurred relatively unimpeded by its accompanying impacts on other industries, regions, and economies. In that sense we can say that the industry has been sustained. We might expect growth in demand for primary materials and energy to be sustained for some time, given well-known correlations between the inventory of materials in use and human well-being.

It is rather more difficult to conclude that future output and continued growth in output will be sustainable for our industry and our businesses. For example, currently slowed growth is already creating an adjustment to industry valuations. The required support for use of land and water for new mining developments can be impacted by perceptions of lack of distributed benefits in the local and general communities.

In the minerals industry sustainable development is as much as anything about the removal of trade-offs. Trade-offs require that improvement in one goal comes at a cost to performance in some other indicator. Our instinct that there are trade-offs comes from our common experience of working within well established, constrained and relatively closed systems (e.g. a mine having established resources, fixed capital installations, environmental approvals, employment systems and supply lines and infrastructure). It is these trade-offs, driving the perception and at least occasional reality that gain comes with net loss to someone, that create competition amongst interests and erode trust. While optimization of any already constrained system of conversion of inputs to outputs must eventually hit a trade-off, there is no long-term constraint to continue to use that system. Removing constraints is at the heart of the link between sustainable development and innovation.

It has long been known that the greatest opportunity for gains in business value from new mine and processing installations resides in iterative processes of systems design and redesign that occur prior to a final investment decision. That is, before constraints are embedded in capital installations that must be long lived.

Industry development that sustains our businesses by supporting growth in primary materials delivery without trade-offs eventually requires systems change-out. Systems change-out requires innovation. Because individual mines are based on finite resources, and must eventually be closed and rehabilitated, the sustainable business of mining is the sustainable development of new mines. New mines having new challenges (e.g. lower grades, more overburden) provide the business platforms and imperative (lower grade without higher cost or unacceptable footprint) for the implementation of new approaches. The story of sustainable growth in the minerals industry is therefore the story of innovation that is embedded in new mines and processing operations. The more this innovation is at the "whole platform," new systems level the more likely it is that trade-offs affecting sustainability will be resolved.

While intuitive for many, the linkage between innovation that resolves trade-offs and the sustainability of future mining and processing operations has been established by objective studies conducted on behalf of business/government partnerships (Herbertson, 2005).

It was found in the diverse innovation projects of two global mining organizations (refer Figure 2) that the more these projects worked towards "whole new platforms" and at the root cause level (rather than merely progressively treating and trading symptoms via add-ons) the more it was possible to achieve new standards of environmental, human and economic outcomes simultaneously.

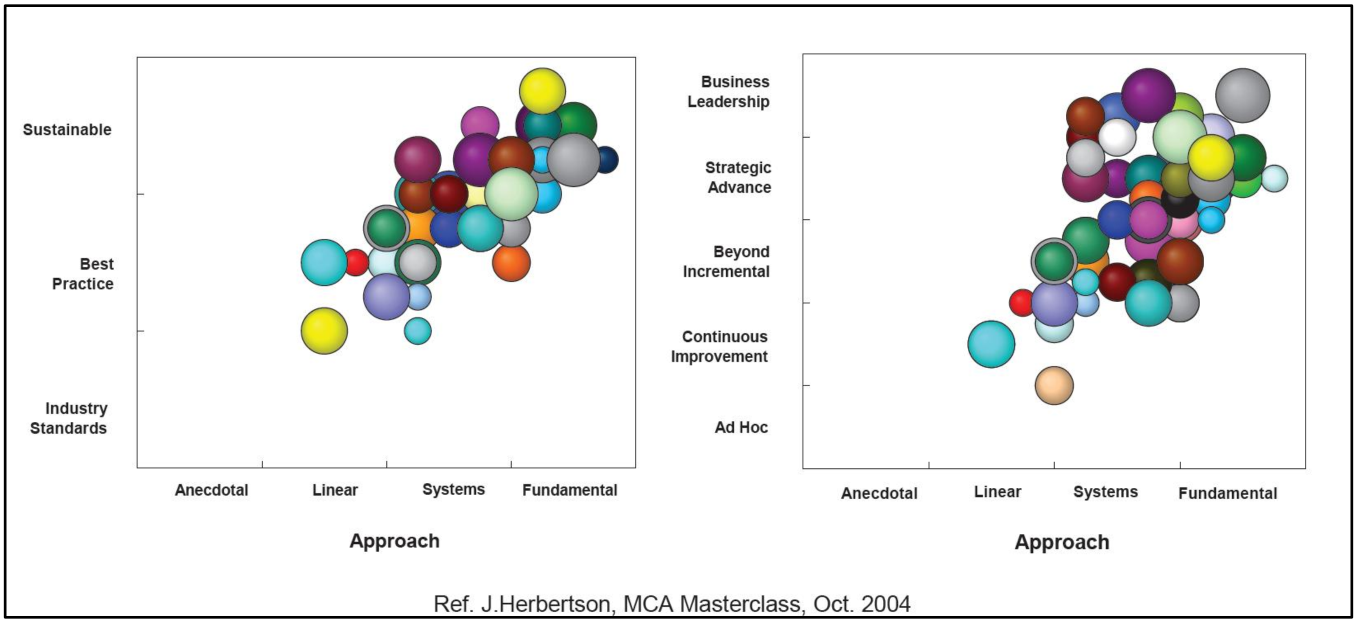

Figure 2. Innovation that works at the fundamental "root cause" level produces long-term sustainable outcomes (Herbertson, 2005)

The ability to resolve trade-offs over time through dealing with fundamental root causes of systems limitations has always been apparent when performances and efficiencies are considered over a sufficiently long period (Batterham, 2003). For successful industry participants the same things that drive better economic outcomes also drive better social and environmental outcomes in the long run, because they are causally linked in the long run.

Sustainable businesses are associated with achieving a simultaneous focus and appropriate balance between maintaining operational capability, market position (new business generation) and a portfolio of innovative "new platforms" that new businesses may be based on in future. Recently, this balanced approach was characterized for technologies used in the mining industry (Hollitt, 2006, refer Figure 3).

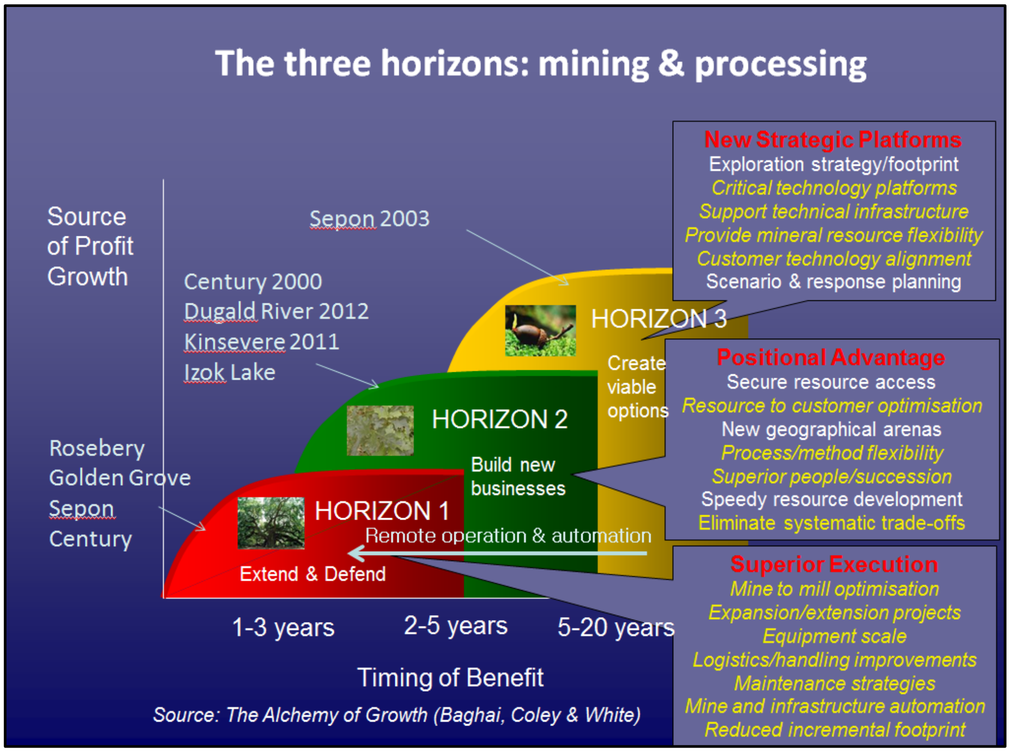

Figure 3. Three horizons characterized for the minerals industry, with MMG examples (Hollitt, 2006)

While individual businesses may from time to time lose balance, and suffer from some of the characteristic patterns of excessive focus on one “horizon” (refer Figure 4), it may be concluded that overall, the mining and mineral processing industries have continued to benefit from sufficient diversity that all three horizons are covered. Operational capability and implementation of new innovative platforms have each contributed to a strongly growing industry based on new mines and expansions.

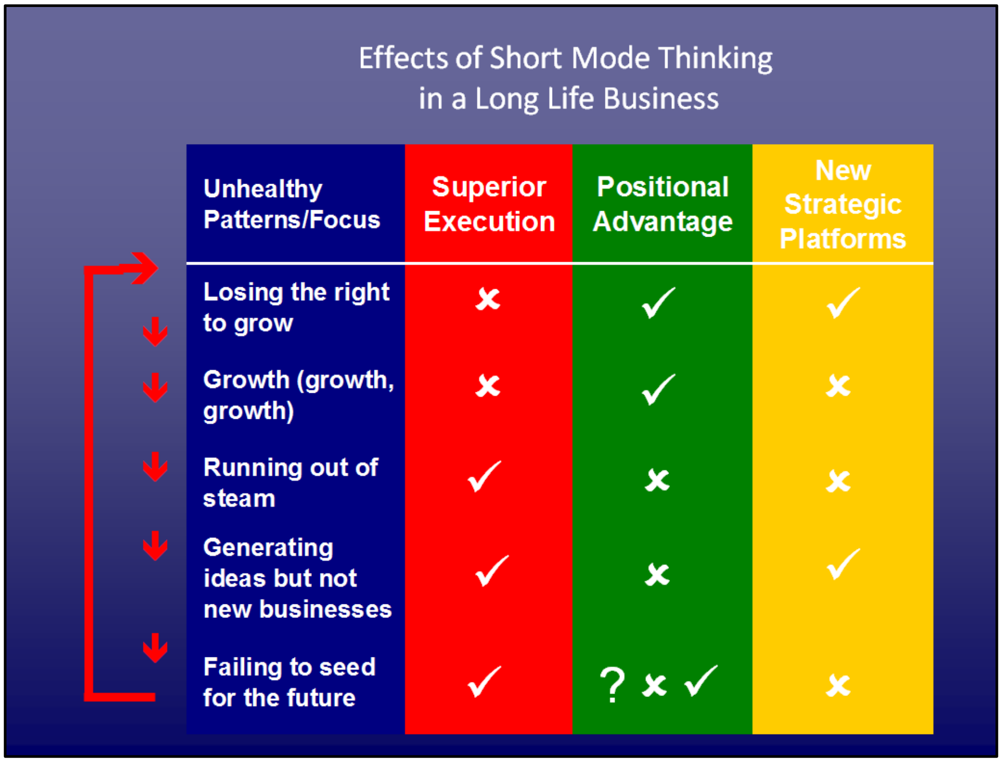

Figure 4. Balance is needed to avoid unhealthy patterns. (Diversity ensures that bases are covered at the industry level)(Hollitt, 2006)

Given the unique character of innovation in the minerals industry, and the huge swings in circumstance of the industry in the last decade or so, two important questions arise:

- Has any obvious gap emerged between the pace of innovation and the pace of growth in the minerals industry?
- Are the necessary conditions for generating and supporting an adequate pipeline of innovative approaches in future decades still present?

“NEW PLATFORM” INNOVATION – A HIGH LEVEL SCORECARD

Innovation has continued as a strong feature of the minerals industry over the last decades (the critical timeframe for capital replacement, new installations, and expansions). Any attempt to list the successful innovations that have reached at least some penetration is sure to miss many. Table 1 provides some examples at the “new platforms” level.

Table 1. Penetration history of some "new platforms"

New platform	Place in value chain	Demonstrated	First modern deployment
Copper heap leach SX/EW	Extraction/metal recovery	1968	1983-1987
Aerated heap bioleach sulphide copper	Extraction/metal recovery	1980	1993
Mechanised block caving	Mining	1970	1976
Acid high temp. pressure oxidation leaching (Cu)	Extraction/metal recovery	1980	2003
Top submerged lance smelting	Smelting	1978	1992
High pressure grinding rolls	Comminution	1985	2006
Shale gas	Extraction	~1980	2005

Rather than look to individual new platforms and approaches as signs of innovation it is useful as a first step to look at macro indicators that are easier to summarize.

Some important macro indicators are:

- working with significantly reduced personal harm
- increased productivity, adjusted for cycle times and resource depletion
- reduced grades of material mined
- increases in reported reserves and indicated and measured resources
- sustained growth and replacement of productive capacity.

There are encouraging signs that as newer platforms are promulgated trade-offs are slowly being replaced. The industry has been "having its cake and eating it too."

Figure 5 shows the continuing improvement in safety statistics in Australia's mining industry (Minerals Council of Australia, 2010). While there remains some distance to travel to the goal of zero harm, the continued improvement is heartening.

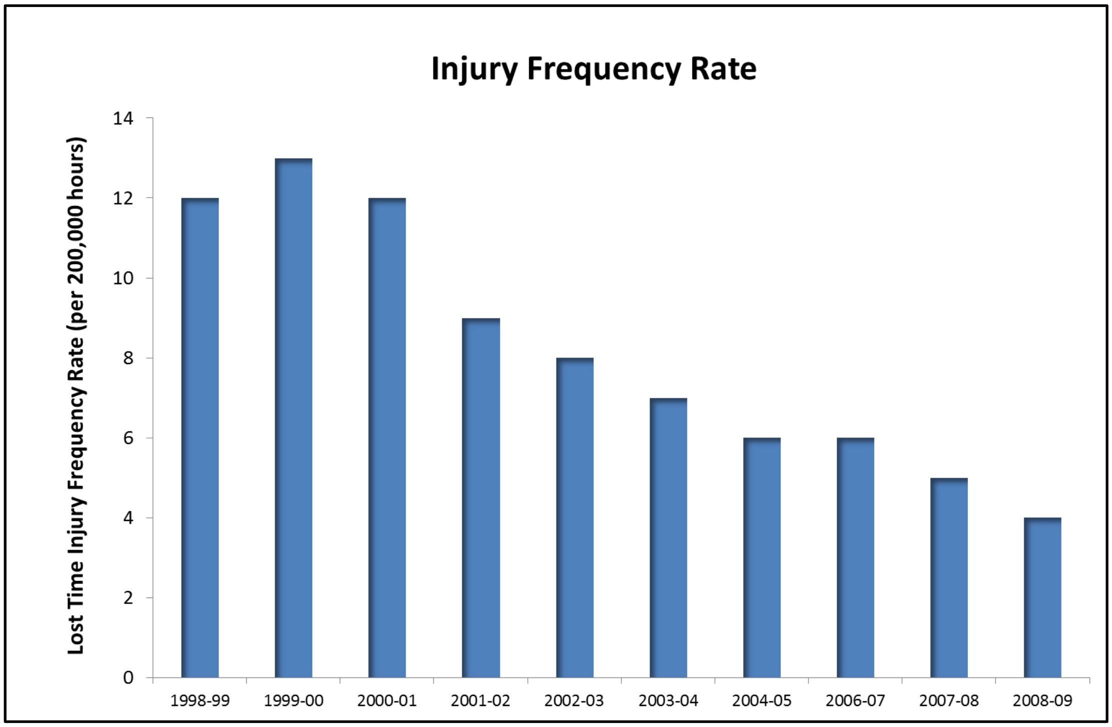

Figure 5. Australian Mining LTIFR continues to fall (Minerals Council of Australia 2010)

Figure 6 illustrates the growth context (US Census Bureau, 2012).

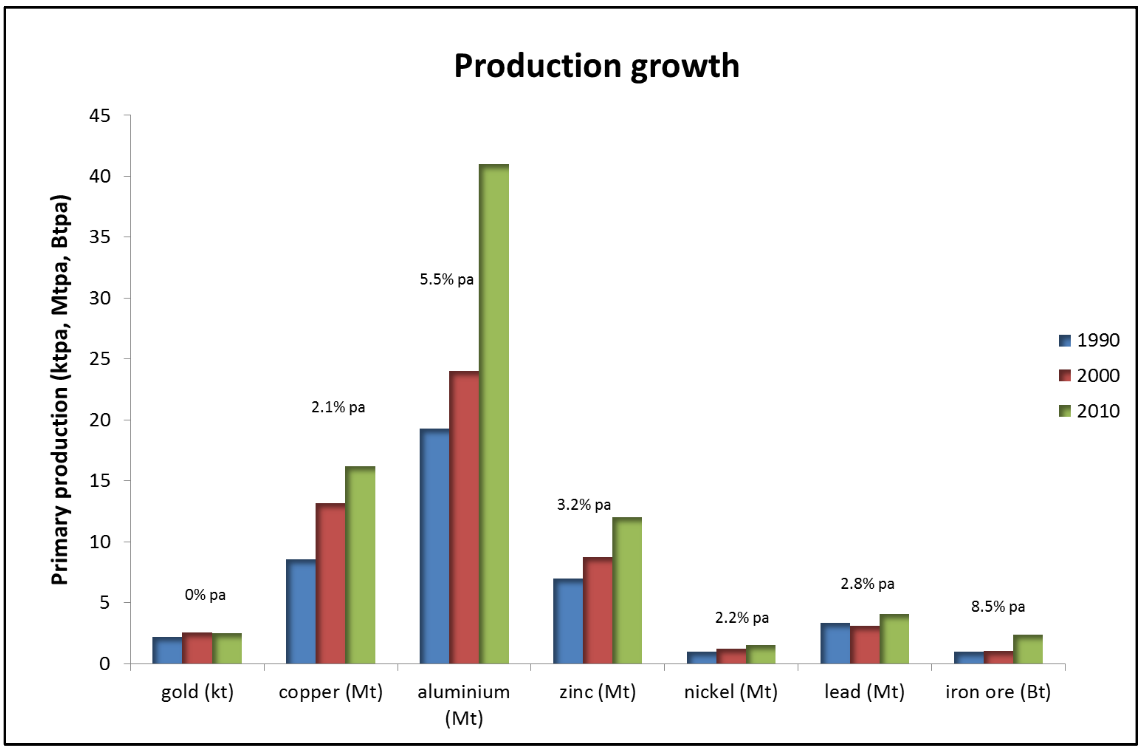

Figure 6. Global production growth in primary materials (source USGS – note differences in scale of comparisons)

Figure 7 provides an assessment of mining productivity (Topp et al., 2008) in Australia's mining dependent economy (60% of the value of Australia's exports are mine related) (PwC, 2012), as a clarified representation and example of productivity changes in the minerals industry in recent years. When the lag effects of capital projects that are in construction (evidence of high growth) and the impacts of declining grades and higher overburden are taken into account, productivity has continued on an upward path.

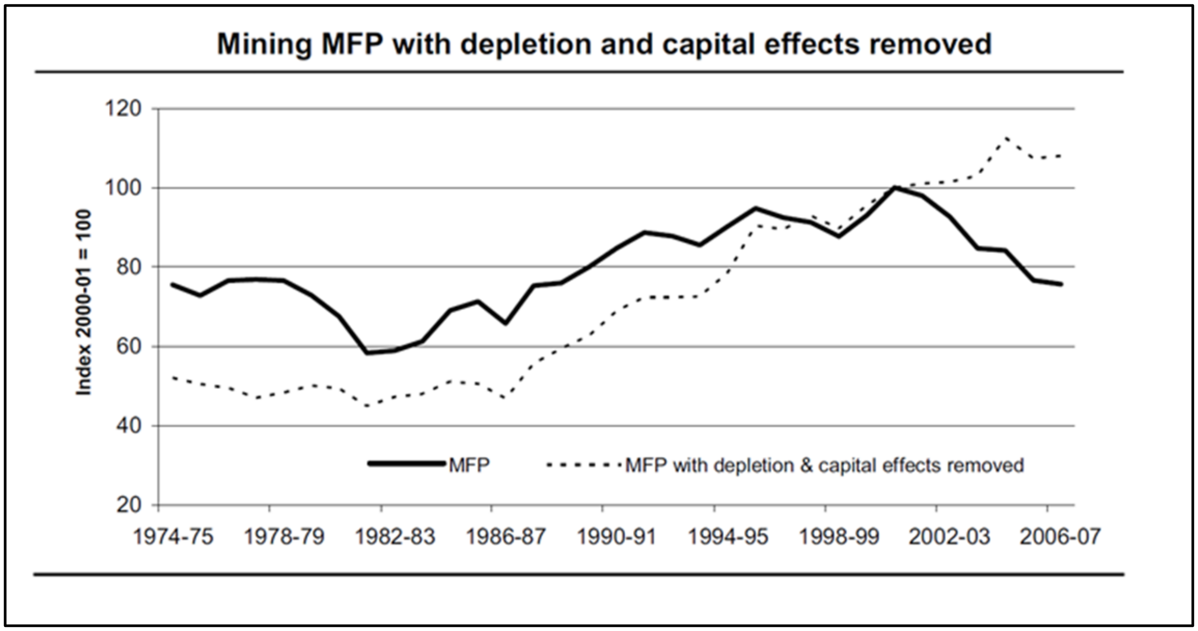

Figure 7. Australian mining industry productivity (when adjusted for yield and capital timing) continued to increase during high growth years (Topp et al., 2008)

Grades have been falling, and are expected to fall further, in some cases to begin to approach the grade of discoveries, indicating significantly reduced constraints on grades that can be economically processed. Figure 8 illustrates this for copper, with the grades of deposits "backcast" onto the original discoveries given eventual grades processed (Schodde, 2010). The downward grade trends are equally apparent for lead and zinc resources (Davis, 2011).

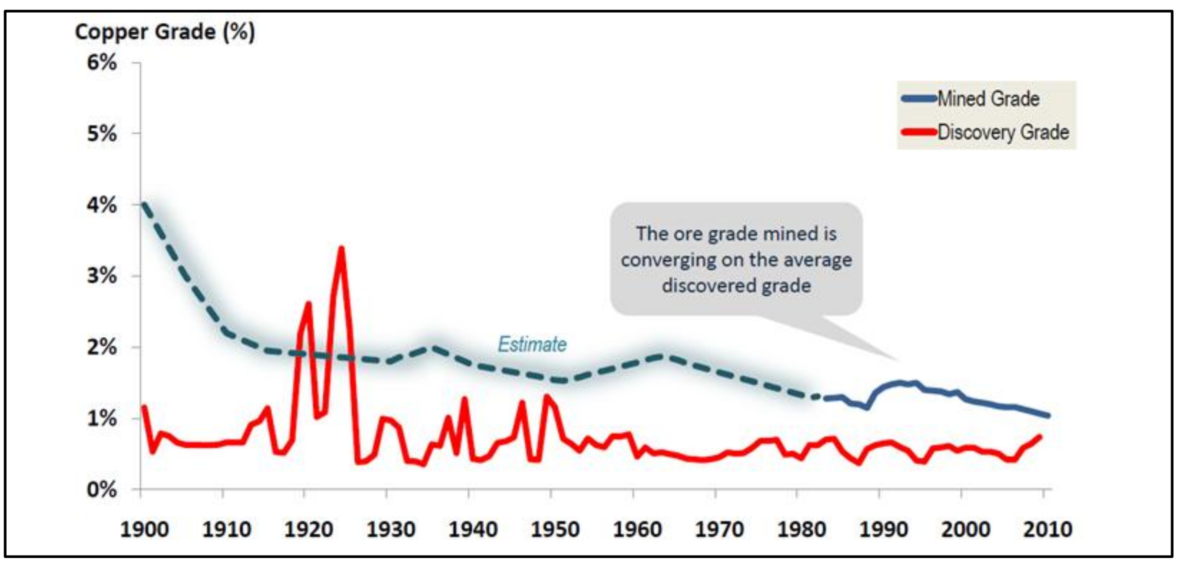

Figure 8. Copper grades processed are declining towards discovery grades. (Courtesy R. Schodde)

At the same time, the relationship between resources processed so far and resources available for future processing has been for the most part maintained. Figure 9 illustrates this for copper (Schodde 2010).

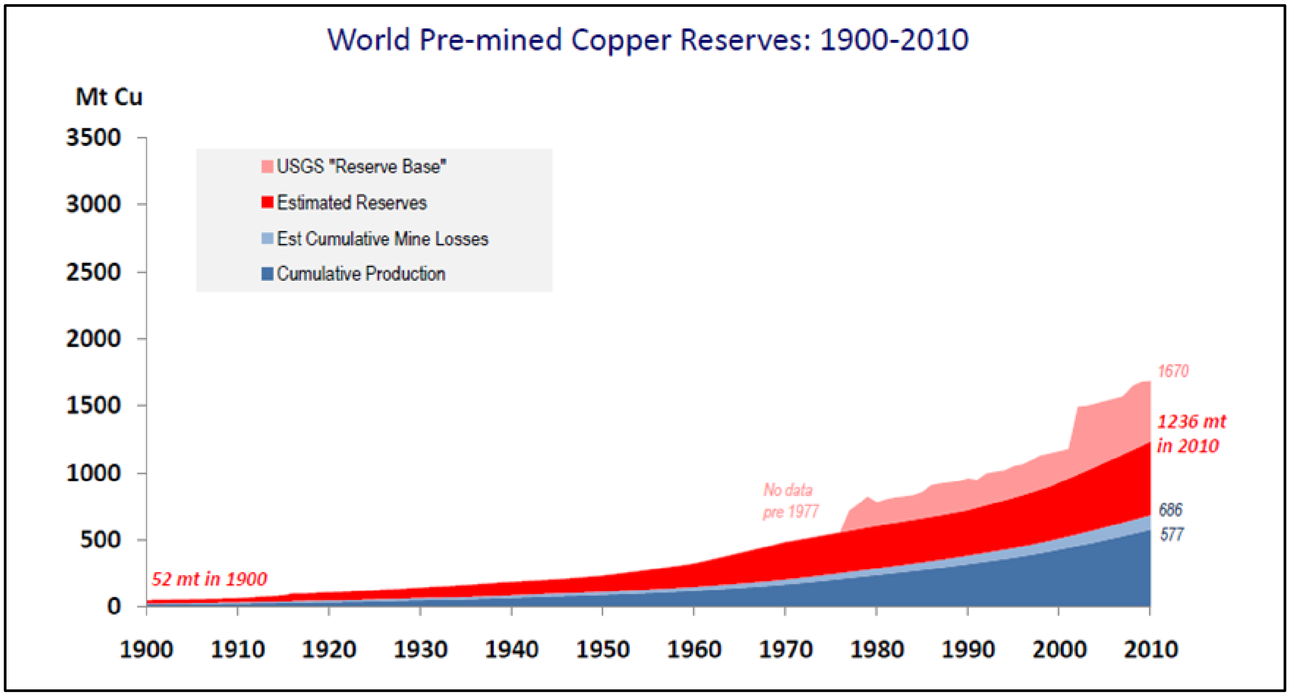

Figure 9. Copper "original" reserves to cumulative production ratio is steady, with reserves growing to meet production growth. (Courtesy R. Schodde, USGS)

Deeper, covered mineralization is now represented in resources under development, reflecting advances in both exploration (especially deviated drilling) and in deep mass mining techniques (refer Figure 10) (Harding, 2010).

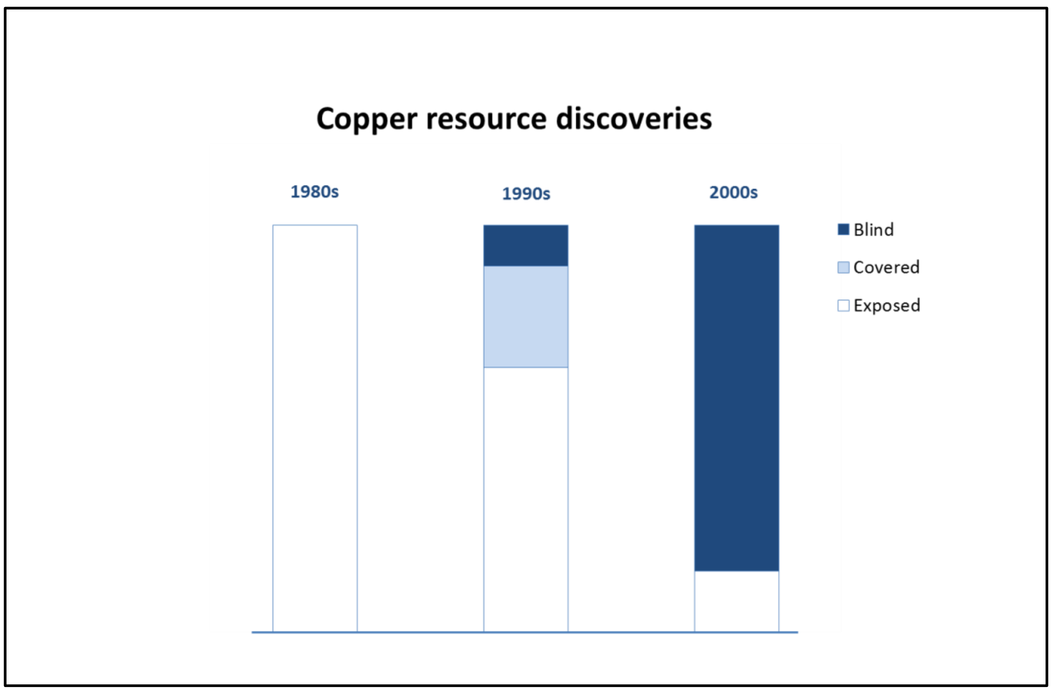

Figure 10. Copper discoveries are now more challenging (Harding, 2010)

At the macro level, there are signs of continued innovation in the mining industry, a strong reflection of the quality of the people that our industry employs and the focus that has been brought to its sustainability. Multi-faceted improvements show that trade-offs have been reduced. Increased production has been on lower grade, often deeper ore, at higher productivity and improved safety performance simultaneously. There is clear evidence that new platforms have been introduced into the capital base as growth has both permitted and demanded new capital investment.

What macro information can't reveal is that the innovation we see implemented is just the tip of a very large iceberg of diverse options that have been generated at some time in the past, and then selected from for promulgation.

THE UNIVERSAL SUCCESS CURVE – MANY ARE CALLED, FEW CHOSEN

Any faithful analysis of innovation in the minerals industry will first recognize that for every successful innovative platform that has been adopted, and then found wide penetration, there are many more unsuccessful attempts. Implementation and promulgation is the exception rather than the rule.

Authoritative surveys (refer Figure 11) have illustrated this dynamic for commerce in general, for which it can be demonstrated that only about 1 in 9 new platforms that reach early stage development result in eventual commercial success (Stevens & Burley, 2003). Importantly, it can be demonstrated that the "universal success curve" of Figure 11 is equally relevant to mining and mineral processing (in a characteristic timeframe), at least for exploration and new resource development (Enders & Leveille, 2004). The relationship between primary activity that targets successful outcomes and the number of actual successful outcomes seems to fit.

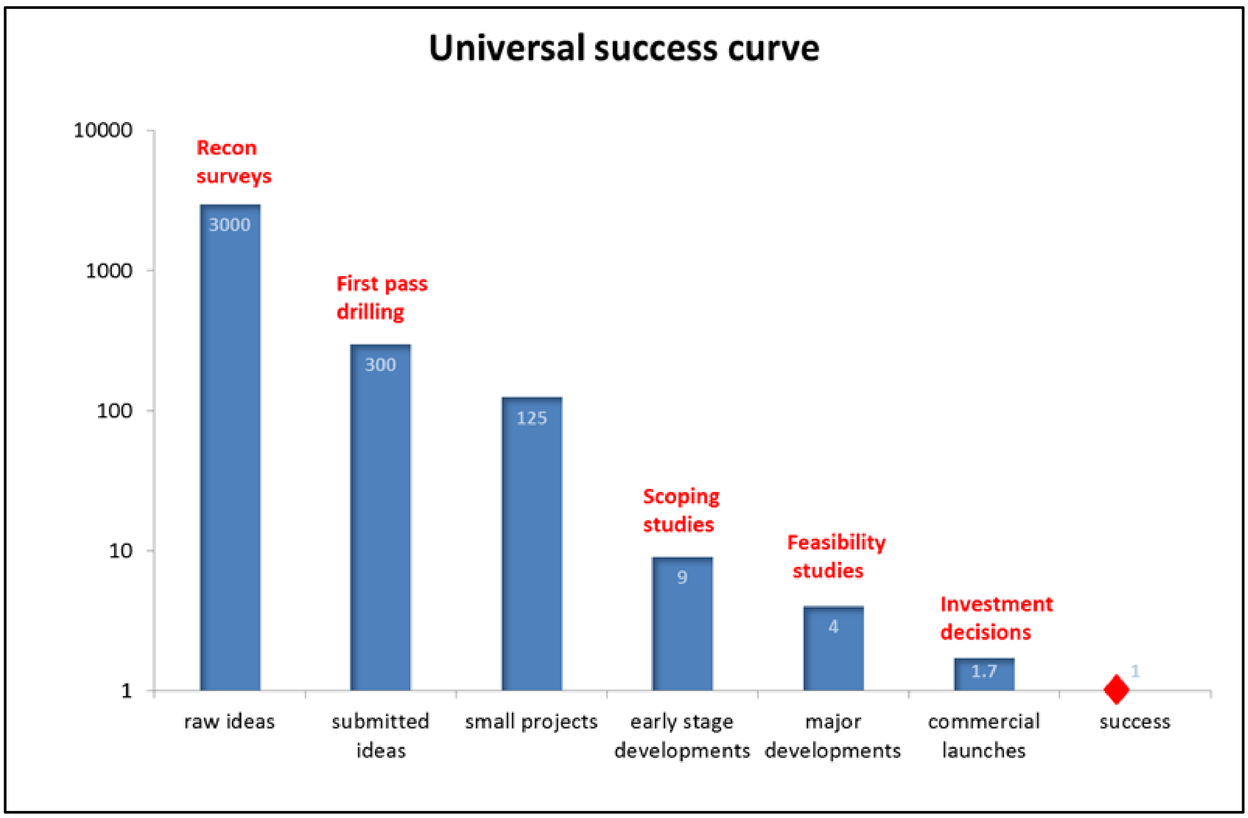

Figure 11. Development is by choice from an available diversity (Stevens & Burley, 2003); the minerals industry fits this model (Enders &Leveille, 2004)

If we accept that Figure 11 also applies to the development of new mining and mineral processing platforms, then it illustrates the importance of not drawing conclusions about early stage opportunities and attempts by sole reference to the surviving successful outcomes. Success gets more attention ("success has many parents, but failure is an orphan”), and the evidence of success is physical and long-lived (in mines and processing facilities). Our experience drives the misleading perception that success in new endeavors is far more common than it actually is, with lack of success therefore indicative of some underlying fatal flaw.

Experienced innovators know that commercial success in “new platforms” innovation is rare, and is necessarily born of diverse unsuccessful efforts, many of which are as technically viable and economically well founded as the success. It seems that new platforms inevitably come from “kissing a lot of frogs,” and then choosing from those that most resemble princes, as circumstances dictate. There is no “magic formula” to be found in emergent successes, and lack of success is not necessarily any indication of poor business fundamentals.

We can learn far more from what is missing from the larger volume of “near misses” than we can from what is present in the very few successful outcomes, which in many cases may involve special circumstances that cannot be repeated easily.

While in other industries the ratio of first concepts to generally implemented outcomes might be explained away by the idiosyncrasies of consumer preference, the same can’t be said for the mining and mineral processing industries. We must look to other explanations for the high ratio. It remains the case that even the few new platforms that reach large demonstration scale in mining and processing mostly struggle to achieve any significant penetration even decades after demonstration.

[Examples are found in new direct iron smelting approaches (Dry et al., 2002), activation of bauxite for productive alumina refining (Hollitt et al., 2002, Smith et al., 2009), halide leaching of concentrates with direct electrowinning (Dreisinger, 2009), in place leaching of hard rock resources (Landmark, 1992), atmospheric leaching of ultrafine sulphide concentrates (Hourn & Duncan 2012), and flotation for concentration and separation of mineral sands (Hollitt et al., 1994)].

It is axiomatic that new platforms that have been adopted and reached further penetration have the following features:

- implementation according to plan is expected to provide higher shareholder returns than customization of already available approaches,
- there is no technical flaw that results in poor performance in practice,
- avoidable risks have been reduced through prototyping at some adequate scale, and
- safety and environmental performance is not compromised.

While the development and implementation of new operating platforms that have these features is far from easy (Morrow & Yarrossi, 1994) experienced technology developers know that these can’t be considered to be the sole or even main criteria for success. The pivotal question is “what sustains successful new platforms across the ‘valley of death’ of high negative cash flows through extended prototyping and first commercial demonstration?”

Developments that haven’t been selected for implementation are less evident to us, having failed to reach significant penetration, but many also have all of the most apparent features of those that were successfully adopted. Some having all of the above features are still awaiting implementation, perhaps providing the “stock of available diversity” from which to choose in future. Some have been “leapfrogged” either by improvements in more conventional approaches (learning curve benefits accrue only to operating approaches) or by even newer approaches that join the development pipeline. Still others leave the pipeline when development funding dries up, with corporate memory lost, and few phoenixes arising from the ashes of previous painful experiences.

Developments that reach the prototyping (demonstration) scale presumably mostly already have the above necessary, but it seems insufficient characteristics. The question remains of what other characteristics separate out the approaches that reach successful penetration.

SURVIVOR CHARACTERISTICS – THE “SUFFICIENT” SET

An example of the difficulties in getting to success in new technology developments is provided by the low success rate of substantial efforts aimed at new technologies for production of primary hot iron metal units that avoid coke ovens, sinter plants and electric furnace melting. After eight different efforts involving billions of dollars in development expenditures over more than 40 yearsonly three (Corex, Finex and HIsmelt) have survived to implementation at scales that could result in wider promulgation. There have been false starts that could have resulted in permanent loss of resourcing along the way, and the future is still uncertain.

In a review of direct iron smelting (Dry et al., 2002), lessons for success in maintaining a new technology development effort (where the focus is fundamental change rather than customization) included an acceptance that:

- timeframes to commercial deployment in decades are more likely than timeframes in years,
- there is no way of avoiding large, high cost trials, and
- there is the need for a strategic motivation that is strong enough to sustain the required effort as business circumstances change (otherwise, "don't do it").

Developments in this area are now centred at least in part on India (Meijer et al., 2011), with Rio Tinto and Tata Steel combining HIsmelt smelting with preheating and melting in a Cyclone Converter Furnace at Tata's Ijmuiden facility (Netherlands) for testing at a scale of 80 tph (hot metal).

Observations for new iron smelting developments mirror the experience across the whole diversity of mining and mineral processing industries. Examples are:

- the first small heap leaching operation for copper, supported by solvent extraction and electrowinning (Bartlet, 1998), was in 1968 (Bluebird, USA), with large developments based on modern geomembrane capability commencing almost 15 years later (Smith, 2008)
- the first small biological heap leaching of copper supported by solvent extraction and electrowinning (Mishra & Champagne) was in 1980 (Lo Aguirre, Chile), but the first large bioleach with forced aeration (Readett et al., 1997) was commenced in 1993 (Girilambone, Australia)
- modern (mechanized) block caving for underground mass mining was first demonstrated in 1976 (Henderson, USA) (Chacon et al, 2004) but has only recently penetrated through increased development of large underground base metals and gold projects (Sainsbury et al. 2012)
- acid pressure oxidation of sulphide concentrates for metal recovery was first established commercially (Berezowski et al, 1991) in 1980 (after unsuccessful commercial attempts dating back to the 1950s) (Fassell, 1952), penetrated into refractory gold processing (Dunne et al, 2009) from 1985 (Homestake, USA), but only reached commercial use in copper flowsheets (for concentrates rather than whole ore) in 2003 (Bagdad, USA) (Marsden 2006)
- top submerged lance smelting technology (Ausmelt and Isasmelt) was first developed in the early 1970s (Courtenay, 2012) but didn't reach commercial scale application in copper until the early 1990s (with now over 80 installations since that time) (Arthur et al, 2003)
- high pressure grinding rolls have been in use in the cement industry and other "soft rock" applications since 1985 (ABB, 2010), and have been in consideration for hard rock applications in place of SAG mill circuits since the early 1990s, but first made the transition to hard rock applications in only 2006 (Dunne et al, 2009, Marsden, 2009).

The most startling change in the delivery of energy resources for many decades, the application of horizontal drilling and multi-stage fraccing that opened up wet shale gas resources, delivering by-product gas at low cost, also had a frustratingly long gestation during which its future remained uncertain. Its "overnight success" since 2005 follows years of technical development commencing in the early 1980s.

While these advances are far from a complete list, they are some of the most successful new platforms that have gained penetration in the last decade the basic features for success must be well met by these technologies. However, over the long development period to first implementation and deployment at greater range, a number of even these platforms had "near death experiences" associated with volatile industry conditions, corporate circumstances and continuity of strategic commitment in the face of temporary setbacks. Indeed, it was not really possible in the early stages of development of these promising platforms that any one of them would succeed in the way that they have over other promising or established approaches.

While the vagaries of industry circumstances coupled with mere chance may account for some of the eventual selections from amongst those that reach the stage of at least early prototyping, it is also true that fortune has been found mainly in the company of strong strategic commitment.

The question of how strategic commitment sustains new platforms across the number of business cycles that elapse during development remains to be answered. What are the characteristics that are not shared between successful and unsuccessful new platforms?

Given the nature of the minerals industry (long capital cycles, long product lifecycles, high capital intensity), coupled with the finite nature of any resource development it is reasonable to expect that successful platforms will be sustained (perhaps even by changing hands) if they have each of the following distinctive characteristics:

- attachment is possible, at good value, to at least one new resource project or significant expansion (there is no need for “creative destruction” of existing capital),
- the new approach is critical to the fortunes of at least one such project or expansion (i.e. there is no other possibility of a satisfactory or sufficient project), or
- the new approach is uniquely suited to avoiding loss of previous gains, including continued growth from resource acquisition or market options, which gains are otherwise under clear threat (the strategic imperative),
- it is expected that that these necessary conditions will still be present in future business cycles in the light of other industry or regulatory developments, and
- sufficient finance or operating cash flows are available (equity rather than debt backed investment) to provide for development across several business cycles.

When not armed with these defences, even very high value new platforms may not be sustained through development to a first commercial installation. (Ralph Waldo Emerson may well have been correct when he observed that “if you build a better mousetrap the world will beat a path to your door”, but that isn’t obvious when there is already a perfectly adequate though imperfect mousetrap, and the better mousetrap has not yet been demonstrated).

The above characteristics, where an organizational “burning platform” meets adequate resourcing from reliable equity financing, are most predictive of success of new approaches. All of the successful approaches of Table 1 had these features for at least one mining or resource processing business before first commercial implementation.

Importantly, it is difficult to think of unsuccessful approaches that possessed all of these features. (An example of a demonstrated but as yet not implemented technology that lacked only one of the critical characteristics for success has been provided in this conference (Batterham, 2012) – bauxite activation (Hollitt et al, 2002)that converts high temperature digestible bauxite to lower temperature digestible form, with better energy productivity and capital productivity while reducing reagent costs. The missing link is that a sufficient alumina refining capability for treating high temperature bauxite at a reasonable return on investment has existed for application in profitable expansions so far).

LESSONS FROM GREENFIELDS EXPLORATION – CHOOSING FROM AVAILABLE DIVERSITY

The current Chairman of Ivanhoe Mines once observed that for a mining company a new economic resource was equivalent to a new drug for a pharmaceuticals company, drawing attention to the logical similarity of exploration and innovation for renewal and survival. In an industry having long lead times based on depleting sources of value, there has to be something in the pipeline.

So, it is perhaps surprising that large mining companies conduct very little greenfields exploration. The exploration budgets of these companies have been moving to a greater brownfields focus since globalization in the late 1990s (Australian government issues paper, 2010). Globally, the proportion of exploration expenditure allocated to greenfields (as distinct from upgrading to higher resource and reserves categories in preparation for mining) has fallen from 50% to 36%.

Nevertheless, greenfields exploration (defined as exploration on license areas for which a resource hasn't been declared) hasn't ceased. While there was a severe global reduction in greenfields exploration in real terms from about 1997, there has since been a recovery, commencing in about 2003 (Minerals Economics Group, 2012). As mining companies began to specialize in resource acquisition and development, selecting the best of diverse available options globally, a new breed of specialist exploration company eventually emerged to provide those options. Fully equity funded, these companies specialize in the risk end of investment portfolios. Rarely themselves developing a prospect, they explore and trade prospects that are discovered and further delineated to generate shareholder value. The most successful of these companies are now geographically diversified, and also diversified across targeted commodities.

The separation of a distinct greenfields exploration industry from mining developers and operators reflects the different skill sets and risk tolerance involved in these activities. Any new development in a capital intensive industry can have little appetite for residual investment risk that isn't shared by similar developments of competitors. Any specialist explorer that is unprepared to lose its investment in a new prospect in its portfolio will soon cease to be an effective explorer (as demonstrated by Figure 11).

Upon globalization, it was soon discovered that the approaches taken by large developers and operators to greenfields exploration were value destroying, with the cost of a significant discovery on average exceeding by large measure the value of any ensuing development (Parry, 2001). The trigger for the inevitable separation was the geographical diversification of capital project developers and mine operators that occurred with industry globalization. Removal of regional constraints enabled mining companies to select from a wider diversity of already discovered opportunities. There was less need to settle for the limited opportunities provided by historical attachment to geography, or to make the most of the opportunities that so presented themselves.

When choosing from global resource opportunities it became possible to specialize in development of larger, longer life resources for which expansions were possible without replacement of infrastructure or the need for new greenfields approvals and acceptances. Greenfields exploration became less important to these companies. Their watching brief on the relative cost of discovery and acquisition has so far not revealed any problem with the sustainability of this approach for their businesses.

The role of innovation in mining and processing platforms supporting these changed industry circumstances is undeniable. Larger, longer life resources are often lower grade, since resource grade influences resource size, both for reasons of the impact of cut-off grade, and because of the distribution of even well delimited mineralization for which high grade on average means small size (Sangster, 2009). So, development of large, long life resources depended on the implementation of new approaches to resource planning and management, new mass mining techniques, and new, lower cost processing (Crowson, 2003) to offset the deliberate focus on lower grade resources. The focus of exploration activity moved to brownfields extensions of these large resources, converting resources to reserves for expansions that progressively matched operating potential to demand. Greater proportions of global production are now coming from large individual mines (e.g. Escondida at 8% of global primary copper production), with a large proportion of these owned by a small number of large global enterprises (Davis, 2011).

With reference to the conditions that sustain the generation of new innovative platforms prior to first commercial implementation, the forces that drove industry restructuring for greenfields exploration had a high influence on the innovation pipeline. Prior to globalization, limitation to regionally available resources provided little option to companies wishing to expand, other than to develop customized platforms that created commercially competitive operations based on those resources. Following globalization and diversification, access to a larger pool of mineral resources enabled a more reliable overlap of satisfactory, sufficient and already demonstrated technologies with large resource opportunities. Narrower technology choices could be made without limiting opportunity.

Innovation that was formerly driven by the challenge to customize for locally available greenfields resource opportunities could be displaced by less constrained application of approaches that had already reached at least first commercial demonstration. Resources could be chosen to suit the available technology, rather than the other way around.

It is no coincidence that minerals related R&D expenditure of major corporations dipped globally (relative to revenue), almost exactly coinciding in time with the global fall in greenfields exploration (Twigge-Molecey, 2003, Upstill & Hall, 2006). These changes were part of improved business efficiencies that were targeted by globalizing companies, and aren't necessarily an indication of any loss of effectiveness. Just as for greenfields exploration, in the more limited circumstances where R&D was needed for growth it could often more effectively be outsourced in now global networks, especially where there were publicly funded organizations that provided R&D infrastructure. As is the case for exploration, the operating and project development arms of the industry that "creatively preserve" and avoid ambiguity were now able to focus more singularly on the later stages of the universal success curve of Figure 11, eventually selecting only those opportunities that have the characteristics for survival noted above.

PROPAGATING FASTER THAN BREEDING

High growth associated with Asian industrialization and urbanization created a paradox. While this historical sequence assisted the propagation and up-scaling of already demonstrated technologies (through opportunities to embed in large new capital installations), it also created conditions that were less likely to sustain early stage innovations to first commercial demonstration. New platforms couldn't realistically be considered for application in fast tracked projects unless they were available "off the shelf". Supply of sought after commodities inexorably advanced to meet demand even on a sharply rising cost curve, so satisfactory and sufficient new resource projects were possible without application of new approaches. Just as high growth drove brownfields exploration over greenfields exploration, it drove promulgation of new platforms over development of them.

With the emergent industry structure dominated by diversified large organizations (but still well populated with smaller, increasingly diversified organizations) the question of how industry cash flows and management resources will be diverted into the development effort and time required to take new platforms to first demonstration and commercial implementation has been raised (Hollitt, 2005), but not yet answered. For example, will specialist equity funded technology development organizations emerge to dominate this work in the manner of greenfields exploration? The timing and "large, one-shot" nature of technology commitments are unlike those of greenfields exploration, reducing risk diversification opportunities. The separation of strategic need from the management of new platform development undermines one of the key requirements for success.

Productivity improvement, when adjusted for resource depletion effects, has continued at a pace that reflects pre boom conditions, a sign of ongoing, healthy innovation in the minerals sector. However, improved productivity on this basis isn't an indicator that the improvements are keeping pace with the effects of growth, or that current rates of improvement are sustainable. Since most of the innovative platforms that have featured in the capital projects of the mining boom were first developed decades ago it is important to consider other indicators. Figure 12 illustrates this well for copper smelting capacity (International Copper Study Group, 2012), where penetration of direct smelting techniques has only been mainly confined to new capacity, building on technology developments that had reached commercial penetration by the early 1990s.

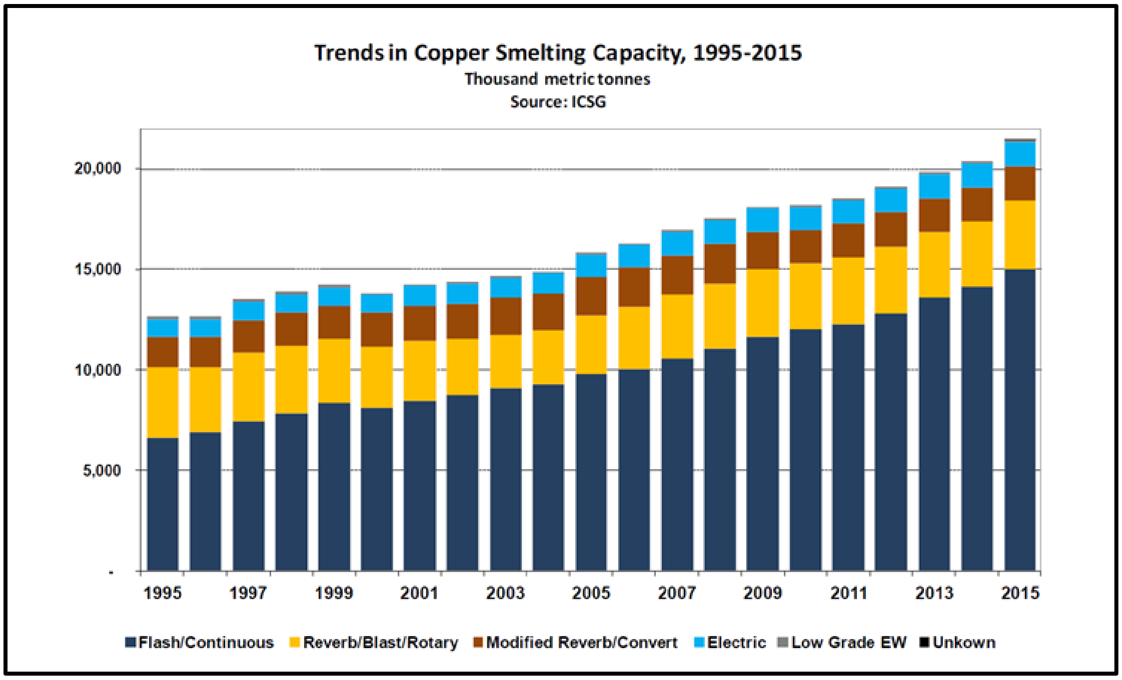

Figure 12. Direct smelting technology has dominated growth in copper smelting, but with little net capital displacement effect (International Copper Study Group, 2012)

Figure 13 illustrates it for copper hydrometallurgical approaches.

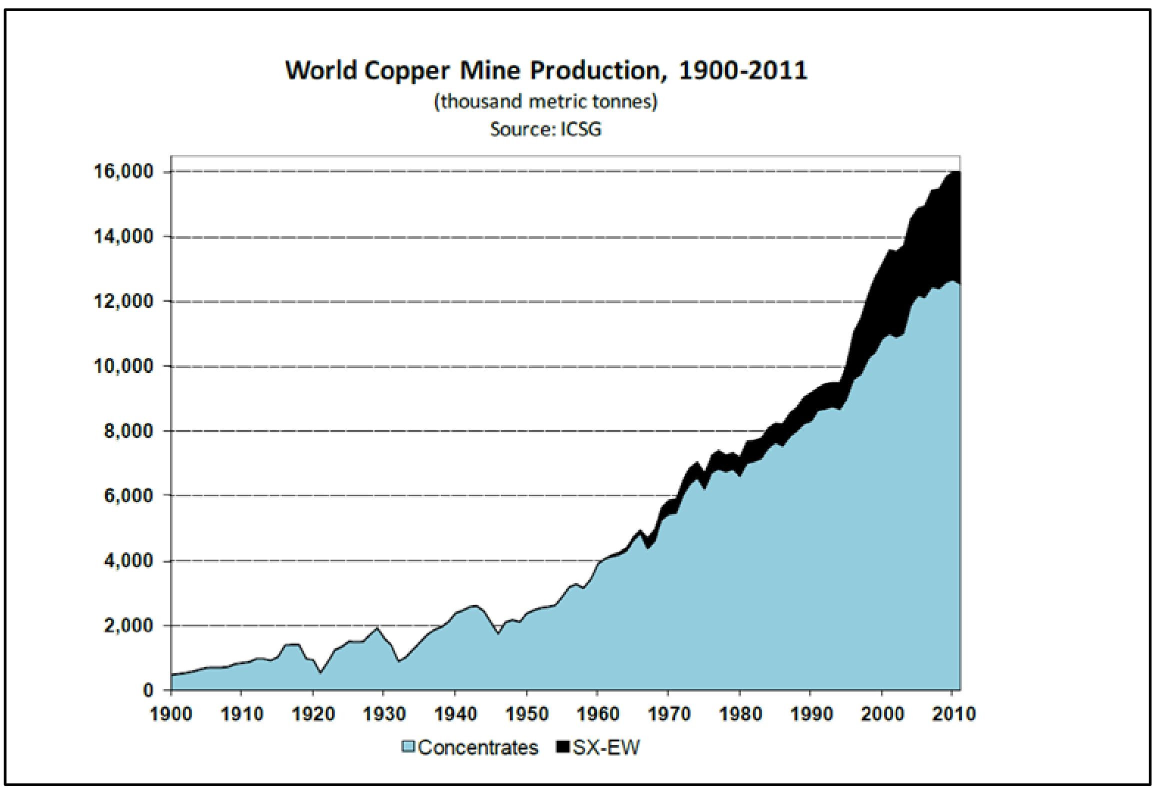

Figure 13. Since 2000 hydrometallurgical routes to copper production have dominated net growth in primary copper supply (International Copper Study Group, 2012)

One of the main influences of the promulgation of innovation is its effect on incentive pricing – the price that is necessary to encourage new capacity. During periods of high growth in demand incentive pricing (rather than the operating cost curve) more correctly takes into account capital commitments as costs incurred in taking up the option to supply. The link between innovation and prices is the link between innovation and enhanced productivity that embeds new platforms in new capital installations.

In the mining industry sharply increasing real commodity prices are inevitable when "multi factor productivity" (a measure of economic output per unit of economic input, including capital) falls in the long term. Lower multi factor productivity shifts the cost curve and marginal incentive price. Sustainable increases in multi factor productivity are necessary to maintain real prices when resources deplete and processed grades fall. For this, there must be innovation involving new platforms (i.e.so trade-offs can be defeated).

In periods where real prices have fallen in the long term, which was typical of the minerals industry in the two decades to 2000, the effects of implemented innovation outpaced the effects of growth and declining resource quality. Indeed, innovation was sufficiently fast relative to growth, and implemented at such scale that grade became a less dominating consideration in development decisions – lower grade resources could now even be chosen for development in preference to higher grade resources (Schodde, 2010, Crowson, 2003). In the mid 1990s (prior to significant globalization and the mining boom) multi factor productivity improved by 4% per year (Upstill & Hall, 2006) i.e. at a rate that more than matched the rate of growth.

In contrast, Figure 14(Topp et al, 2008) shows that in Australia the multi factor productivity of mining (when adjusted only for capital lag effects, including the effects of resource depletion) actually fell across the boom period, from 2003 to the present. During this period innovation has been unable to keep up with the impact of resource depletion globally, with real prices adjusting accordingly. Other periods in the past century where this occurred on a global scale include 1910 to 1920, the post war period 1945 to 1955 and 1965 to 1970 (Marsden 2009). The period 1970 to 2003, has the unusual distinction of exhibiting the longest run of declining real commodity prices in modern history, reflecting high innovation relative to growth, with productivity improvements outrunning the effects of resource depletion.

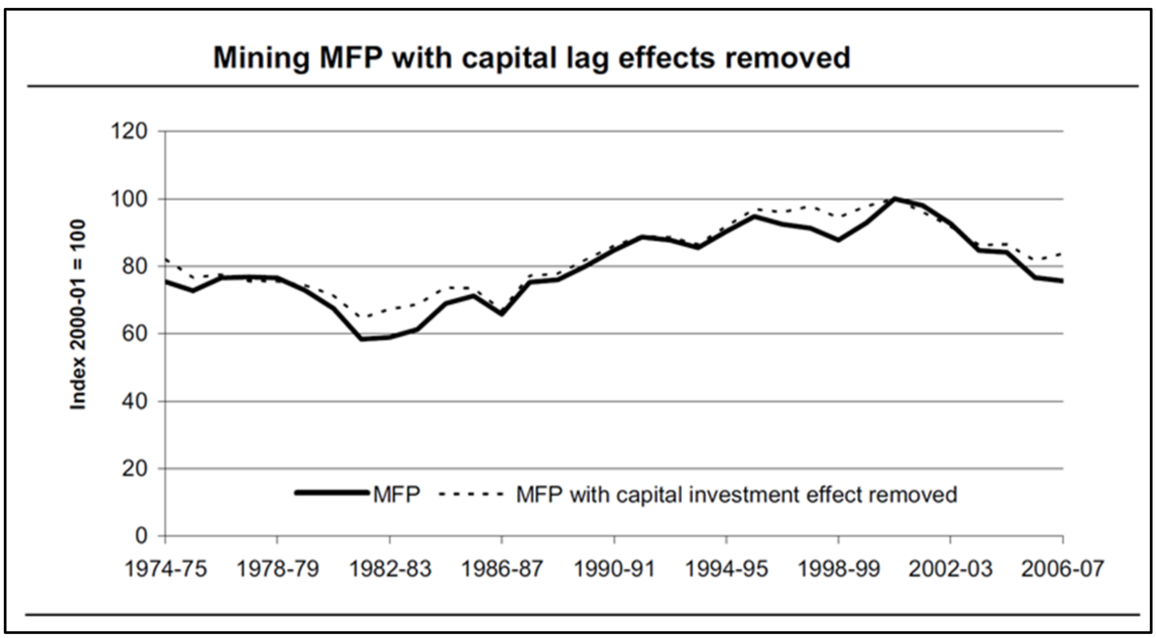

Figure 14. Australian mining productivity has fallen when there is no adjustment for resource depletion effects (Topp et al., 2008)

So, while there has been no deceleration in productivity improvements, the step up in the pace of growth since 2003 has outstripped the industry's ability to respond with implemented innovation that offsets the economic impacts of that growth. As new resources come into production, the net effect is a fall in multi factor productivity, matched by sharp increases in real prices.

The history of costs of metal production also starkly demonstrate the impact that new technology platforms have on productivity and pricing (and vice versa). In the case of copper 70% of the cost improvements of the last century are attributable to new operating platforms (Schodde, 2010), with the rest due to economies of scale and general productivity improvements. As successful new platforms reach significant and growing penetration they reduce the incentive price that justifies marginal supply, with an effect on pricing across the entire industry that is quickly felt and then sustained until multi factor productivity is again reduced by combination of growth and resource depletion when the new platforms have reached maximum penetration.

That is, reduced multi factor productivity due to resource depletion creates the trigger for implementation of new platforms, with improved productivity that then reduces the incentive for the development and implementation of even newer platforms.

In response to the productivity/price trigger, the most significant innovative platforms impacting copper and gold processing in the last century were:

- An alliance between flotation and open pit mass mining techniques in the second decade of the 20th century opened up large near surface low grade disseminated resources, with the side benefit of enhancing base metals recoveries generally. The effect was global, with flotation a dominant concentration technology ever since.
- Solvent extraction was coupled with very large scale heap leaching of whole ore and extended to sulphide ores, enabling even lower grade resources to be developed in the 1980s and 1990s, enabling a distribution of ore between mill feed (for flotation) and leach feed.
- Carbon in leach technology was applied to gold extraction from low grade ores, having high impact in combination with new techniques for opening up refractory gold, such as pressure oxidation and fluid bed roasting.
- New smelting technologies also offset the impact of declining grades on all of value chain costs. Each of these new platforms fundamentally transformed the technology basis of new projects (and marginal production) within less than a single capital cycle.

It appears that real price increases above certain bounds, e.g. above $3/lb (real 2009) for copper, bring forward successful new technology platforms quickly, with sharp downward impacts on prices. Price effects are mature within about a decade. The evidence is that even a successful new platform doesn't result in sustained high rents for its developers. Benefits are in competition based on lower costs, rather than in higher margins.

So, while "in a commodity business the only true source of competitive advantage is low cost" (Michael Porter) "in the final analysis the only source of competitive advantage is innovation" (Tom Peters).

Simply put, in the minerals industry, a reduction in productivity associated with fast development of poorer quality resources directly reflects a lower than historical availability of "new platform" innovation. The link to sustainability is clear – irrespective of economic impacts and merits it is only through continued availability of new platforms that trade-offs between economic and social success factors can be avoided.

History suggests that new technology platforms are episodic. First commercial implementation awaits periods where new capacity is required at a rate that is faster than can be met by low cost brownfields expansions and debottlenecking, and marginal opportunities to expand using existing platforms are exhausted.

It is significant that commodity prices aren't expected to soften to historical averages in real terms as capacity that better meets demand is brought on, reflecting an indirect understanding that there are insufficient new platforms waiting in the wings for current first commercial use. Large projects are being shelved in recognition that new technology approaches will be needed (BHP, 2012). At the same time advances in mine automation and remote operation, rapid shaft and tunnel development, sensing (macro and micro) for resource discovery and ore selection, and whole ore processing are already extending current capabilities in mass mining and processing to deeper, lower grade and more refractory mineralization (McGagh & Stegman, 2012). These new platforms are considered to be material to corporate value.

Overall, the evidence is that the forces of globalization and rapid urbanization have reduced the supply of prototyped new platforms while increasing the need for them in new greenfields developments. The rapid promulgation of already commercial platforms has enabled increased demand to be met from more challenging resources, but with overall reduced productivity that provides an enhanced premium for future innovation. While there are new platforms in the wings (the history of innovation is far from over) it seems the generation of diverse options from which choices can be made opportunistically may still only be geared to the growth rates of the 1990s.

WHERE WILL NEW PLATFORMS BE BORN?

Experience with greenfields exploration suggests that structural change at the industry level can't impede the development of pathways to economic development and renewal for long. New structures emerge to fill any gap.

We can expect emerging and successful approaches to new platform development to continue to depend on strategic commitment, to rely on connection to strong operating cash flows, and to be associated with new capital investment in greenfields projects, significant expansions or major renewals.

Large, self-contained, in-house strategic process development facilities having full time staffing are now rare. Over the last decades there has been a growing reliance on outsourcing of laboratory and small pilot scale work to professional service providers, particularly where that work is primarily related to response testing and customization in support of feasibility studies. This work is opportunistic, taking advantage of the diverse capability that is available globally, and agile.

For proven technology platforms, distribution of process engineering, equipment testing, equipment manufacturing and licensing is the arena of both highly specialized and highly diversified companies, the latter with wide reach across technology platforms and global geography. These companies (examples are Outotec and Sandvik) play a key role in the propagation of new platforms in new capital projects, and the penetration of specific process technologies into new sectors.

For either large or smaller mining companies, work on strategic new platforms is aligned with either existing mineral resources or with targeted acquisition and development of particular resource types. For each company the focus is likely to be different, having greater breadth in companies that have greater diversification across commodities. Strategic technology platforms are generally narrow in focus but deep in detail. A well- known example, supporting new mass mining platforms for bulk commodities and minerals, is Rio Tinto's "Mine of the Future". Its components come together to support low cost mining of large, low grade, possibly deep mineralization, with faster development to the point of positive cash flows.

Development of strategic technology platforms is typically managed in distributed partnerships formed with companies having specialist skills that may have been acquired for altogether different purposes in other industries. Individual components of new technology platforms are developed in different partnerships, with the full technology advantage coming together in the operations and projects of the mining company. In some cases, where mining companies have a lead in common, they may seek to form an alliance that shares costs while keeping control of advantage.

That is, in-sourcing of the full scope of technology development is now rare. The transition from in-house development of technology platforms that suited specific geographically limited resource portfolios was relatively recent (commencing with industry globalization). Given opportunities for proving up new platforms where there are co-owned operations, some mining companies have ownership in process engineering companies that also provide limited in-house services in new platform development. (An example is XStrata).

For now, the new model for bridging the "valley of death" for whole new platforms appears to consist of two main paths:

- individual process developers, funded by equity or government/industry support for R&D, who take new platforms to first small scale prototyping, achieving scale up in new, smaller mines, and (eventually) license the developed technology through process engineering firms, and
- company managed alliances, funded by cash flows from operating mines, with partners chosen because of specific capability, and where components of the new platform come together for prototyping in mines and projects in company specific resource development plans.

Over time, this model places the broadest and deepest capability in prototyping and first commercial implementation into the hands of globalised process engineering firms and strategic partners. The strategic need and main cash flows required for success with new platforms will come from the mining companies themselves so that there is no transfer of risk. Global networking, and skilful management of intellectual property becomes a key skill for the mining company.

Should gaps emerge that would restrict the ability of a mining company to develop its resources effectively by customization of existing technology platforms, an alliance is the first port of call, with in-house development a slower but still valuable last resort.

There is no guarantee that structural adjustments will always provide a good match between innovation and the demands of growth (just as there is no guarantee that greenfields exploration will deliver the best resources to developers), but mechanisms exist to provide that match. History shows that over time the most successful companies will be those that are able to take most advantage of emerging gaps.

OPPORTUNITIES

At almost any time in the last two decades it seemed possible to state clearly where opportunities for innovation were emerging. Either well demonstrated technologies were promulgating to reach mature shares of production, or new technologies were in the R&D wings, awaiting intersections with favorable business circumstances.

A clear winner has been the advance of hydrometallurgy following the earlier development of heap leaching and pressure oxidation. Nevertheless, some of the outcomes appear at first to be paradoxical. Heap leaching for copper coupled with solvent extraction made a dominating penetration in new capital projects. However, there was no corresponding penetration for zinc, despite solvent extraction having penetrated both (albeit to a lesser degree in zinc), and heap leaching being technically demonstrated for zinc sulphides (Lizama et al., 2003).

In the case of copper, heap leaching dramatically changed the face of resource development, enabling large but low grade resources to take advantage of mass mining techniques with recovery of copper without the high costs of milling. Heap leaching has allowed copper resource developers to target large near surface resources that mainly occur at low grade. The availability of “smelt to metal” options for copper concentrates enabled parallel development of independent concentrator/smelter and whole ore leaching (hydrometallurgical) options.

In the case of zinc, no such opportunity emerged. For zinc there is no clear relationship between resource grade and resource size (Goodfellow & Lydon, 2007). Technology advances that enabled economic production from lower grade zinc resources provided few strategic advantages in economies of scale or life of mine. With the exception of oxide resources, pathways for zinc rely on first making a concentrate. The closure of much imperial smelting furnace capacity removed “smelt to metal” options for zinc. The irony is that while most zinc is made hydrometallurgically, virtually none is made by heap leaching.

Looking at the reasons that heap leaching didn’t emerge for zinc it is clear that there were already satisfactory and sufficient means of producing zinc, and no clear advantage to be had at the systems level from a new platform. At the time heap leaching was trialed for zinc it was far from clear that it would only displace concentrates production in copper for low grade ores, where its main advantage would be in supporting development of large, long life resources. It is sometimes difficult to see in advance what is clearly seen in retrospect. Zinc heap leaching may yet emerge as a means of treating low grade stockpiles at end of life.

An important message is that predicting future successful platforms is much more difficult than explaining what has driven successful developments to date. It is also impossible to contemplate a complete list.

Looking to work that is already in hand, we can list some (far from all inclusive) examples that are likely to take first commercial steps in the next decade or soon thereafter:

1) Copper heap leaching will extend to include low grade (primary) chalcopyrite ores.

1. Long considered a “golden dream” (Hurtado et al., 2010), the practicality of heap leaching of low grade primary copper ore at good recovery has already been reliably shown for some ore types (Hollitt et al 2008).
2. Low grade secondary copper ores are already heap leached in economic preference to milling, so chalcopyrite heap leaching merely awaits scale up that demonstrates recovery. (Analysis suggesting that milling will be economically superior to heap leaching (Peacey et al, 2011) should be updated to better reflect the observed high growth in new installations for heap leaching of low grade ores, at whole of

scope capital costs per metal unit that are comparable with milling of higher grade ores, taking into account achievable, modern, multi-lift metal recoveries).

3. Large projects are currently planned, requiring only successful demonstration in large heaps (Rio Tinto, 2011). Issues associated with arsenic contamination and fine polymetallic intergrowths are also avoided, providing multiple benefits.

2) New large copper developments will rely more on underground mass mining (caving) coupled with mill/concentrator circuits or open pit mining dependent at least in part on chalcopyrite heap leaching. Underground development times will reduce substantially.

3) Gold will be produced commercially without cyanide.

4. The benefits in increased recovery and reduced reagent costs available when novel lixiviants are used for processing double refractory gold ores provide a continuing incentive to persevere with commercial developments47. Residual environmental and safety concerns attached to the use of cyanide will also be resolved.

4) Pressure oxidation leaching of zinc concentrates will penetrate further, including in stand- alone operations.

5. The advent of commercially proven zinc solvent extraction that effectively separates impurities while upgrading zinc tenor (Fuls et al., 2005), when coupled with the ability to separate iron as hematite provides new stand-alone benefits for pressure oxidation of zinc, especially for low grade concentrates.

5) Flotation and leach circuits will more commonly be integrated.

6. As leach circuits promulgate further for ore types that don't suit milling and concentration by flotation, opportunities to use chemicals generated in leaching to assist mineral separations are created. Chemical liberation of sulphides from pre-concentrates can provide large benefits in grade/recovery curves in subsequent final flotation, especially where there are ultrafine associations, such as in sediment hosted ores (Baxter et al., 2003). Further, pressure oxidation of recovered sulphides can provide the heat, acid and iron (where desired) for a supplementary leach circuit(Marsden, 2009).

6) Ore discrimination and selection will become a more primary means of reducing milling energy. Development of sensing tools will provide opportunities for more sophisticated grade control for mill feeds, both at the mine face and after crushing, and for mill control. A driver for these developments is the enabling development of lower grade resources without as much limitation from milling capacity and costs (McGagh & Stegman, 2012).

7) Mine automation and remote operation will gain large penetration, reducing costs, improving safety and reducing the social impacts of fly-in fly-out operations.

8) As hydrometallurgical processes continue to penetrate into commercial use solvent extraction will find greater use in concert with chemical precipitation to produce sequential separations in leach streams from complex polymetallic ores, concentrates and residues.

9) As the circumstances in rock hardness and circuit response characteristics that best separate SAG milling from new, lower energy milling platforms (e.g. HPGR) are established each will find a stable share of comminution demand.

10) Fuels for heavy vehicles, rail and shipping will develop further to reduce the impacts of carbon pricing on business costs (e.g. LNG fuelling).

The promulgation of these new platforms will depend on their intersection with strategic imperatives, some of which are already in place. In particular, we can expect this to occur where new mining and processing capacity will be installed, so first promulgation of new platforms will now have a higher focus on China and India. By the time another decade has passed we can expect a review of new platforms to include a large number that have originated where growth is now highest.

These are only some of the many possibilities that can be considered in the next decade. Many can't be apparent to us now. IMPCXXVI 2012 will consider many more.

SUMMARY

There is strong evidence that the mining and mineral processing industries have continued to benefit from innovation in the last decade, during which industry dynamics have changed from low growth under continued price pressure to high growth under continued cost pressure. In particular, there has been strong promulgation of available new technology platforms in new capital installations that have been drawn into production.

However, it also seems that for the first time in decades the pace of innovation has been surpassed by the pace of growth, with resource depletion having the effect of a net reduction in industry productivity.

We can expect that as high growth in demand continues into the second decade of the 21st century, with some interludes that may be expected but perhaps not always predicted, new platforms will find their way into development wherever there is a strategic imperative that sustains them across business cycles, with that imperative growing. The well-established link between new technology platforms and balanced, sustainable outcomes suggests we will see an acceleration of development, with long term competitive success critically dependent on use of available new platforms in new capital installations.

Business approaches to technology development are now highly outsourced, with global networking and formation of partnerships as core capabilities. As our organizations mature to participate more deeply in “the Asian Century” the intersection of strategic needs with technological capability is likely to put a new complexion on the development and promulgation of mining and processing platforms. First applications of technologies will be more geographically diverse, as will the locations of key networks and partners.

REFERENCES

ABB, 2010.High pressure grinding rolls applications, www.abb.com/minerals.

Arthur, P.M., Fountain, C., Hunt, S. and Tupperainen, J., 2003.The Isasmelt process – an example of successful industrial R&D, Yazawa Symposium, San Diego, March 2003.

Australian Government Policy Transition Group 2010, Policies to promote exploration expenditure, 1 October 2010, pp107-112.

Bartlet, R. W., 1998.Solution Mining: Leaching and Fluid Recovery of Materials, Routledge publishers, 1998, p.113.

Batterham, R. J.,2003. Ten Years of Sustainability: where do we go from here?, Chemical Engineering Science 58 (2003) 2167 – 2179.

Batterham, 2012.Paper in IMPC XXVI.

Baxter, K., Dreisinger, D., and Pratt, G., 2003.The Sepon copper project: development of a flowsheet, Hydrometallurgy 3, Vol 2, TMS 2003, pp1487-1502.

Berezowski, R.M, Collins, G.S., Kerfoot, D.G.E, and Torres, N., 1991. The commercial status of pressure leaching technology, JOM 43(2), 1991, pp 9-16.

BHP Billiton, http://www.bhpbilliton.com/home/investors/news/Pages/Articles/Olympic-Dam.aspx.

Chacon, J., Gopfert, H., Cade-Adepe, and Ovalle, A., 2004.Thirty years evolution of block caving in Chile, MassMin 2004, Santiago, 22-25 August 2004, pp 386-392.

Courtenay, A., 2012. http://www.csiro.au/en/Portals/Publications/Magazines/resourceful/Global-adoption.aspx, 9 Jul 2012.

Crowson, P., 2003. Mine size and the structure of costs, Resources Policy 29, 2003, pp 15–36.

Davis, M., 2011.Mining: opportunities and challenges, MCA Minerals Week, June 2011.

Dreisinger, D., 2009. Hydrometallurgical Process Development for Complex Ores and Concentrates, Proceedings of Hydrometallurgy 2009, Johannesburg, March 2009, South African Institute of Mining and Metallurgy.

Dry R.J., Batterham R.J., Bates C.P., and Price D.P., 2002. Direct Smelting: Why Have So Few Made It? International Conference on Iron Ore Processing, Kiruna, June 2002.

Dunne, R., LeVier, M., Acar, S., and Kappes, R.,2009.Newmont's contribution to gold technology, World Gold Conference 2009, The Southern African Institute of Mining and Metallurgy, 2009, pp 221-230.

Enders, M.S. and Leveille, R.A (2004)., Meeting Quarter-Century Exploration Requirements in a Quarterly Results Business World, PACRIM 2004, p27.

Fassell, W.M. Jr., 1962.Hyper-atmospheric extractive metallurgy – Its past, present and future, Pure and Applied Chemistry,1962, Vol. 5, Issue 3, pp. 683-700.

Fuls, H. Sole, K.C., and Bachman, T., 2005. Solvent extraction of zinc from a primary source: the Skorpion Zinc experience, International Solvent Extraction Conference, Beijing, China Academic Journal Electronic Publishing House, 2005.

Goodfellow, W. and Lydon, J., 2007.SEDEX Deposits, in Mineral deposits of Canada—A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods, Geological Association of Canada, 2007,p. 163–184.

Harding, A., 2010.Long term copper fundamentals expected to remain strong, Rio Tinto corporate presentation to analysts, April 2010.

Harvey, B.E., 2002.New Competencies in Mining — Rio Tinto's Experience, CMMI Congress Cairns, Qld, 27 - 28 May 2002, pp1-6.

Herbertson, J., 2005. Process Engineering for a Sustainable Future, National Process Forum, 11 March 2005.

Hollitt, M.J., McClelland, R.A., McIntyre, S.V., and Smart, J., 1994. The CRA RUTILE Process – Implications for Titania Feedstock Supply, 11th Industrial Minerals Congress, Berlin, April 1994.

Hollitt, M.J., Kisler, J.P., and Raahauge, B., 2002. The Comalco Bauxite Activation Process, Sixth Alumina Quality Workshop, Brisbane 2002, pp. 115-122.

Hollitt, M.J., 2005. Risks in development and commercialization of new process technology, keynote paper for John Floyd International Symposium on Sustainable Developments in Materials Proc., Melbourne, July 3-6 2005.

Hollitt, M.J., 2006.Process Technology: A Sustainable Business Context, Met Plant Conference, AusIMM, 19 September 2006.

Hollitt, M.J., Shaw, R.W. and Rees, K., 2008. Leaching Ores, International Patent Application PCT/AU2008/000928, published 31 December 2008.

Hourn, M. and Duncan, D.W., 2012.Commercialisation of the Albion Process, ALTA conference 2012, 1 Jun 2012.

Houston, Schiller, Atchison, Crawford, Norman & Ryser, 1984.The Death of Mining, Bus. Wk., Dec. 17, 1984, at 64.

Humphreys, D., 2002. Rio Tinto report to analysts, Sydney, 22 February 2002.

Hurtado-Guzmán, C., Jo, M. and Bastidas, G., 2010. Chalcopyrite atmospheric leaching, the golden dream for hydrometallurgists: experience, state of the art, and outlook, Hydroprocess 2010, Santiago, 11-13 August 2010.

ICMM, https://www.icmm.com/about-us.

International Copper Study Group, World Copper Factbook 2012,www.icsg.org.

Landmark, J., 1992.Gunpowder Copper: in-situ leaching at Mammoth Mine, NW Qld, AusIMM Bull., no.6, p.12, 1992.

Lizama, H.M., Harlamovs, J.R., Belanger, S. and Brienne, S.H., 2003. The Teck Cominco HydroZinc process, Hydrometallurgy 2003, Vol 2., TMS, pp1503-1516.

Marsden, J.O., 2006, Recent developments in copper hydrometallurgy, Sohn International Symposium on Advanced Processing of Metals and Materials, TMS, August 27-31, 2006 – San Diego, CA, USA.

Marsden, J.O., 2009. Lessons Learned from the Copper Industry Applied to Gold Extraction, World Gold 2009 Conference, Johannesburg, South Africa, October 30th, 2009.

Meijer, K., Guenther, C., and Dry, R.J., 2011.HIsarna Pilot Plant Project, METEC Conference, Dusseldorf, 27 June 2011.

Michelmore, A., 2012.Mining for the Asian Century, Melbourne Mining Club address, 28 August 2012.

Mishra, C.S.K and Champagne, P., Biotechnology Applications, I.K. International, at p. 309.

Peterson D. J., LaTourrette, T., Bartis, J.T., 2001.New Forces at Work in Mining: Industry Views of Critical Technologies, RAND Monograph Report MR-1324, http://www.rand.org/pubs/monograph_reports.

Minerals Council of Australia, 2010.Annual Report 2010, p.14.

Minerals Economics Group, 2012. World Exploration Trends 2012, PDAC International Convention, Toronto, 3-6 March 2012.

Parry, J., 2001.The future of mineral exploration in Australia, CPA Resources Convention, Perth, 16 August 2001.

Peacey, J., Schaming, J., and Csicsovszki, G., Chalcopyrite Heap Leaching - An Evaluation of its Current Status & Potential Future Viability, Hydrocopper 2011, Vina del Mar, 6-8 July 2011.

PwC, 2012.Productivity Scorecard, pwc.com.au, March 2012, pp4-14.

Readett, D., Walsh, D, and Lancaster, T., 1997.Girilambone Copper Company – Developments in heap leaching of copper sulphide ore, 3rd Annual Copper Hydrometallurgy Roundtable, British Columbia, Nov 2-5 1997.

Rio Tinto, 2011.http://www.riotinto.com/annualreport2011/performance/copper.html

Sainsbury, C., Wilkins, C., Seeney, D, and Schwarz, M., 2012.Block Caving - The future of underground mining, Citi Investment Research and Analysis, 31 May 2012.

Sangster, D.F., 2009. Geology of base metal deposits, Encyclopedia of life support systems Vol. 6 (Geology), UNESCO, 2009, pp. 91-116.

Schodde, R.,2010. The key drivers behind resource growth: an analysis of the copper industry over the last 100 years, 2010 MEMS Conference, Phoenix, 3 March 2010.

Smith, M., 2008.Emerging Issues in Heap Leaching, EuroGeo4 Paper number 270, Edinburgh, 7 September 2008.

Smith, P., 2009. The processing of high silica bauxites – Review of existing and potential processes, Hydrometallurgy 98 (2009) at p.169.

Stevens, G.A. and Burley, J., 2003.Piloting the Rocket of Radical Innovation, Industrial Research Institute Inc. Research Technology Management, March-April 2003, pp 16-25.

Topp, V., Soames, J., Parham, D., Bloch, H., 2008.Productivity in the Mining Industry: Measurement and Interpretation, Productivity Commission Staff Paper, Australian Government, December 2008.

Twigge-Molecey, C., 2003.Knowledge, technology and profit, Cobre 2003, Met. Soc. CIM, Santiago, 30 Nov 2003.

U.S. Census Bureau. 2012., Statistical Abstract of the United States: 2012, International Statistics, Table 1379, p.862.

Upstill, G., and Hall, P., 2006.Innovation in the minerals industry – Australia in a global context, Resources Policy 31, 2006, pp 137-145.