Technology Development and Competitive Advantage: Sustainable or Short Term?

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Technology development has played a crucial role in the minerals industry throughout history. The development of new technology allows mankind to produce metals and minerals at progressively lower cost of production in real terms, and therefore at progressively lower prices, improving their availability, accessibility and utilization worldwide. However, the developers of such technology are not guaranteed to reap the benefits from this effort: There is an expectation that technology developers will gain an advantage over their competitors. Is this a short-term benefit that results from a temporary cost or efficiency improvement, or is it a sustainable longer term "edge" that prevails even after metal or mineral price has been eroded by the implementation of a major step change technology? This issue is examined by reference to several case study examples in the copper industry.

Background

The development and adoption of new technology has played a crucial role in the commodity minerals industry throughout history. As new, cost-efficient technologies are commercialized, the cost of production decreases, and this enables lower grade ore to be processed profitably. This in turn increases the availability and supply of the metal or mineral of interest, and ultimately (in a free market environment where the supply-demand balance determines price) inevitably decreases the metal or mineral price. This leads to the question: Why should mining companies invest in (new) technology development if the result is a decrease in the product price? The answer is to achieve competitive advantage, where the application of new technology enables one or more commodity producers to gain a cost advantage over their competitors, at least for a period of time. The more sustainable and longer term, the greater the competitive edge achieved.

Technology development is costly and, in general, the greater the potential benefit, the higher the cost. The commercial implementation of new technology is inherently risky — the technology has not been applied before and must be proven over time. The risk must be managed, and this involves additional cost and intellectual effort. Finally, both technology development and commercial implementation typically requires significant investment of time. This latter factor is significant where the metal/mineral of interest is a commodity that exhibits cyclical pricing with extended periods of depressed pricing followed by periods of strong pricing. This will be discussed further later.

Sources of Competitive Advantage

There are many sources of competitive advantage that can result from the development and application of new technology. Each of these is listed and briefly reviewed below:

1. Prevent competitors from using the technology

The mining industry is well-accustomed to the use of patenting of technology, processes, equipment, chemicals and reagents, non-commodity supplies, and other aspects of the mining industry. Patents can provide companies with an effective way to protect competitive technology for a significant period, up to twenty (20) years. In addition, the ability to maintain technical know-how, operational expertise and trade secrets as confidential and proprietary information is an alternative (or complimentary) way to protect competitive technology in both the short and long term.

2. Make it hard for competitors to use or duplicate the technology

In some cases, maintaining technical know-how, operational expertise and trade secrets as confidential and proprietary information may be a successful strategy in achieving competitive advantage. The downside with this option is that it is difficult to keep such information as truly confidential and proprietary for a significant period of time. In addition, such a strategy stifles technical and operational interchange between mining operations and companies, and this approach is probably unproductive in the long term.

3. Apply the technology more rapidly than competitors

Being the first to apply a particular technology cost effectively, to rapidly improve the technology, and quickly make a significant impact on a substantial proportion of overall production and costs may provide significant competitive advantage. Alternatively being a "fast follower " or a rapid adapter of technology may provide similar benefits.

4. Apply the technology better than competitors

If you apply a particular technology better than your competitors, either with greater efficiency, at a larger scale, or at lower cost (capital or operating), then competitive advantage may be achieved. A company's ability to do this depends largely on the quality of people and the resources at their disposal to effectively apply technology and innovate within their operations. As a practical matter, it is difficult to achieve sustained competitive advantage by this manner alone because of the mobility of staff (much greater in recent years than historically) and the relatively rapid and free interchange of information throughout the mining industry.

5. Apply the technology to a greater proportion of metal production than competitors

If a technology can be applied broadly across multiple operations or divisions within a company, it is likely to be more advantageous than its application at a single operation by a competitor. For example, a company that can effectively apply a new nickel laterite hydrometallurgical process to 50% of their mineral reserves will derive greater advantage than a similarly sized company that applies the same process to only 5% of their reserves.

6. Derive more value than competitors due to specific geographical, geological or other conditions

One company may have specific geographical or geological factors or other site-specific conditions that renders the application of a particular technology to be more favorable at one or more of their sites than for others. This can be a source of sustained competitive advantage. An example might be a blend of potential acid-producing mineral resources located close to acid-consuming mineral resources that can utilize a technology that produces acid as a by-product.

7. People development and motivation

Technology development activity excites, invigorates and motivates capable and energetic technical and

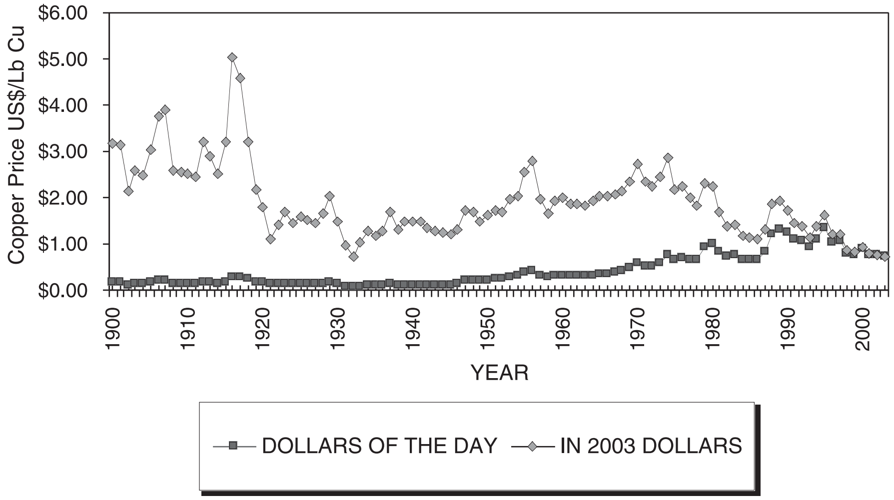

Figure 1 Annual copper price between 1900 and 2003

operating people. Technology development activity gives staff the opportunity to get involved in something new and to create value out of nothing, purely through innovation. This environment gives staff the chance to grow along with the technology being developed. Technology development breeds a contagious enthusiasm — a commodity that can't be easily bought or traded.

Technology Development and Implementation

The "players " in the implementation of new technology fall into four categories, as follows:

"First Mover"

The first mover has the highest risk in applying a new technology, and generally the highest cost. However, there is the potential to apply the technology rapidly and leverage the technology with competitors to gain advantage. The first mover has the potential to reap the largest benefits and, potentially, a sustained competitive advantage.

"Fast Follower " (or Adapter)

The fast follower gains the benefit of the "first mover" experience with the implementation of a new technology. The fast follower or adapter has lower risk compared with the first mover, but risk may still be high because some aspects of the technology may not be fully proven. There may be some potential for the fast follower to leverage the technology and gain significant competitive advantage. In some cases, there may be an ability to gain greater competitive advantage than the first mover as a result of lessons learned.

"Conservative Follower"

The conservative follower takes a low-risk approach, but does whatever needed to stay competitive over the long term, even if the benefits may not be achieved from the technology during its initial period of application. The conservative follower has little opportunity to leverage the technology to achieve competitive advantage and may end up as the one being leveraged.

"Lagger"

The lagger takes the lowest risk option at every opportunity and stays with well-proven technology. They are the last to adopt and apply new technologies, but rely on other ways to stay competitive (e.g., resource quality, captive market or integrated market) or end up exiting the market voluntarily or involuntarily.

Case Study: Technology Development in the Copper Industry

The Copper Price Cycle

Let us consider the example of technology development in the copper industry throughout the 20th century. Figure 1 shows the annual average copper price from 1900 to 2003, with the price expressed in constant 2003 dollars. The period is characterized by peaks and valleys that reflect the market forces for the commodity traded in the western world and, more recently, on a more global basis. During periods where demand has outpaced supply, the peaks occur. Conversely during periods where copper supply exceeds demand, then periods of low price prevail. In general terms, peaks have occurred in 1907, 1912, 1916, 1929, 1937, 1947 – 48, 1956, 1970, 1974, 1979 – 80, 1989, and 1995. Similarly, valley "troughs " have occurred in 1911, 1914, 1921, 1932, 1945, 1958, 1972, 1978, 1986, 1993 and 2002.

During the period 1900 – 2003 shown in Figure 1 (103 years), there have been approximately 9 major price cycles. Table 1 shows the major periods of increasing copper price.

Without exception, these periods of increasing price are related to strong copper demand and consumption, low production (either slow recovery of curtailed production and/or insufficient new production brought onstream to keep pace with demand), or combinations of the two.

Table 2 lists periods of decreasing copper price.

The periods of decreasing price are related to 1) periods of weak copper demand, with excess copper going into exchange invento-

Period	No. of Years
1902 –1907	5
1911 –1916 (Beginning of 1st World War)	5
1921 –1929	8
1932 –1937 (Post-depression)	5
1945 –1956 (Post-2nd World War)	11
1958 –1970	2
1986 –1989	3
1993 –1995	2
Total	41

Table 1 Periods of increasing copper price

Period	No. of Years
1900 –1902	2
1907 –1911	4
1916 –1921	5
1929 –1932	3
1937 –1945	8
1956 –1958	2
1970 –1986	16
1989 –1993	4
1995 –2003	8
Total	52

Table 2 Periods of decreasing copper price

ries or other easily accessible inventories, 2) excessive copper production, either due to slow curtailment of production during a copper cycle downturn or too much new production brought on line in excess of demand requirements during the peak period of the copper price cycle and, as some have postulated, 3) technology developments that increase production and/or lower the cost of production significantly and on a sustained basis.

While there is no doubt that the supply-demand balance drives the copper price, the question of whether significant technology development adversely affects the copper price is more complex. This issue will be examined further using three examples of step change technology development in the copper industry: open pit "bulk " mining, flotation, and solvent extraction-electrowinning (SX/EW).

Large Scale (Bulk) Open Pit Mining

The widespread adoption of bulk, open pit mining methods in the 1920s and 1930s represented a significant technology development for the copper industry. During the period from 1910 to 1945 there were significant increases in ore milling rates, in large part made possible by the bulk open pit mining method. According to A. B. Parsons, Daniel C. Jackling first proposed the use of large-scale, bulk, open pit mining at Utah Copper in 1899. His proposal was based on mining 2,000 tons per day of ore. At the time his proposal was made, the largest copper concentrator was 500 tons per day, so his proposal represented a "stretch " for both mining and processing technology. In 1905, Utah Copper made the decision to proceed with the open pit plan and production started in 1907.(1) It may seem obvious to us now that open pit "bulk" mining makes good economic sense, but at the time this was far from obvious and intuitive. Utah Copper was milling almost 15,000 tons per day by 1910, increasing to 25,000 tpd in 1913 and to about 75,000 tons per day by 1940.(2,4) By contrast, Morenci began large-scale mining in 1942, supplying ore to a 25,000 tons-per-day concentrator, which was increased to over 40,000 tons per day by 1947. El Teniente (originally "Braden") was processing only 6,000 tons per day of ore prior to 1920, but increased to 15,000 tons per day by 1927, and then to about 30,000 tons per day by 1947. Open pit mining started at Inspiration in 1948 and at Ray in 1950. Large-scale open pit mining started at Chuquicamata in about 1927 at a rate of more than 20,000 tons per day and increased to about 50,000 tons per day by 1952.(2) This chronology indicates that many companies were slow to adopt open pit mining methods, even though this ultimately proved to be the most effective mining method.

The above discussion indicates that the major copper producing (porphyry) mines increased ore mining and processing rates dramatically between about 1925 and 1947, with the majority of the major expansions occurring between 1940 and 1947. By 1947, 73% of the US copper production was obtained by open pit mining. (6) Similar developments in Chile followed. As open pit mining took off, the increased scales of economy for the bulk mining and significantly larger processing facilities reduced the cost of production significantly. Then, the mining engineers of the day translated the reduced costs into lower cutoff grades, resulting in a steady decrease in the average grade of ore processed. At many operations, ore grades dropped from over 2% (typical underground mining grades) to 1.5% and in some cases below 1%. Gradually, as ore grades decreased and as wages and other costs inflated over time, production costs shifted back to the prior levels.

A review of the copper price curve (Figure 1) shows that the metal price experienced a sharp decrease from 1916 to 1921, but then a long period of general price increase occurred from the early 1920s to the mid-1970s. This is discussed further at the end of the flotation section.

Re-employment Listings

The re-employment program is a FREE service offered by ESWP on an ongoing basis to all unemployed members and Affiliated Technical Societies members. These individuals are eligible to submit a resume and have a one paragraph summary of their qualifications published in the e-TC, the online TechniCalendar — ESWP's monthly newsletter and calendar, and in the *Pittsburgh ENGINEER*, ESWP's quarterly publication. Potential employers contact ESWP to receive candidates' full resume.

Anyone who meets the above qualifications and would like more information should contact ESWP at 412-261-0710 or eswp@eswp.com.

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#142 — Seeking a position in construction management in operations, business development or management. Experience: construction management, business development, construction inspection, material sampling/testing. Skills: strong computer skills including proficiency in Word, Excel and other specialty applications; excellent written and verbal communication skills. Degree: BS-Env.Sci, BS-Civil Eng., MS-Civil Eng.

#144 — Seeking a program/project management position to utilize 17 years of experience in a dozen different industries, domestic/international, commercial/government projects, including P/L responsibility, all phases of project life-cycle, risk management, salvaging damaged projects, and optimizing performance of operations, processes and teams. Degrees: MS, PhD, PMP.

#**146** — Seeking position as chemical process engineer. Hard working, tenacious and experienced chemical process engineer; for the past 10 years, the only engineer in a chemical plant with 80 employees, five batch reactors and two Fisher-Provox DCS systems. Experience is broad and includes: process improvement, process trouble-shooting, process control, training, regulatory management, and more. Degrees: MS, BS Chemical Engineering.

#148 — Results-driven manager with expertise in project management, production planning, process improvement, and operations management. Expert at turning around troubled projects. Skilled in translating between business needs and technology requirements. Excellent mentor and manager.

#149 — Customer focused IT Manager with experience in network implementation and support, application, user and desktop support. Skilled at vendor management and purchasing. Experienced in NetWare, Windows and Linux. Implemented variety of systems including Citrix WinFrame, Opentext Document Management and Lotus Notes.

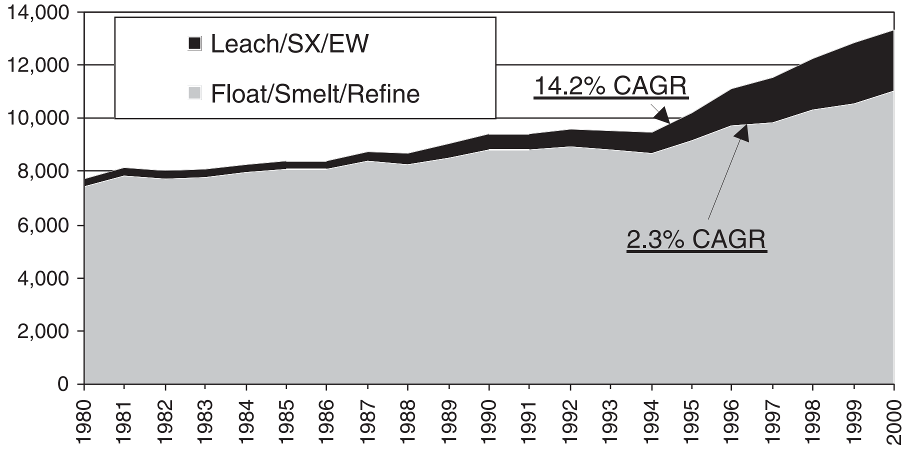

Figure 2 Annual copper production by leaching/SX/EW and flotation/smelting/refining from 1980 to 2000

Flotation

Bulk-oil flotation was patented by Mr. Francis Elmore in 1898 and was first applied commercially on a small scale at the Glasdir mine in Wales in 1899. It was described as a "dirty and nasty process " that cannot have presented much appeal to the owners and operators of the mining and smelting operations of the day. Mr. Elmore further developed this technology into a vacuum-oil flotation process in 1927, and several others developed and patented flotation processes between 1902 and 1907. The Minerals Separation Company was established in 1903 specifically to purchase and exploit the flotation patent that incorporated the use of air, water-soluble oil and dramatically reduced the amount of oil required (below 1%). The early days of flotation, between 1907 and 1923, are marked by extensive legal wrangling and litigation between many of the major copper producers of the day, Minerals Separation Company and others involved with the development and commercialization of flotation technology? This makes for highly entertaining nighttime reading.[3,4]

A number of copper producers tested and used flotation on a small scale. The Central Mill of Broken Hill in Australia is generally recognized as the first commercial application of the flotation process as we know if today, where the process was used to recover zinc. A large number of companies around the world tested the process between 1907 and 1915. In 1907. The Butte and Superior Copper Co. installed a 150-tpd flotation mill for zinc recovery and, because they ignored the Minerals Separation Patent, provoked the first lawsuit. In 1912, Inspiration Copper started testing the response of chalcocite ore to flotation and achieved 87% recovery from 2% copper ore into a concentrate containing 15% copper. The concept was to use flotation in place of traditional gravity concentration. Inspiration built a 50-tpd pilot plant in 1913 and a 600-tpd facility in 1914. Inspiration subsequently agreed to license the flotation process from Minerals Separation Company in 1915, and a 15,000 ton-per-day mill was commissioned in 1915. This plant achieved about 80% copper recovery, with approximately 72% obtained by flotation and 8% by gravity concentration. At the time. This was the second largest concentrator in the world, superceded only by Utah Copper's gravity-based concentrator (25,000 tpd).

Several copper companies tested and licensed the flotation process from Minerals Separation Company, including Anaconda, Miami and Utah Copper. Chino had a 15,000 ton-per-day concentrator that utilized flotation in operation in 1915. In the case of Utah Copper, flotation was first employed at Garfield in about 1918 at a modest scale, and then subsequent expansions and remodeling resulted in the eventual total conversion to flotation by about 1930. During this period, copper recovery increased from 64% prior to 1917, to over 80% by 1919, and then to 90% by 1930.

The importance of these initial large-scale commercial applications cannot be overstated. Firstly, flotation provided a step change in concentrator efficiency and performance by increasing the recovery from typical chalcopyrite and chalcocite ores from typically 64% – 66% by gravity concentration to between 64% - 66% by flotation. Secondly, the widespread commercialization of flotation occurred in parallel with the broad application of open pit bulk mining methods in the copper industry. These two technology developments were intimately linked. Referring to the commercialization of the flotation process, Hines (4) makes the statement "the total effect on the thinking of the mining industry was enormous even if the industry was slow in accepting all the new ideas." In this statement, he was apparently referring to the slow rate of adoption of flotation technology by the industry. But how slow really was this rate? The first large commercial facility was commissioned in 1947. By 1928, there were large flotation mills at Utah, Chino, Miami, Inspiration, Braden, Chuquicamata, and many other copper mines. By 1930, over 50% of US copper production was generated by flotation. It is estimated that over 65% of copper production worldwide (which was dominated by the US and Chile) came from flotation plants at that time.

It is notable that the concentrator operating costs for flotation were about the same as those for the traditional gravity concentration process. However, on average, flotation technology increased copper recovery by about 15%, increasing the divisor by an equivalent amount for the purposes of production cost calculation. This was a huge step change in copper production technology.

Who benefited from the development of flotation? 1) The owners of Mineral Separation Company made a significant amount of money off licensing flotation technology until their patents expired in 1907. The company was liquidated at that time. 2) The first commercial users of the technology and the fast followers gained a significant and sustained production cost benefit. In addition, the reserves of many mines were increased as a result of lowering the cutoff grade of ore processed by up to 20%. This in turn allowed expansions to occur. It is possible that the widespread commercial application of flotation contributed to the dramatic copper price decline experienced in 1930 – 1932. However, undoubtedly this dramatic price decline was heavily influenced by the Great Depression in the US, which greatly reduced copper demand for an extended period. It is interesting to note that this was immediately followed by an extended period of generally increasing price from 1933 – 1973, with some relatively minor dips. It is impossible to determine the exact impact of flotation on copper price. What is clear is that the most progressive, adaptive and innovative copper producers were able to achieve 10 –15 years of competitive advantage from the rapid, broad and large-scale adoption of flotation at their operations. The slow adopters and "laggers " eventually followed or disappeared. By the 1970s, over 90% of primary copper (excluding scrap) was produced by flotation. Flotation has maintained its position as the dominant technology for processing of chalcopyrite and chalcocite ores from 1930 to the present day, although heap leaching is playing an increasing role in the processing of chalcocite ores.

Solvent Extraction and Electrowinning

The third and final example of technology development in the copper industry is the commercialization of solvent extraction (SX)and electrowinning (EW). Liquid ion exchange technology, or "SX " as it is now called, was first used commercially at the Ranchers' Bluebird mine, near Miami, Arizona, in 1968 (5) SX/EW technology replaced the preexisting iron cementation process for the recovery of copper from low-grade copper solution obtained from leaching of oxide ore. Nine million pounds of copper were produced by the new process during its first full year of operation. In 1971, Bagdad installed an SX/EW facility to recover copper from stockpile leach solution. A tailings leach operation was commissioned at the Nchanga division of Zambia Consolidated Copper Mines (ZCCM) in 1974, utilizing SX/EW technology for copper recovery. Additional commercial-scale plants were then installed at Miami-BHP (1976), Miami-Inspiration (1979), Cananea (1980), Pinto Valley (1981), Tyrone (1984), Ray (1985), Gibraltar (1986), Morenci (1987), Sierrita (1987), Chuquicamata (1987), and Chino (1988). Widespread adoption in Chile did not occur until the mid-1990s with applications at Zaldivar, El Abra, Mantos Blancos, Quebrada Blanca and many others.

The major advantages for most of these operations were 1) the replacement of costly and labor-intensive iron cementation process that generated a precipitate for further processing by smelting, and 2) the ability to expand heap and stockpile leaching operations significantly by the use of larger volumes of leach solution as a result of the ability to efficiently process large volumes of low-grade copper solution by SX. This provided a low-cost supplement of copper production to the core flotation concentrator facilities in many cases. The Miami-Inspiration concentrator shut down in 1986 and the Tyrone concentrator shut down in 1992, resulting in both of these operations evolving into an all-SX/EW production base. These events were major milestones that allowed copper companies to consider stand-alone leaching and SX/EW operations to be developed, providing a lower cost process for extracting copper from chalcocite and oxide ores. While many factors affect the production cost calculation and comparison between leaching/SX/EW and flotation/smelting/refining processes for chalcocite ores, it is apparent that the former process route initially presented a 15% – 25% cost advantage. Once again, this was not intuitively obvious at the time and it took a number of years for this concept to germinate into a commercially applicable technology. In the 1990s many stand-alone chalcocite and oxide ore leaching/SX/EW operations were developed and successfully placed into production.

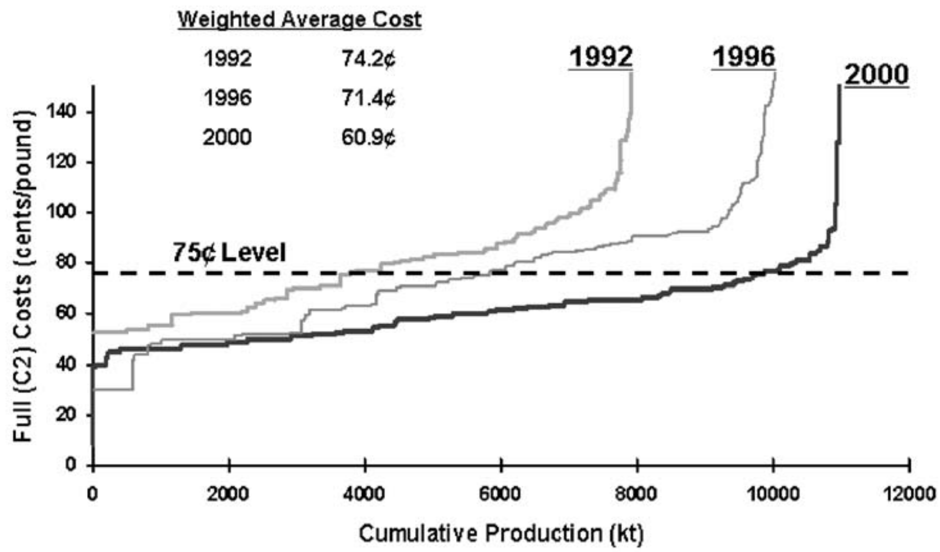

Figure 3 Estimated copper production cost curves for 1992, 1996 and 2000

How did the advent of SX/EW technology affect copper market fundamentals? Figure 2 shows the production of copper by leaching/SX/EW and flotation/smelting/refining from 1980 to 2000. SX/EW accounted for about 3% of total primary copper production in 1980, increasing to about 8% by 1927, and to just over 18% by 2000. Similarly to flotation, it is difficult if not impossible to directly link the commercialization of SX/EW technology with a period of copper price decrease. The most likely period of impact is the period 1994 – 2000 when the proportion of copper produced by SX/EW more than doubled. It can be seen that the copper price decreased significantly during the period 1995 – 2001; however, other market forces played a significant role during that period and it is unlikely that technology played a dominant role. The next decade of the copper cycle will reveal more on the impact of SX/EW technology.

Based on remaining copper reserves by ore type, it is projected that leaching/SX/EW will account for about 21% of total production by 2010. This assumes that there is no technology breakthrough for the atmospheric leaching of low-grade chalcopyrite ores and excludes any impact of leaching processes to treat concentrates as an alternative to smelting and refining.

Other Technology Developments

There have been many other technology developments that are not discussed here. Some of the other significant developments include the reverberatory furnace, tube and ball milling, flash smelting, autogenous and semi-autogenous milling, in-pit crushing and conveying, computer control of processing and mining operations, and use of increasingly large-scale mining equipment. (7) There have been many other incremental improvements, changes and innovations that have helped shape the copper industry over time. Many of these have provided sustainable competitive advantage to the users of the technology.

Impact of Technology Developments on Production Costs

Figure 3 shows the full production cost curve for primary copper production (excluding scrap) for 1992, 1996 and 2000. The full cost includes cash production cost plus depreciation and amortization. The graph shows that as production volume increased over time from 1992 to 2000, the cost curve flattened and the average production cost decreased from \$0.74/lb to \$0.61/lb. A significant portion of this decrease was due to low cost, new production coming on line, but a portion was due to technology developments. However, an important point to make from this graph is that relatively modest decreases in production cost can have a huge impact on competitiveness between mines and companies. For example, a 15% decrease in production cost, say from

$0.70/lb to $0.60/lb, moves a producer from the bottom of the fourth quartile to the top of the second quartile on the cost curve. The producers who adopted open pit mining, flotation and SX/EW technology reaped the benefit of similar order-of-magnitude changes in their cost profile and changed the fate of their companies forever. Sustainable competitive advantage indeed.

Summary and Conclusions

Competitive technology developments have reduced the production costs for all commodity metals over time, either through significant step changes, such as those discussed in detail above, or by incremental change. In the case of copper, there is some evidence that major step change technology developments have contributed to an increased availability of commodity metals, resulting in downward pressure on metal prices. However, other market forces including reserve and resource availability and quality, mine investment decisions, commodity metal demand, economic conditions and trends, and other factors have dominating effects on the long-term commodity metal markets.

In the case of the three examples used in the copper industry case study, much of the industry was slow to adopt new technology, even after its effective use had been clearly (and publicly) demonstrated. Step change technology developments allow the innovative and progressive producers to achieve a sustained advantage over a significant proportion of their competitors for periods of 10 –15 years, and in some cases even longer.

While the use of patenting and the confidential retention of proprietary know-how, trade secrets and expertise can be effective in providing short-to medium-term competitive advantage, it is probably other factors such as the speed of adoption, the effectiveness of implementation, and the scale of application of new technology that provides the biggest competitive advantage. The ability to apply technology more widely throughout an organization than a competitor is an advantage that in many cases cannot be duplicated due to geographical and geologic (resource) factors.

In conclusion, this author believes that a strategically-driven and sharply focused technology development effort, along with an effective implementation program that actively manages risk, is a requirement for every thriving, sustainable mining company.

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