

Equities

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Metals & Mining

Mining's Technological Revolution

- **High prices and short supply force technological innovation:** High prices and a scarcity of supply for some key raw materials are forcing both consumers and producers to look to technology as a way of mitigating the supply imbalance. Whilst technology and the mining industry appear to be odd bedfellows, technological revolutions like the emergence of SXEW copper production in the 1970's have changed the face of the sector.
- **Key commodities at risk – coking coal, thermal coal and nickel:** Coking coal is the sector we believe is most at risk from a shift in technology. Shortages of coking coal supply is forcing steel makers to look at alternate steel making technologies that use other sources of carbon rather than coking coal. Every 1% market share from non-blast furnace steel making reduces global coking coal demand by 8mtpa. Briquetting of thermal coal has the potential to unlock production from previously sub-economic coal basins. If the technology can be commercialized the process could deliver +50mtpa of supply by the middle of the decade (c10% of seaborne market).
- **Potential Winners:** Stocks that could benefit from the technology advancement are Posco (Corex and Finex systems), Sumitomo (investors in numerous technologies), New Hope Coal & Linc Energy (coal to liquids), Iluka (titanium metal) and Nautilus (marine).

Industry Overview

Craig Sainsbury
+61-2-8225-4871
craig.sainsbury@citi.com

Alan Heap
+61-2-8225-4853
alan.heap@citi.com

Meredith Schwarz
+61-2-8225-4892
meredith.schwarz@citi.com

Clarke Wilkins
+61-2-8225-4858
clarke.wilkins@citi.com

David Haddad
+61-2-8225-3162
david.haddad@citi.com

Daniel Seeney
+61-2-8225-4862
daniel.seeney@citi.com

Figure 1. Technology Summary By Metal

Commodity	Technology	Snapshot	Potential Supply/Demand Impact
Coking Coal	Direct Reduced Iron	Steel made without coking coal	High
Coking Coal	Corex & Finex	Steel made without coking coal	High
Thermal Coal	Briquette coal	Upgrades low rank coal	High
Nickel	High Pressure Acid Leaching	Allows processing of nickel sulphides	High
Titanium	Armstrong Process	Production of titanium metal powder	Medium
Copper	Bio-Leaching	Bacteria used to leach out metal	Low
Uranium	Uranium Oxide Leaching	Flotation and tank leaching of uranium	Low

Source: Citi Investment Research and Analysis

See Appendix A-1 for Analyst Certification, Important Disclosures and non-US research analyst disclosures.

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Technological revolution

At first glance technology and the mining industry appear to be odd bedfellows. However the sector has a long tradition of embracing new technologies, especially when faced with a need to deliver new supply, reduce costs or access stranded deposits. Major technological revolutions like the emergence of SXEW copper production in the 1970's and in-situ leach of uranium have changed the face of the sector. Other lower tech solutions like nickel in pig iron production have delivered new supply in to the market and had a serious impact on commodity prices. Substitution and thrifting have also increased in times of high metal prices and low metal availability.

Whilst high metal prices are forcing some consumers of the commodities to look at ways of reducing their consumption, we believe that the looming scarcity of supply for some metals may significantly alter consumption patterns for the industry. The shortage of metal supply from traditional avenues is also seeing an increased level of investment in to new technologies/methods to deliver more supply to the market. And with the high metal price environment many a technology that was historically uneconomical starts to look increasingly attractive.

Environmental legislation change, particularly carbon pricing, will also have an impact on the development of new technology in the mining space. Miners will be forced to try to cap emissions, but consumers of energy and carbon will also look to new ways of meeting their energy requirements from cleaner sources.

Rising energy demand as well as the potential for briquetted coal and coal to liquid processes are likely to see some previously un-economical coal deposits come in to production potentially altering the supply demand balance in the sector.

Technological evolution is far from a certainty and many risks present themselves. High Pressure Acid Leaching (HPAL) and Hot Briquette Iron (HBI) have both been high profile cases of technology failure. Both cases saw significant overspend on capex and neither delivered economic production on a commercial scale.

Despite the failures technology will continue to change the face of the metals markets. And the major areas of technological advancement that may have near term implications on metals supply and demand balance are:

- **Upgrading low rank coal:** Low cost source of coal from previously untapped sub-economic resources. Both coal to liquids and briquetting coal could potentially add meaningful new supply in to the industry and alter the cost curve
- **New steel making technology:** Development of processes such as Corex and Finex that avoid the use of coking coal in the steel making process could be the answer for a steel world that is facing a significant shortage of premium hard coking coal
- **Nickel laterites:** Will the HPAL technology work economically? If it is not commercially viable nearly 75% of all nickel growth projects could be mothballed and the market could face a nickel deficit mid decade
- **Hydrometallurgical processing:** A bunch of small scale technologies like Activox and bioleaching that open up the processing of new ore bodies or the re-processing of waste dumps

- **Undersea mining:** The next frontier which is aimed at accessing the high grade sub marine deposits. Targets have copper grade of +10%. A long way from commercialization but could be a new source of supply.

Figure 2. New technologies overview

Technology	Metal impacted	Overview	Cost	Current Supply	Impact potential on underlying commodity	Chance of success
Briquette coal	Thermal coal	Upgrades low grade coal by removing the water and increasing the energy units	Limited capital cost and a cash cost mid cost curve	Sub 2mt globally which is less than 1% of supply. Potential for 100mt by 2020	High	High
Coal to liquids	Thermal coal	Liquefies coal underground to produce liquid fuels	Most process economic at a \$50/bbl oil price	Sasol is the world largest producer.	High	Medium
Smelting Reduced Iron (Corex/Finex)	Coking coal	Reduces the need to use coking coal in the steel making process by using other sources of carbon such as thermal coal or gas	Lower capital cost of construction than a normal blast furnace given no need to build coke ovens. Operational costs on par with a blast furnace. Reliability is the issue	Limited commercialization of the process but it is rising. India the main region of growth and estimates are for sub 10mt of production currently operating	High	Medium
Direct Reduced Iron	Coking coal	Reduces the iron out of the ore in a solid state using thermal coal or gas as a reductant. Removes the need for coking coal	On par with a standard blast furnace if cheap gas available.	Global capacity is around 70mt in 2010	High	High
High Pressure Acid Leach	Nickel	High pressure and temperature to dissolve the nickel out of the ore	Significant capital costs as well as higher than anticipated operating costs. Both capex and operational costs are higher than nickel sulphides	Around 170ktpa but HPAL accounts for 75% of all nickel growth projects	High	High
Direct Nickel	Nickel	A tank leach process that operates at atmospheric pressure (with the option of mild pressure) and relatively low temperatures	Still in trial phase. But as it leaches at atmosphere should be lower cost than HPAL	Nil	Low	Low
Bio-leaching	Copper, Nickel	Bacteria are used to leach out metal from primary sulphide ores	Still in trial phase. Will be upper end of cost curve as its benefit is mainly focused on low grade ores	Limited as process is too slow. Work being done on how to accelerate the process.	Low	High
Marine technology	Copper, Gold	Sub sea mining targeting high grade gold and copper deposits. Technology derived from deep sea oil and gas industry	When out of the R&D stage each unit should have limited potential capex costs but high operational costs	0mt at present. But each 'unit' could mine c100kt of copper and 200kozpa of gold	Medium	Low
Titanium Metal Production	Titanium	Chemical process for continuous titanium powder production to produce grade 1 pure titanium	~50% reduction in cost of titanium sheet production	Nil at present however first commercial size facility currently in construction and due for completion at end 2010	High	Medium
Shale Gas	Oil, Gas	Extraction of gas from shale deposits	Cheaper than many traditional sources of gas supply	20% of all USA gas supply and may double in the next 5-10 years	High	High

Source: Citi Investment Research and Analysis

Some of the technologies are interrelated. For instance one of the drawbacks to the DRI process of making steel has been the high gas costs in various regions of the world (mainly Europe and USA). As such DRI production is dominant in regions such as the Middle East and Russia where there is cheap gas.

However if shale gas technology improves like other processes such as CTL then there may be more, cheap sources of energy that the DRI processes can tap in to. This would further reduce costs, increasing the economic positioning of the project, driving more supply and ultimately seeing a bigger pull back in coking coal demand.

Catalysts of Technological Innovation

We can identify a small number of common catalysts of technical change:

- **Scarcity.** In the mineral sands industry declining availability of natural rutile forced the development of synthetic rutile and titaniferous slag production in the 1980's. A scarcity of high quality coking coal may induce the development of alternative steel making technologies in the coming decade. And a lack of high calorific value thermal coal may encourage the development of beneficiation.
- **High Prices.** Probably the most common. A recent example is nickel in pig iron production in China; originally opportunistic, it is now an enduring source of supply as technology has improved.
- **Low Prices.** Technical change can be a forced survival strategy. The adoption of SxEw processing of copper in the USA in the 1970's is an example (discussed below).
- **Environmental considerations.** Are likely to become increasingly important. Coal seam methane and shale gas are current examples.

SxEw the case study

The development of the solvent extraction electro winning (SxEw) is a classic case study in how technology can alter the supply and cost curve on an industry.

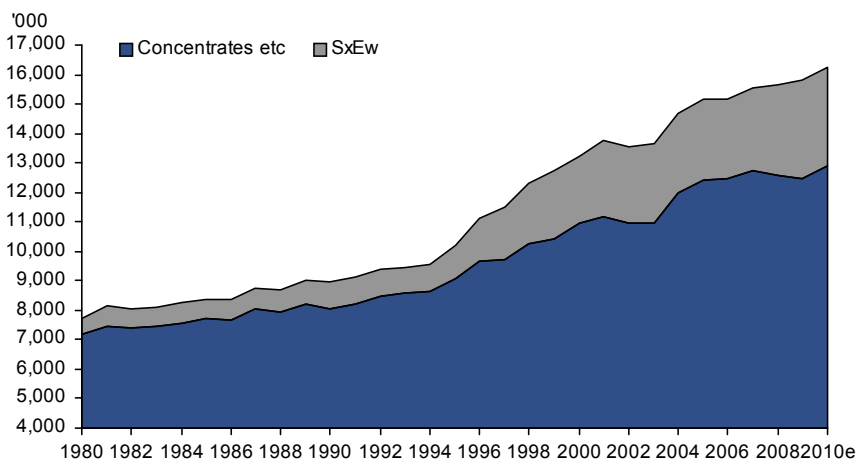
The SxEw technology was first widely applied commercially in the 1970's in the US for leaching of waste dumps. It is notable that the new low cost technology was introduced at a time of low depressed copper prices and was a central component of the survival strategy of the US copper industry.

However, SxEw production took off in the mid 1990's with the opening of large oxide deposits in Chile.

Traditionally, SxEW is lower cost than concentrate production. However Figure 4 shows that in recent years it has become more expensive as energy costs have increased and by-product credits have lowered concentrate costs.

SxEW production has increased from 5% of total in 1994 to 20% currently.

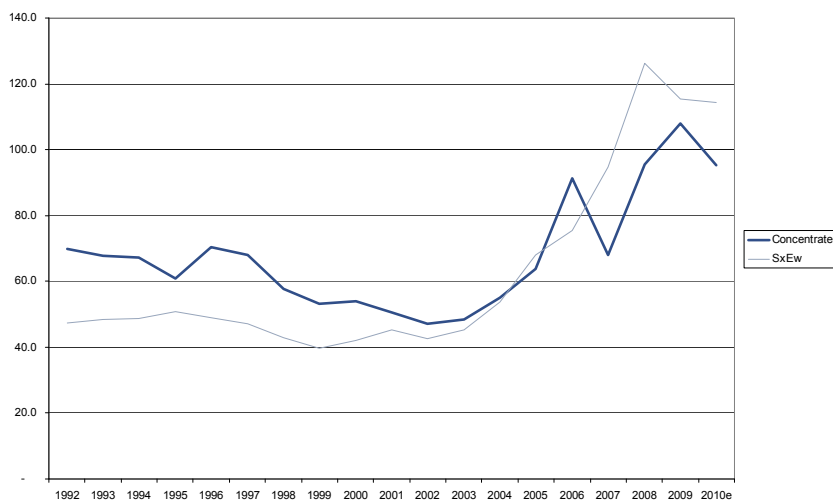
Figure 3. Copper Mine Production – Concentrate and SxEW



Source: Citi Investment Research and Analysis

SxEW production is usually low cost, although not now, due to high input costs (sulphur, energy) and no by product credits.

Figure 4. Copper Production Costs



Source: Citi Investment Research and Analysis

Supply implications

Quantifying the impact on supply of the new technologies is difficult given the issues in developing the technology, cost of production, prevailing price etc. However we have attempted to gauge the potential impact of the new supply on the markets to provide an overview of just how important new technology may be for future supply.

Figure 5. Potential Supply

	Production potential (2020e)	% of Supply	Commodity Incentive price
Direct Reduced Iron	150mt steel	10%	\$200/t coking coal
Corex & Finex	50mt steel	3%	\$200/t coking coal
Briquette coal	100mt coal	10% of seaborne market	\$80/t thermal coal
High Pressure Acid Leaching	300kt nickel	15-20%	\$8/lb nickel

Source: Citi Investment Research and Analysis

The failures

The development of technology in the mining space has not been without its failures. Technology revolution have come, cost billions and produced nothing. Below is a short list of some of the major failures in the advancement of technology in mining.

- Ravensthorpe was acquired by Billiton from Comet Resources in 1999. The project entailed an upgrade of the ore from 0.8%Ni to 2% feed for processing via a complex flow sheet combining HPAL and atmospheric leaching. A mixed nickel-cobalt hydroxide intermediate was to be produced for refining to metal at Yabulu. Capital cost of the project blew out from an initial \$920million to \$3.2 billion. The closure decision was co-incident with a depressed nickel market and ongoing technical challenges, even after several capital cost escalations. This raises significant questions over other large scale high pressure acid leach operations.
- Goro was discovered by Inco in 1969 and has been developed slowly. After acquiring Inco, Vale reviewed the project and decided to proceed. Capital costs have blown out to US\$4-5bn. Commissioning has been delayed and ramp-up extended over 4 years. Other leaching projects have also been delayed or postponed.

Potential Winners

The technological development in the mining industry will create both winners and losers from an investment perspective. Below we highlight some of the companies we think may benefit from the drive towards technology as well as some of the sectors/commodities that may see their investment perception from the market change over time as the technology develops.

Posco (PKX) – The leader of pack when it comes to non-coking coal steel production. If Corex and Finex work Posco will be at the front of the pack in new steel production as well as have the potential to benefit from licensing of the technology

Siemens (SIE) – Whilst not a mining company, Siemens are involved in the development of the Corex and Finex technologies. If the technology becomes commercialized, Siemens should benefit from increased demand for the product, capital construction and licensing fees.

Nautilus (NUS.L) – The company is at the forefront of sub marine mining. Research and development are continuing, but NUS has identified resources around the world that it plans to mine. Targets are very high grade copper and gold (+5% copper and 5g/t). The original target in PNG and could potentially deliver over 100ktpa of copper and 200kozpa of gold from the project

Linc Energy (LNC.ASX) – At the forefront of the development of CTL technology in Australia. The company owns a UCG plant in Uzbekistan and is working on developing similar projects in Queensland.

New Hope Coal (NHC.ASX) – Developing a CTL business. Small scale at present but given NHC's cash position there is significant amount of R&D budget to be put to work. If successful the CTL business for NHC could be an interesting differentiator from the other coal names in the Australian market.

Iluka Resources (ILU.ASX) – One of the dominant producers of high grade TiO₂ which is used for titanium metal production. As low cost technologies are developed for titanium metal production and new markets are established Iluka will be at the forefront of TiO₂ supply.

Upgrading Low Rank Coal

Technology Overview

Increasing coal demand & price and the need for coal technology is driving the push towards new technologies within the coal industry. Currently low rank coals have limited use due to their high moisture and low energy content, as well as being highly volatile and susceptible to spontaneous combustion. New technologies are being developed that enable low cost, low rank coals such as lignites or sub-bituminous coal to be upgraded increasing their marketability and use.

There are two main processes when it comes to upgrading low rank coal;

- coal to briquettes and
- coal to liquids.

Whilst both methods of utilising low grade coals are in their infancy. The scramble for coal from emerging countries and the voracious appetite from China mean that new coal supplies are being examined. Further leading to the development of these new technologies is the infrastructure bottlenecks facing the coal industry. Port, rail and barging supply chains are stretched in the main coal export regions of Australia, South Africa and Indonesia. The limited ability to increase supply, coupled with the increased demand for coal is causing the need to look for alternate sources of energy.

Furthermore the capital cost of new coal mines, with their associated need to build port and rail are altering the investment decision in favour of lower capital intensity technologies.

Figure 6. Coal Technology Overview

Technology	Overview	Issues	Capital Cost comparison	Cash cost comparison	Current Supply	Future supply
Briquette	Removes the moisture content in low grade coal through drying and thus increases the energy content of the coal	Stability of the briquette, efficiency of the plant	Lower capital cost than a Greenfield mine	c\$50/t placing it in the mid tier of cash costs	Trial basis at present	50-100mt by 2020 (15-20% of the thermal market)
Coal to Liquids	Liquifies coal in the seam underground to produce syngas or sun fuels	Capital intensity	Higher than new coal mines	\$30-\$40/bbl	Limited	N/A

Source: Citi Investment Research and Analysis

Binderless Coal Briquetting

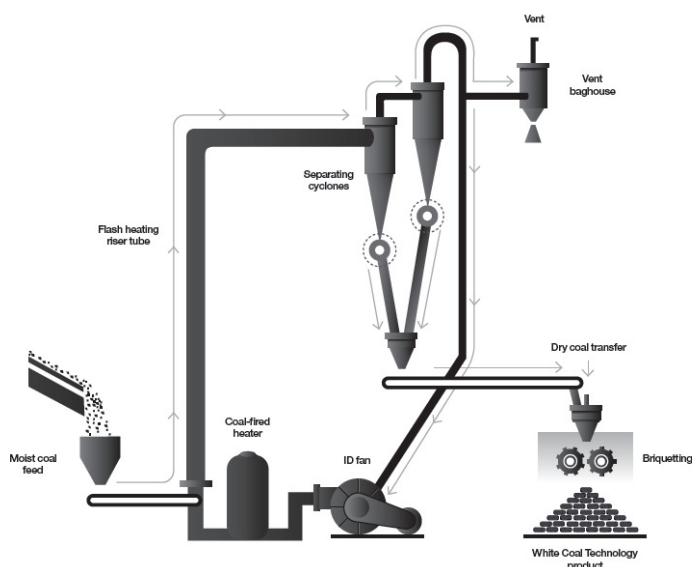
The process

Upgrading low rank coal is carried out through a process of coal drying and briquetting. The technology is used to convert low grade thermally unstable coal into high energy briquettes.

The raw coal is firstly crushed then flash dried to evaporate water contained in the coal. The amount of water varies depending on the quality of the coal. The coal is dried using a hot gas that is generated in a furnace and finally briquetted.

The briquetted coal is stockpiled where it stabilizes and reaches its “stable” equilibrium moisture content.

Figure 7. WEC's Binderless Briquetting Process



Source: White Energy Company report

Uses of the technology

Briquetted coal can be used for power generation. This process of briquetting coal is used to upgrade coals that previously were not economic for power generation due to transport costs.

CSIRO spent a number of years researching and developing the binderless briquetting technology for upgrading coal which White Energy Company has purchased. There are a number of companies looking at similar techniques, however, they have not reached the commercialization stage.

Pros and cons of the technology

Figure 8. Pro's And Con's Of New Technology

Pro's

- increases the thermal energy from 4500 kcal/kg (8000 BTU/lb) to 6200 kcal/kg (11000 BTU/lb)
- Lower ash and sulphur oxide content compared with high rank bituminous thermal coal
- The converted low cost, low rank coals to bituminous quality thermal coals compare favorably with higher priced bituminous coals
- Can be used to upgrade both high moisture coals and high energy discarded coal fines to a stable and transportable product
- Lower pollutants such as ash and sulphur
- Increases rail efficiency with a reduction of dust
- Physically and chemically stable which is a major advantage for storing and transporting the coal
- Decreases water content and moisture thus decreasing load volumes and reducing transportation costs

Con's

- High capital costs
- If the briquettes are not stabilized then they remain spontaneously combustible
- Prolong use of fossil fuels
- May not be commercial in domestic markets
- Transport must be long enough to justify capital

Source: Citi Investment Research and Analysis

Risks

Binderless briquetting technology has been through a number of pilot plant testing stages. Early performance has been disappointing with sub-optimal fan sizing, excessive dust and variable moisture content of the feedstock coal. The biggest risk for the binderless coal briquetting is ensuring that a facility is expandable, a market is created for the briquetted coal and steady-state performance is achievable.

For example, Evergreen Energy (formally KFx) suffered a +90% decline in market cap when it failed to achieve sustainable production from its pilot plant in the US.

Costs

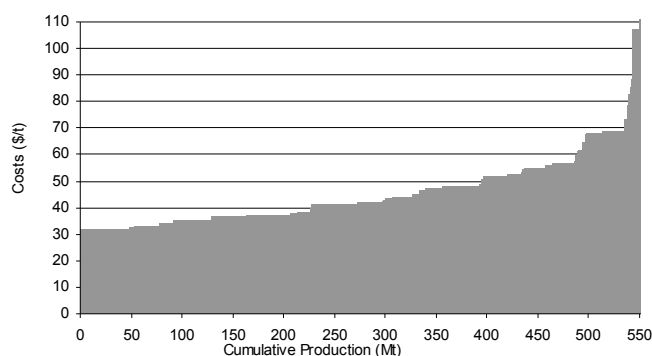
Cost of production will vary significantly on the location of the coal as well as coal quality. Infrastructure savings are one of the major drivers behind the upgrading of the coal and as such if you are sitting closer to the demand sources for the coal, the better the costs and the operational metrics. Given the technology is in its infancy it is difficult to get a direct view on the cash costs. However, White Energy is probably closest to commercializing the technology and we look to their cost base to provide an overview.

WEC's claimed cost of production is US\$34.60/t FOB. By comparison, Australia average FOB cost for thermal coal was US\$48/t FOB in 2009. The key to WEC's low cash costs is inexpensive feedstock. A breakdown of costs for Tabang as stated by WEC is as follows:

- **Feedstock:** US\$9.00/t of feedstock or c.US\$12.60/t of product
- **Processing:** US\$6.00/t
- **Transport & handling:** US\$16.00/t including 489km of barging
- **Total cost:** US\$34.60/t

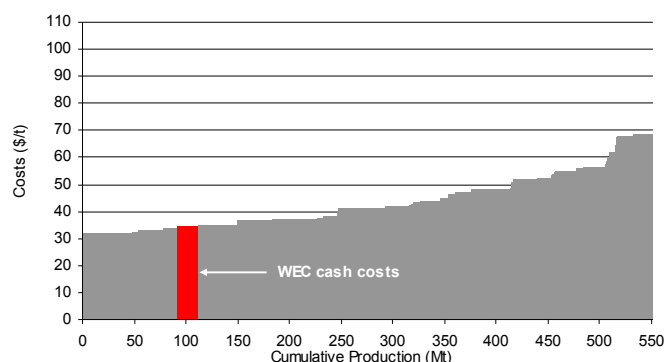
Each 1Mt plant module has a nominal life of 20 years and is estimated by the company to cost c.US\$55m in Indonesia including 10MW of new power per module. Initial estimates of capex were overly optimistic as an August 2007 estimate placed expenditure at US\$28m plus US\$7m for a power plant, or about one-third the final cost. In any case, capex adds about US\$3-5/t to costs over the life of the plant in Indonesia. For the USA, capex is higher. We believe a similar plant would cost an additional US\$20-25m if built in the Powder River Basin but benefits would include a link to grid power.

Figure 9. Thermal FOB Cash Cost Curve, 2009



Source: Citi Investment Research and Analysis

Figure 10. Thermal FOB Cash Cost Curve After Inclusion Briquettes



Source: Citi Investment Research and Analysis

Supply potential

The supply response will be proportionally dependent on the success of the technology. Current western world plans for briquetted coal are for c75mtpa by the end of the decade. However an uptake of the process by China could fast track the potential supply response.

Our best estimate is that if the technology works, it could account for c100mtpa of coal production, but the bulk of that is likely to be in to the domestic coal markets of China and the USA. Seaborne briquetted coal production is likely to be under the 50mtpa level.

Companies exposed to the technology

- **White Energy:** Holds the patent to a Binderless Coal Briquetting technique that upgrades lower energy sub-bituminous coals by as much as 50% through drying and mechanical briquetting. The company has spent 15 years developing the technology and completed its first 1Mtpa commercial plant with JV partner, PT Bayan Resources, at Tabang in Indonesia in August 2009. Commissioning of the plant has been problematic and remedial work on the plant continues.
- **GTL Energy Ltd:** GTL has a very similar profile to White Energy. It completed the construction of its first commercial scale plant (250kt) in North Dakota, USA in July 2010. According to the company, its plants are modular, like White Energy and it too produces a binderless briquette. It has conducted trials on sub-bituminous coals from the Powder River Basin (PRB) and lignites from North Dakota, New Zealand and Australia. For example, PRB test coals had their moisture reduced from 30% to 10% with a corresponding energy upgrade from 4,800kcal/kg to 6,000kcal/kg. It claims to reduce CO₂ and NOX by 10% and 25%, respectively.
- **PT Upgrading Brown Coal Indonesia (UBC):** UBC is an initiative of Japan's Kobe Steel, which began developing the process in 1993. UBC commissioned a 1,000t/d demonstration plant near Satui in Indonesia in December 2008 in partnership with PT Bumi Resource and PT Arutmin Indonesia. In the process, brown coal is crushed to a few millimeters in size and mixed with oil and asphalt to form a slurry. The slurry is heated causing water to evaporate and the asphalt to fill the voids. The coal is separated from the oil and pressed into briquettes. From 1,000t of 4,000-5,000kcal/kg feedstock, 600t of 6,350kcal/kg product is made. The investment over 2006-10 has been about US\$100m and Kobe states a processing cost of c.US\$8-10/t of product.
- **Evergreen Energy Inc (formerly KFx):** EEI in partnership with Bechtel Power Corp manufactures K-Fuel, a registered trademark. Low grade coals are upgraded using heat and pressure to remove moisture and lower mercury, NOX and SOX content. The heated coal is mildly carbonized and extruded into pellets. According to the company, the energy of PRB coals is improved from 4,700kcal/kg to 5,750kcal/kg with a commensurate reduction in moisture and mercury of 53% and 73% respectively. For tests on Indonesian coal, moisture was reduced 83% while energy increased from just over 3,600kcal/kg to almost 5,650kcal/kg. EEI has a 750ktpa plant in Wyoming but operations were suspended in March 2008 due, amongst other things, to an inability to achieve continuous production. In July 2010, it signed a JV agreement with China's Gang Jing Hong Ren Technology Co. Ltd and the company has stated that the country offers the best opportunities to develop the K-Fuel technology.

- **Exergen:** brown and sub-bituminous coals have moisture removed through a process known as Continuous Hydrothermal Dewatering. The process uses a vertical autoclave located in a deep shaft to circulate a coal slurry under pressure of 100 bar and 300°C. These conditions result in the occlusion of pore spaces within the coal, thus removing water and raising the energy. Exergen has stated that its aim is to develop a 12Mtpa coal export project in the Latrobe Valley in southeast Australia. Investors in the company include India's Tata Power, Itochu Corp, Sedgman and Thiess.

This is not an exhaustive list and there are other methods for drying coal prior to combustion, particularly at the power plant site. The key issues around the adoption of these technologies on a large scale revolve around the energy balance required to upgrade an energy product. The R&D investment over 15-20 year timeframes in many cases to reach the current level of progress suggests that upgrading coal for commercial application has been anything but simple.

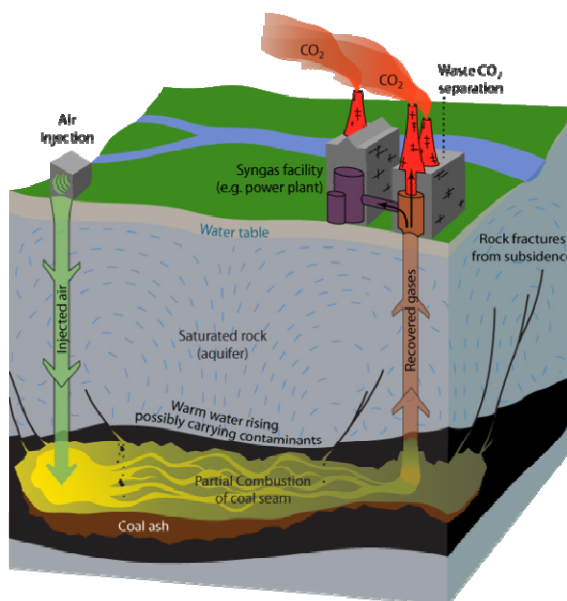
Coal To Liquids

Low rank coal can be upgraded to a liquid by the process of liquefaction. This technology is well established and is used commercially. Whilst not a new technology (CTL has been used in Uzbekistan for 50 years) the increased prices of fossil fuels has seen an increase in the economics of the CTL projects which could see a sharp increase in potential supply.

Injection wells are drilled in to the coal seam and oxidants are injected to ignite the seam. The oxidants force the coal to undergo gasification to produce synthesis gas (syngas) which is a mixture of carbon monoxide and hydrogen and then goes through a conversion process. The ultimate product of CTL depends on the next refining step. Some producers like Sasol use the CTL process to provide hydrocarbons from their chemical process. Other sources of ultimate end fuel are Naptha, jet duel, diesel and base oils & waxes.

Sasol are the pioneer in the CTL technology and currently produces about 40mt of coal per annum to be used in their gasification feedstock process.

Figure 11. Underground CTL



Source: Linc Energy

There are some major disadvantages with the coal to liquids in that they produce large amounts of greenhouse gases, use a lot of water and there is also large up-front capital costs required. The refinement process can cost three to four times more than to refine the equivalent amount of oil.

Pros and cons of technology

Figure 12. Pros And Cons Of Technology

Pros	Cons
■ Utilisation of stranded coal reserves	■ High initial capital cost
■ Cheap feedstock coal	■ Refining capacity
■ Replacement of domestic coal	■ Refining costs 3-4x standard refining process
■ Lower environmental foot print. Less disturbed land than traditional mining	■ Higher emission footprint

Source: Citi Investment Research and Analysis

Costs

The exact cost of the CTL technology is difficult to ascertain given that much of the existing production is vertically integrated in to chemical operations (i.e Saslo) and as such transfer pricing prevents a clean understanding of the exact cost of the process.

We believe that CTL could be produced for c\$30-40/bbl depending on taxes as well as the quality of the coal seams. Whilst the cost is significantly higher than standard oil production, the cost of production is cheaper than the prevailing oil price and as such represents an opportunity for development from oil short regions. Most industry experts expect the CTL process to be break even with an oil price of c\$50/bbl.

Figure 13. Capex Intensity

	Capex (US\$bn)	Recoverable mbbls	Capex/boe
Deepwater Oil - Norway	9.4	1300	7.2
CTL - USA	4.2	660	6.3

Source: Citi Investment Research and Analysis

Supply and demand implications

CTL has been much talked about as a new technology for the industry, but there has been little advancement on production in recent years. Much of that has been due to low commodity prices and the high cost of capital construction for the technology. Now with high export coal prices forcing up the cost of domestic coal, the potential for CTL to ramp up is increasing. However CTL will suffer from direct competition from other forms of gas such as LNG and shale gas.

From a potential supply side perspective the CTL technology will look to utilize the same coal reserves as briquetting. Areas where the technology is likely to be adopted are in regions of constrained domestic liquid fuel production, mainly China. Regions that have high levels of domestic coal reserves, high power demand but limited export infrastructure (again China and Australia too) are likely to adopt the CTL technology.

The EIA believe that CTL production accounted for 1.8mboe in 2008, but could lift to 8.4mboe in 2010 which is an 8% CAGR.

Shenhua who is the largest CTL producer in China are planning to use 5.2mtpa of coal in the CTL process by 2013 and lift this to 21.5mtpa by 2020. There has also recently been an announcement of a 10mtpa plant in Mongolia. So clearly there is a growing trend of consumption of sub economic coal in to the CTL process.

Companies exposed to the technology

- **Linc Energy:** Emerging as the forerunner of the CTL technology in Australia. Looking to use the UCG and CTL technology to develop assets in Australia and abroad.
- **Sasol:** Largest producers of liquids and gas from gasification of coal seams. More used in the chemicals business than a liquid fuel.
- **Shenhua:** One of China's largest coal producers is developing a large CTL pipeline with the potential for 20mt of coal to be used in the process by 2020.

Alternative Steel and Iron Making Processes

Technology Overview

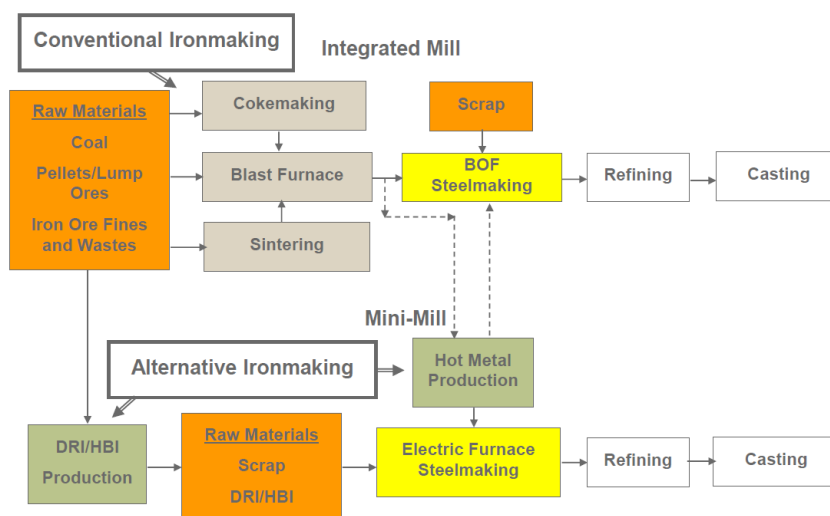
The blast furnace continues to dominate the steel making process accounting for around 75% of steel of total steel production with EAF's contributing c20% of demand and alternate steel making process c5%.

However whilst blast furnaces rule now we believe that the high cost of raw material and the limited availability of crucial materials are likely to force a technological revolution in the steel making industry. The major area of concern for most steel producers is the looming supply shortfall in the coking coal market. Most industry experts expect the coking coal market to be tight if not in deficit by the middle of the decade. With that looming shortfall alternate technologies that don't use coking coal are likely to grow.

The major alternatives to the standard blast furnace technology are

- Electric arc furnaces (EAF)
- Direct reduced iron (DRI) – Midrex,
- Smelting Reduced Iron (SRI) - Corex, Finex etc
- Other technologies such as PCI coal & stamp charging

Figure 14. Ironmaking-Steelmaking Routes



Source: Company reports

The major drawback of many of the alternate steel making technologies is the successfulness of the blast furnace and the lack of need to look at new technologies. The cost of developing the new technologies, both from a capital cost and an operating cost perspective have been prohibitive. The ability to scale up the operations from trial plant to commercial plant stage has been another major drawback which has hampered the operational and production flexibility of the projects.

Figure 15. The Steel Making Balance

Reasons to develop alternate steel making processes

- Avoid coke making and sintering
- No coking coal
- Use less expensive iron ore fines
- Reduced energy requirements
- Provides an alternate to scrap
- Lower capex
- Quick build time
- Take advantage of low gas prices

Reasons to favor blast furnaces

- Large volume production
- Existing infrastructure
- Known process
- Operational flexibility
- Existing sinter plants
- Ready available coke from local sources

Source: Citi Investment Research and Analysis

However as we move in to an environment where we see high raw material costs as well as the potential scarcity of coking coal we believe that the steel companies will put more R&D in to the development of new steel technologies. Whilst these will not replace existing blast furnace capacity, the new technology could account for a greater share of future steel build which potentially has the ability to alter demand patterns for key raw materials. A snapshot of the new technologies are highlighted below.

Figure 16. Main Alternate Steel Making Technologies

Technology	Type	Raw products	Issues	Capital cost comparison (US\$/t annual production)	Current Supply (mt)
Corex	SRI	Lump/Coal	Most advance of the SRI processes but still lagging DRI. Being rolled out in India and China. Major issues it reliability of hot metal feed to the BOF	200	<20mt
Finex	SRI	Fines/Coal	Yet to reach commercialisation phase as furnace not getting permeability and movement of slag due to removal of the lump nature of the ore and coke	n/a	0mt
Midrex	DRI	Lump/Gas	Most commercial developed of the technologies and accounts for 50% of all alternate steel making process (c30mtpa)	145	~40mt
ITmk3	DRI	Lump/Coal	Commercial, but the fact that a hearth is used limits the size of the process to under 1mtpa. Not a real alternate to blast furnaces	na	~20mt

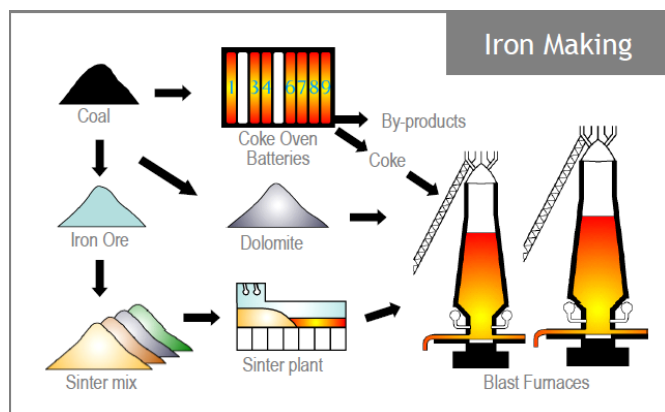
Source: Citi Investment Research and Analysis

Standard Blast furnace technology

The iron ore, coke and limestone are added at the top of the furnace whilst heated air is forced through the bottom. The denser iron sinks to the bottom of the furnace where it is run off and cooled (known as pig iron). The slag is run off separately and can be used in road construction or agriculture.

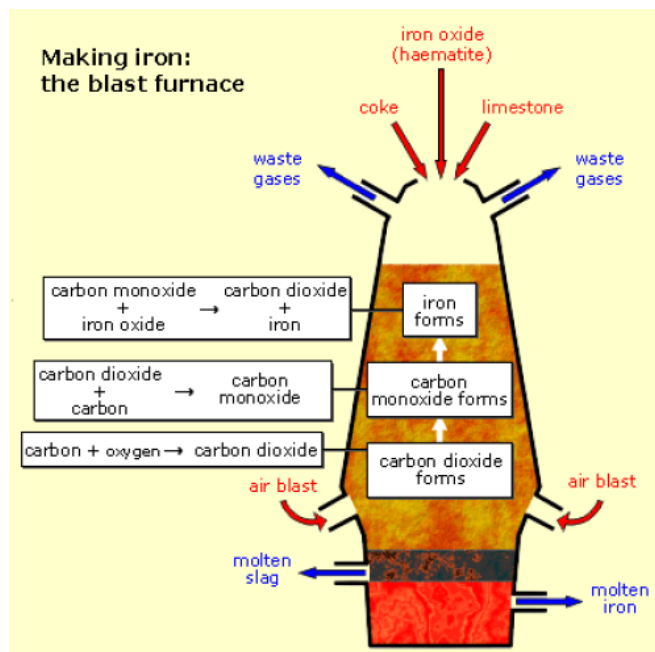
In the process each tonne of steel requires roughly 1.5t of iron ore and 0.6t of coking coal/coke. Whilst the blast furnace process has changed little in recent times, it is the costs and availability of the coking coal in the process that is starting to put pressure on rethinking how iron is made.

Figure 17. Iron Making Process



Source: Bluescope Steel

Figure 18. Standard Blast Furnace



Source: Bluescope Steel

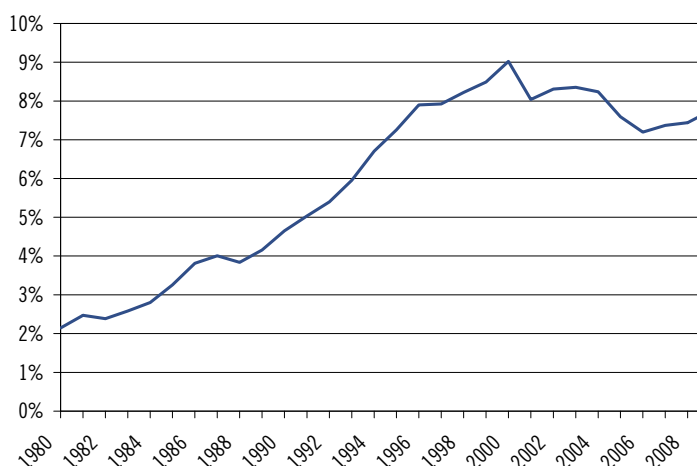
Coking coal is primarily used for its carbon content which reacts with the oxygen forming carbon monoxide which then reacts with the iron ore forming iron and carbon dioxide. Coking coal is desirable because it provides an energy source, is strong and supports the slag, doesn't generate fines, irregular shaped so doesn't pack and allows permeability, it is porous, has low ash and a low sulphur content.

Despite its numerous beneficial properties in a blast furnace, if coking coal is not available (which is our supply/demand forecast for 2015) then steel producers will need to look for other sources of carbon. Currently blast furnaces are using PCI coal as a supplement to coking coal. But if a severe shortage of coking coal is looming, then we may see a shift away from the traditional blast furnace in to other types of steel making technology. There have been a number of alternative technologies developed but they to date have not made much progress into replacing typical blast furnace technology.

Supply Potential

Currently SRI/DRI accounts for approximately 8% of the global steel market with an annual production capacity of c70mtpa. Whilst we do not believe that DRI & SRI have the ability to go significantly above a 10% market share in the next 5 years, there is certainly the potential for the amount of DRI intensity to increase. The rate of DRI uptake will likely be dominated by the Indian steel market and as such penetration rates on a global basis are likely to be determined by Indian steel production.

Figure 19. DRI/SRI Production As A % Of Global Steel Production



Source: Citi Investment Research and Analysis

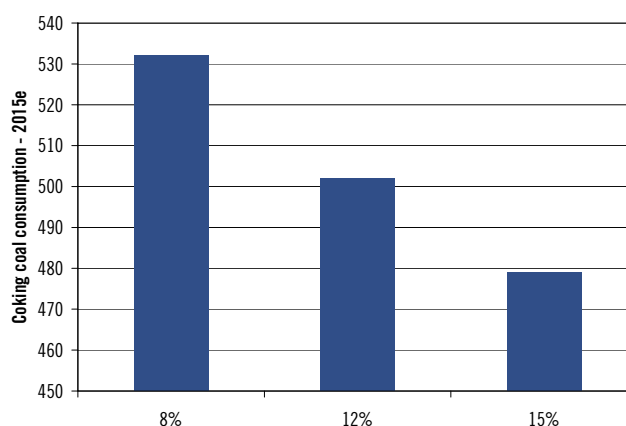
We expect global steel production to be c1,267mtpa in 2015 which equates to an absolute growth figure of 221mt over that period of time. Of that steel growth China will account for 63% of the growth and India 30%. By 2020 global steel production could be closer to 1,500mt. The table below looks at the requirements for coking coal depending on various penetration rates of alternate steel making technologies.

Figure 20. Coking Coal Demand Under Various DRI Market Shares

Steel Production	mt	2015	2020
		1267	1500
Base Case			
SRI/DRI mkt share	%	8%	8%
EAF Share	%	22%	22%
Blast Furnace share	%	70%	70%
Coking coal demand	mt	532	630
Mid Case			
SRI/DRI mkt share	%	12%	12%
EAF Share	%	22%	22%
Blast Furnace share	%	66%	66%
Coking coal demand	mt	502	594
Bear case			
SRI/DRI mkt share	%	15%	15%
EAF Share	%	22%	22%
Blast Furnace share	%	63%	63%
Coking coal demand	mt	479	567

Source: Citi Investment Research and Analysis

Figure 21. Coking Coal Demand



Source: Citi Investment Research and Analysis

On the analysis above an increase in alternate steel making technologies up to 12% would reduce the consumption of coking coal in the market by c30mt. In other words, every 1% gain in market share from DRI/SRI reduces global coking coal consumption by 8mtpa.

On an absolute tonnage level, for DRI/SRI to account for 12% of demand by 2015, 90mt of new capacity would need to be built which would be 25% of all new steel capacity additions. Clearly not a likely scenario by 2015, but a possibility given the lack of coking coal.

China and India – heading in different directions.

The above discussion on global trends conceals divergent trends in the two main centers of crude steel capacity growth – China and India- and these have important implications for alternative steel making technologies and coking coal demand.

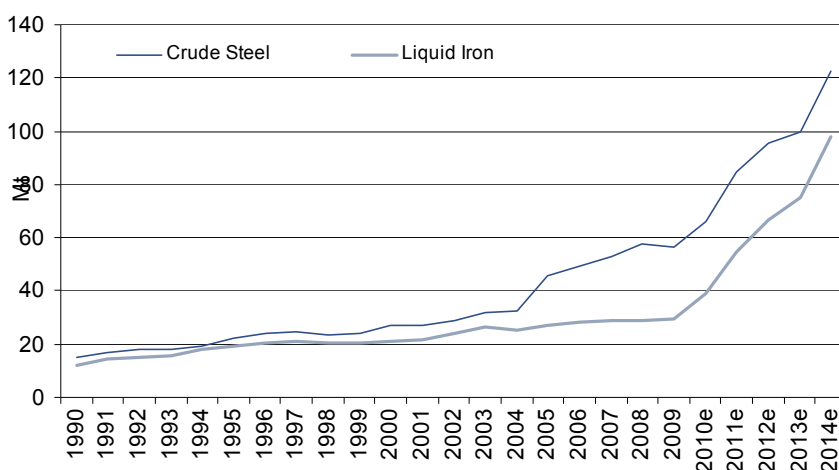
China's steel making capacity is 95% BF, 5% EAF. There has been little incentive to build EAF capacity – the capital cost of new BF capacity is very competitive, coke supplies have been adequate, and there is limited scrap supply. EAF capacity may increase to 17% by 2020 as scrap supply increases, but there has been little development towards alternative technologies.

In India, by contrast BF capacity is 37% of the total and EAF 58% (there is a residual 2% of open hearth). Economics in India favoured EAF – low capital cost, availability of sponge iron and shortage of coking coal. In India EAF plants use sponge iron feed produced using thermal coal rather than coking coal and the steel they produce is low grade long products.

However BF capacity is now displacing EAF- sponge iron plants and this is a major source of increased coking coal demand - most of which will have to be imported. By 2014 we expect India to displace Japan as the largest importer of coking coal.

Up till now most growth in Indian steel production has been from EAF plants using sponge iron. But Blast furnaces are taking over.

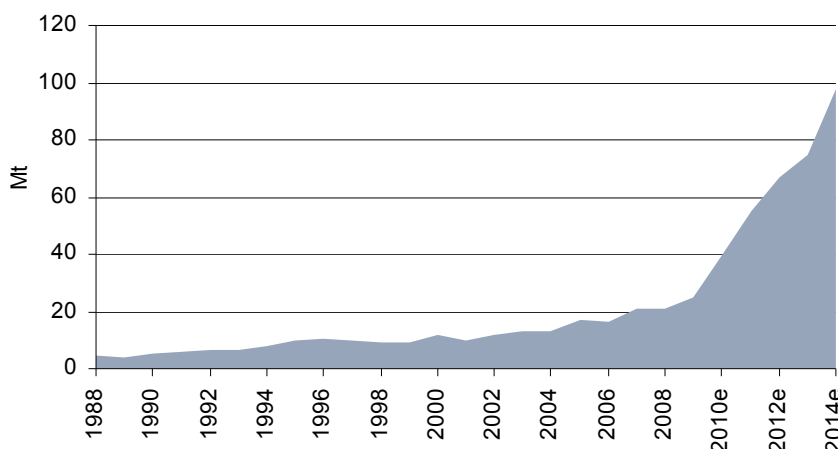
Figure 22. Indian Crude Steel and Hot Metal (Blast Furnace) Production



Source: World Steel Assn., Citi Investment Research and Analysis

Coking coal demand will boom as a result, mostly from imports.

Figure 23. Indian Coking Coal Imports



Source: TEX, Citi Investment Research and Analysis

The tensions this demand will put on global coking coal markets explain why Indian steel companies are at the forefront of adopting alternative steel making technologies which avoid the use of coking coal (Corex, Midrex, Finex) or use lower rank coking coal (stamping) or PCI. These technologies are discussed in the next section.

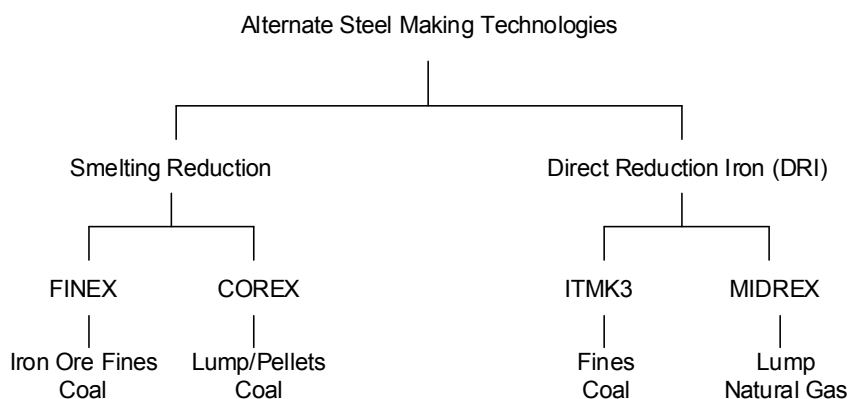
As an extreme scenario, if half the projected growth in Indian steel production were produced from non-coking coal using processes, growth in seaborne demand would be reduced by 5-10%, (~20Mt) enough to push the market closer to equilibrium.

Alternate Steel Making Routes

The two main alternate steel making routes involve:

- **Smelting reduction** which is a liquid based production which effectively replaces the blast furnace and
- **Direct Reduction Iron (DRI)** is a solid based reduction process

Figure 24. Main Alternate Steel Making Technologies And Their Raw Material Usage



Source: Citi Investment Research and Analysis

Direct reduced iron (DRI or also called sponge iron) is a solid iron product that is generated when iron ore is exposed to a reducing agent. A variety of DRI processes have been commercialized since the 1970's. The DRI technology can use either thermal coal or natural gas as the agent to reduce the iron ore. The advantage of natural gas is that in countries where there is an abundant supply it can be a cost effective alternative to coal. However current DRI technologies are focusing on the use of thermal coal as a substitute for coking coal and coke.

DRI is formed by the removal of oxygen from iron ore at temperatures below its melting point (800°C – 1050°C) using a reducing gas produced by either natural gas or thermal coal. The reducing gas is a mixture of hydrogen and carbon monoxide. A hearth is used rather than a furnace and as such operating sizes are typically much smaller than standard blast furnaces. The DRI plants are generally sub 1mtpa although some of the latest plants in India are reaching output levels of 1.7mtpa. The most advanced of the technologies are Midrex and ITmk3.

Smelting reduction iron (SRI) is effectively aimed to be a straight replacement for the blast furnace technology. The SRI principle is very similar to that of a blast furnace, but thermal coal or gas is used instead of coke. The final product is liquid steel or liquid pig iron

Iron ore undergoes a solid state reduction in a pre-reduction unit. The resulting product is then smelted and further reduced in the vessel where thermal coal (or gas) replaces coke. The coal is gasified which delivers the heat and the CO rich hot gas which is used to reduce the iron. The reduced iron oxides are transferred to a further smelting vessel where hot metal is produced and blast on to the BOF.

The SRI process can use either gas or coal as the reductant, however coal is the preferred option given the benefits it has in the process of moving the slag through the vessel. Iron ore lump or pellets are predominantly used, although the technology is being amended to have a growing focus on the use of fine material. Corex is the most commercially advanced of the technologies. However the Finex system which uses iron ore fines rather than lump is a promising technology given the lack of volume growth in the lump market.

The use of the various applications will also depend on their geographic location. For instance in India where there is a possibility of shale gas the Midrex process may be more applicable given the consumption of gas. Indeed we believe that much of the potential pick up in the alternate steel making technologies will be in emerging steel markets such as India as well as potentially replacement to old and power inefficient blast furnaces in China. The table below summaries the key differences between the 4 main alternate processes.

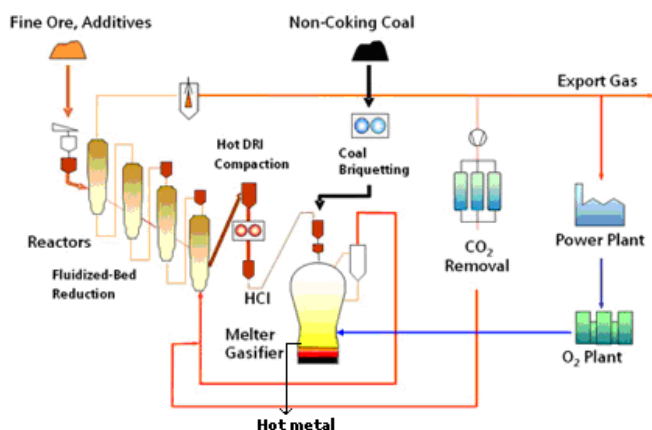
Figure 25. Reductants And Iron Source In The DRI Processes

	Corex	Finex	Midrex	ITmk3
Process	SRI	SRI	DRI	DRI
Iron ore	Lump	Fines	Lump	Lump
Reductant	Coal	Coal	Gas	Coal

Source: Citi Investment Research and Analysis

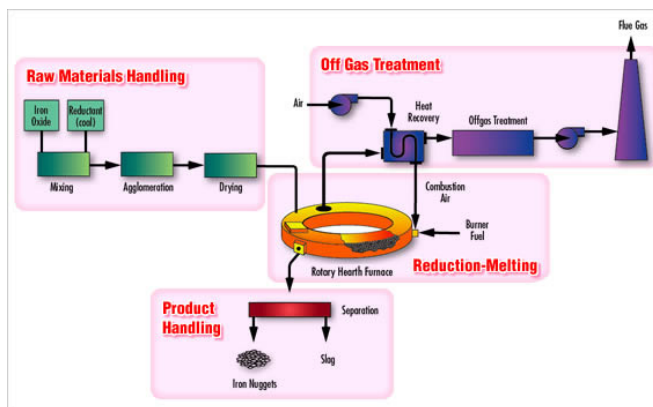
As we mentioned above the major differential in the DRI vs SRI process is that the SRI still uses a vessel similar to a blast furnace but substitutes gas and or other types of coal to replace the hard coking coal. Given that it is still a vessel the size of production is generally larger with production bases aimed to be over 1.5mtpa and as such can compete with blast furnaces. The DRI process generally uses hearths which become a limiting factor on size. Most DRI plants are small in scale (sub 500ktpa output) but there are several developments in India where plants in excess of 1mtpa are being built.

Figure 26. Finex DRI Process



Source: Posco and Siemens VAI Metals Technology

Figure 27. ITmk3 DRI Process



Source: Midrex and Kobelco

Whilst the major benefit of the alternate steel making routes is the ability to not use or at least use significantly less coking coal, the processes also have other benefits such as lower capital costs and lower emissions.

Figure 28. Key Operational Statistics

	Blast Furnace	EAF	Corex	Midrex
Capital Cost (US\$/t of annual capacity)	273	90	200	145
CO2 emissions (mt/mt of metal)	1.5	0.05	2.9	0.65
Electricity (PJ/mt metal)	0.5	1.9	0.32	0.37

Source: ETSAP and Citi Investment Research and Analysis

Industry estimates are that at a long term hard coking coal price of USD200/t these alternative processes become cost effective. In addition however, the business risk from lack of availability may also be a catalyst.

Some of the other benefits of the alternate technologies are detailed below.

Figure 29. Pros and Cons Of Alternate Steel Making Technologies

	Corex	Finex	Midrex	ITmk3
Pros	<ul style="list-style-type: none"> ■ No coking coal required ■ Lower capital cost through the elimination of the need for sinter and coke plants ■ Smaller and more economic plant sizes ■ Reduced emissions and environmental impact ■ Pig iron produced is as high quality as that from blast furnaces ■ Excess gas generated is a valuable by-product and can be re-used for other heating purposes ■ Comparable output capacity to blast furnaces and has operational flexibility with raw material feed 	<ul style="list-style-type: none"> ■ No coking coal required ■ Low cost raw materials minimizing capital and capital cost by 20% and 15% ■ Reduced emissions and environmental impact ■ Pig iron produced is as high quality as that from blast furnaces ■ Heat generated in coal gasification can be used as an energy source ■ Excess gas generated is a valuable by-product and can be re-used for other heating purposes ■ Comparable output capacity as blast furnaces 	<ul style="list-style-type: none"> ■ Use natural gas as a reducing agent for the iron ore ■ no need for costly coke ovens, sintering or pellet plants ■ larger capacity of 1.5mtpa ■ Scalable depending on capacity requirements 	<ul style="list-style-type: none"> ■ Emits 20% less CO₂ than blast furnaces due to lower energy consumption ■ use thermal coal as reducing agent for iron ore ■ no need for coke ovens, sintering or pellet plants ■ suitable for mine sites and small scale operations ■ iron nuggets are slag-free and high-purity (96% - 97% metallic iron) and same quality as pig iron ■ iron nuggets are high density and do not re-oxidize or generate fines ■ Easy to transport and handle
Cons	<ul style="list-style-type: none"> ■ Process cannot tolerate coal particle sizes below 16 mm as this reduces the permeability of the char bed, High capital costs 	<ul style="list-style-type: none"> ■ Has an increased investment costs associated with the four stage fluidized bed reactor system which is required to overcome some of the metallurgical limitations of a one stage system 	<ul style="list-style-type: none"> ■ The natural gas driven shaft furnace can only be utilized where there are sustainable reserves of natural gas 	<ul style="list-style-type: none"> ■ Energy consumption increases when processing lower grade ore ■ Lower capacity plant of 500ktpa ■ Uneconomical in high electricity cost scenarios

Source: Citi Investment Research and Analysis

Risks

Alternate steel making processes are not new and DRI production has been occurring since the 1950's. However despite the long lead time in developing the technologies, many have yet to reach full commercialization and have yet to enter the main stream in the steel making process. Part of that is the lack of reliability of the new processes, especially Corex and Finex as well as the capital cost of continually trying to tweak the plants. However as we mentioned high commodity prices and the lack of availability are likely to push further demand for the alternate technologies. The key risks we see to the uptake of the new technologies are:

- Blast furnaces dominate the market and are easy to expand. So cheap addition of volume
- Ability to scale up process to commercial size to match the 2mtpa capacity of new blast furnaces
- Energy prices and availability of energy
- Availability of iron ore lump and pellets
- Operational flexibility and quality of end iron produced

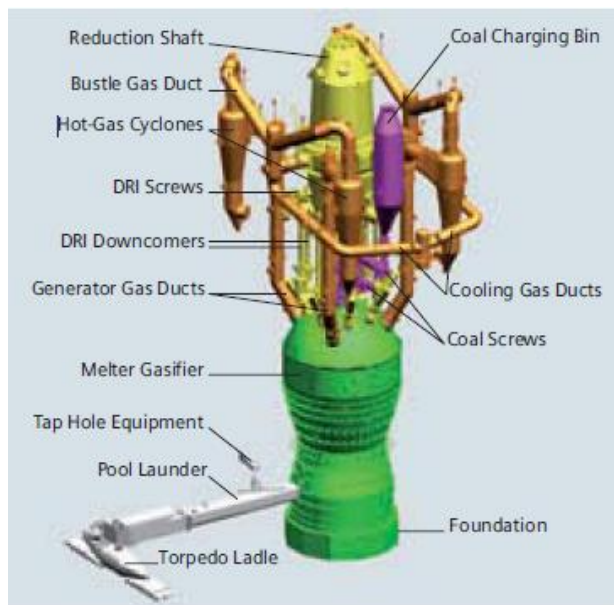
The technologies

Corex

In the Corex process non coking coal can be used directly for ore reduction and melting work. The use of lump ore and pellets means that there is no need for sintering plants. The ore (lump or pellets) is charged into a reduction shaft where they are converted into direct reduced iron (DRI) by reduction gases. The DRI is feed into a melter gasifier where final reduction and melting takes place with the addition of other metallurgical and slag reductions.

The optimum particle size of coal used in the Corex process is between 20 and 30 mm. The coals most suited have air dried fixed carbon content from 55 to 70% (semi soft or PCI).

Figure 30. Corex



Source: POSCO and Siemens

Uses of the technology

The Corex process is currently widely used as an alternative to blast furnaces for the generation of hot liquid metal. The unit is easily attached to a BOF where the hot liquid metal produces steel.

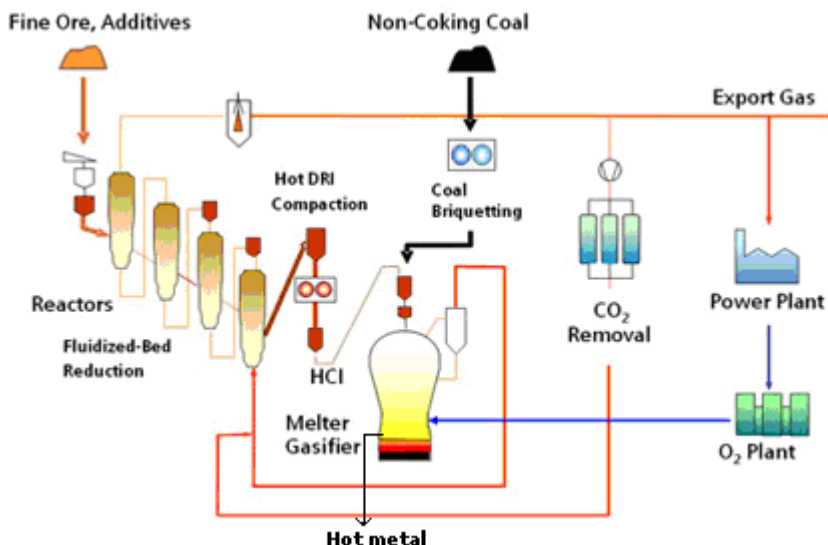
Finex

The Finex process is able to use sinter feed (fines) iron ore up to 12mm. The fine ore is charged into three or four fluidized bed reactors with some fluxes (limestone or dolomite). The iron ore fines are heated and reduced to DRI by reduction gases comprised of CO and H₂ that are derived from gasification of the coal.

The DRI fines are hot compacted to hot compacted iron (HCI) and transferred to the charging bin where they are charged by gravity into the melter gasifier. Smelting takes place in the melter gasifier and hot liquid metal is produced which is equivalent to that produced in a blast furnace.

The heat generated in the coal gasification is used as an energy source in the process. Also the excess gases are collected and can be used for heating purposes in steel works, power generation or additional DRI production.

Figure 31. Finex®



Source: Posco and Siemens VAI Metals Technologies

Uses of the technology

In 2007, the Finex technology was commercialized by POSCO and an annual output of 1.5 million tones has been reached

In 2007, the Finex technology was commercialized by POSCO and an annual output of 1.5 million tones has been reached. If the process can continue to meet expectations in the trial operation stage without any risks then demand for the process should increase as it utilizes the lower cost iron ore fines and non-coking coal.

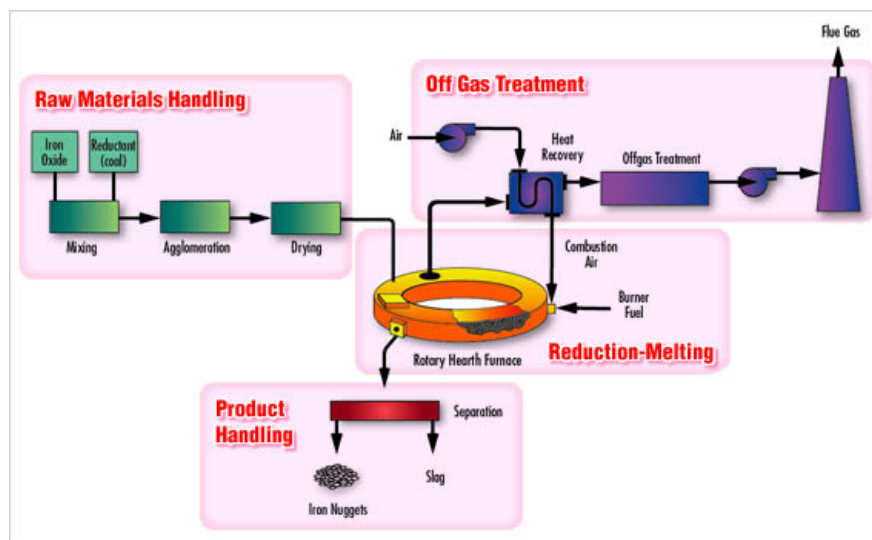
ITmk3

DRI is formed by the removal of oxygen from iron ore at temperatures below its melting point (800°C – 1050°C) using a reducing gas produced by either natural gas or thermal coal. The reducing gas is a mixture of hydrogen and carbon monoxide.

There are two methods used for DRI production: smaller capacity rotary hearth furnaces (RHF) and larger scale shaft furnace plants.

The RHF use iron ore fines and pulverized thermal coal. These are agglomerated into composite pellets. The pellets are charged into the RHF then heated to 1350°C-1450°C, reduced and melted. The molten iron is solidified into nuggets in the furnace, discharged after cooling and separated from the slag.

Figure 32. ITmk3 DRI Process

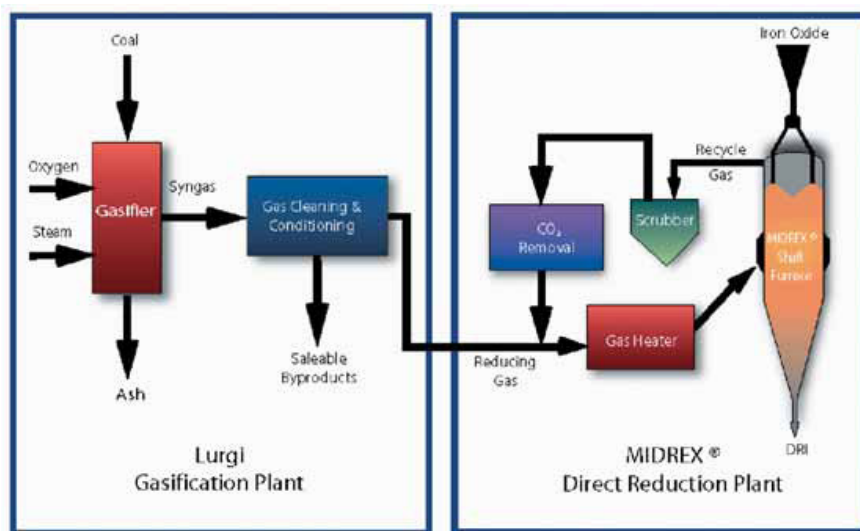


Source: Midrex and Kobelco

Midrex

The shaft furnace is fueled by natural gas and feed with iron oxide pellets or lump ores. A recent innovation has been oxide coating. The pellets can be coated with a thin layer of limestone, cement or bauxite increasing the reducing gas temperatures. As a result production can increase up to 20%. The Midrex plant can also be fueled by syngas which is a reducing gas generated by the mixing of coal, oxygen at temperature.

Figure 33. Midrex DRI Process



Source: Midrex Technologies

Other Alternate Steel Processes

The above section examines the major alternatives to steel making technologies that could replace the blast furnace. However there are some alternate measures that can be used to lower the amount of coking coal that goes in to the standard blast furnace.

PCI and direct injection

Pulverised coal injection (PCI) coal is used as a partial alternative to coking coal in the steel making process. The PCI is crushed into a fine powder and injected into the blast furnace in the production of pig iron.

PCI coal is suitable for direct injection into the blast furnace in a pulverized state and can displace some of the coke required.

In terms of the replacement ratios of low volatile PCI to coke, these vary based on individual blast furnace requirements. Traditionally high volatile coal has been used as a PCI coal by steel mills but there is increasing demand for low volatile PCI which have higher carbon and energy content, providing superior performance.

Under current technologies the maximum PCI loading in to a standard blast furnace is around 160-180kg per tonne of hot metal. In terms of the total coal in to the blast furnace the injection rate represents about 15%. Technological changes could see the PCI injection rate lift in some blast furnaces to over 200kg per tonne of hot metal. And the injection process is not reliant on PCI coal and other sources of carbon can be sourced if the PCI market itself became tight. Oil, gas and tar can also be co-injected in to the blast furnace to provide the carbon content required to reduce the iron. In Japan, technological advancements have used plastics and animal fats have been used as an energy source.

Whilst PCI coal is a substitute to coking coal in a blast furnace we see it as a short term 'stop gap' measure rather than a long term solution to the scarcity of coking coal.

Stamp charging

Stamp charging is the process of compacting lower rank coal using "feet" attached to vertical rods. The resultant block of compacted coal has an increased bulk density and is fed into the coke oven where a higher quality and stable coke is produced. In essence by increasing the bulk density of the poorer quality coals the properties of the final coke are improved.

Stamping allows for use of poorer quality and volatile coal to be put in to coke oven and reduces the need for premium hard coking coal. As such stamp charging is a technology that offers a reduction in coke production costs.

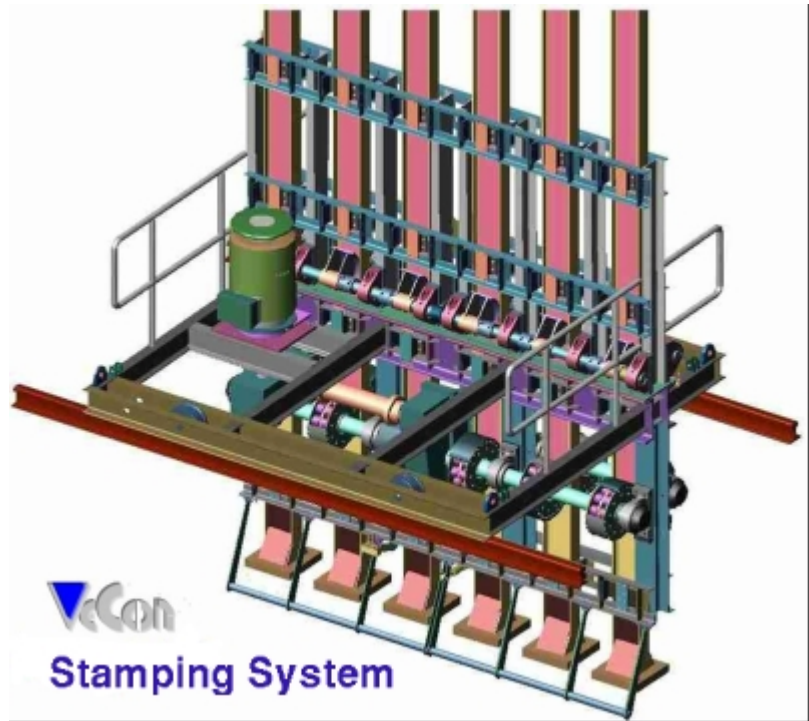
A major problem with the stamping technology is that when used in conventional coke slot ovens, the higher density coal increases oven wall pressure. The increased pressure causes the charge in the oven to swell and stick to the walls. Over time this causes wall damage and may also reach the extreme of coke oven failure requiring extensive and expensive repairs.

India has been leading the way with stamp charging and is currently investigating methods to overcome increasing oven wall pressures. These include:

- Designing coal blends that do not swell in the oven
- The use of heat or non-recovery ovens

The current problems with the technology need to be eliminated before the stamp charging process can be used to bypass coking coal in the iron making process.

Figure 34. Stamp Charging Machine



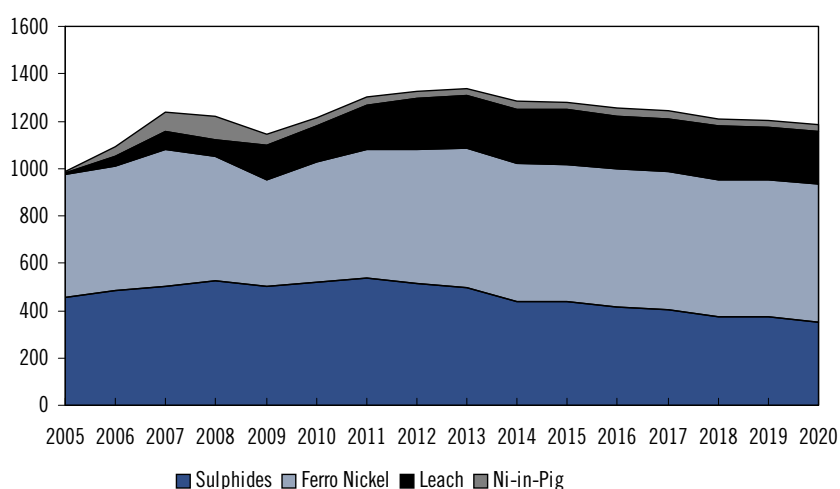
Source: VeCon

Nickel Laterite Processing

Technology Overview

Approximately 60% of the world's nickel resources are held in laterite deposits. It is critical to have efficient and economical processing technology to extract the nickel from these deposits. However nickel laterite production (ex-ferro nickel) only accounts for around 10% of the world's nickel production but closer to 75% of all the growth projects. Whilst the technology in the nickel market is not new, nickel is a classic case study in terms of how technology can be difficult to implement in the mining sector (issues with the HPAL technology). It is also a sector that shows how low tech solutions such as nickel in pig iron (NPI) can add supply to a market when prices are high.

Figure 35. Nickel Production Profile (kt)



Source: Brook Hunt, Citi Investment Research, Brook Hunt

Given the abundance of laterite ores, technology has focused on being able to unlock and commercialise the deposits. Laterites are formed from the weathering of ultramafics and the ores are metallurgically complex making them not readily amenable to concentration, pyrometallurgical smelting and refining to metal. The technology development around laterite ores has been focused on

High pressure acid leaching (HPAL) – uses sulphuric acid to leach the nickel out of the host rock at high temperatures and extreme pressure

Heap leaching – similar to HPAL but sulphuric acid leaching is conducted at atmospheric pressure and temperature

Direct nickel – Developed with funding from the CSIRO the process looks to leach out the nickel in a bath solution

Ammonia leaching (Caron process) – dries and grinds the ore before roasting. Then placed in an ammonium carbonate solution to leach out the metal

Laterite ores

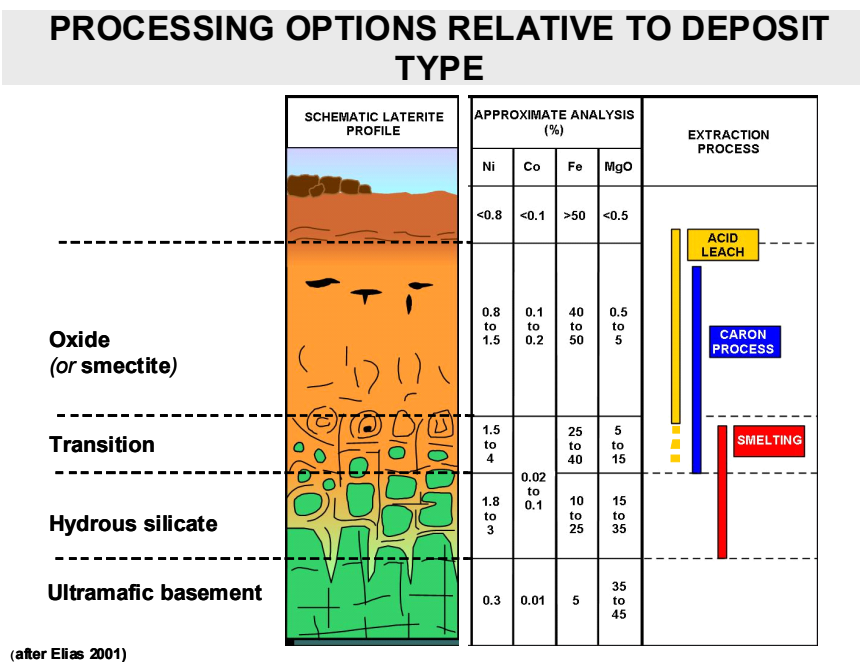
Lateritic nickel ores are formed by intense tropical weathering of ultramafic deposits.

There are two types of lateritic nickel ore:

1. Oxide (limonite type) – highly enriched in iron and contain 1-2% nickel
2. Silicate (saprolite type) – forms beneath the limonite zone and generally contains 1.5-2.5% nickel however some higher concentrations can be present in discrete structures.

Typically nickel laterite deposits are low grade but high tonnage and close to the surface.

Figure 36. Schematic Of Presence Of Laterite Nickel Ores



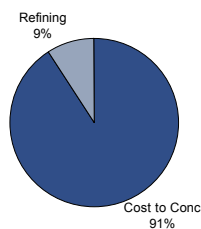
Source: Elias 2001 and CRCLEME

Costs

Mining, smelting and refining costs varying between sulphides and the laterites. Within the laterites cost drivers are also different between ferro-nickel leaching. Sulphide costs are dominated by mining costs. Energy accounts for about 20% of cash costs.

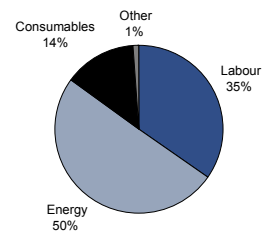
Smelting and refining costs are a much more important component of laterite costs than for sulphide costs. Laterite costs are dominated by processing.

Figure 37. Typical Sulfide Cost Breakdown %



Source: Brook Hunt, Citi Investment Research

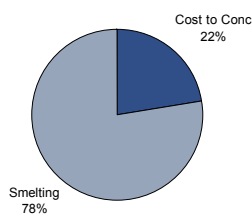
Figure 38. Sulfide Refining Cost Breakdown



Source: Brook Hunt, Citi Investment Research

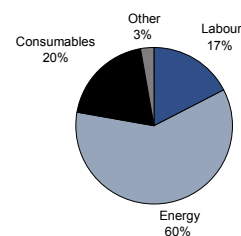
Laterite costs are much more influenced by smelting (for ferro nickel) and refining (for leach). Energy costs account for about 47% of Fe Ni and 12% of leach costs. Consumable (mostly acid) accounts for more than half of leaching costs.

Figure 39. Typical Ferro Cost Breakdown %



Source: Brook Hunt, Citi Investment Research

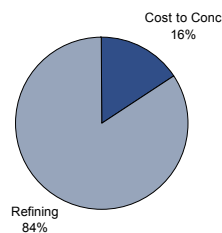
Figure 40. Ferro Smelting Cost Breakdown



Source: Brook Hunt, Citi Investment Research

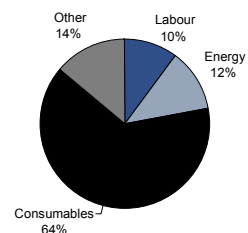
HPAL are impacted by consumable costs (acid) followed by power costs.

Figure 41. Typical HPAL Cost Breakdown %



Source: Brook Hunt, Citi Investment Research

Figure 42. HPAL Refining Cost Breakdown



Source: Brook Hunt, Citi Investment Research

The failures to date

Of the three initial pressure acid leach projects in Australia (Bulong, Cawse and Murrin Murrin) only Murrin Murrin has survived, yet not without massive additional capital and technical investments.

Bulong had the least proven technology and flowsheet and experienced equipment problems with gypsum precipitation in SX and was slow to ramp up. The operation was closed in 2003 after it lost its acid supply from the WMC's Kalgoorlie Nickel Smelter.

Cawse had flowsheet adapted from the Bulong operation yet was undercapitalised and the Centaur group sold the operation to OMG. OMG terminated downstream processing and sent an intermediate precipitate to Finland for refining. Cawse was closed by its current owner Norilsk.

Murrin Murrin was another variation to Bulong's direct solvent extraction flowsheet and experienced several processing problems. Anaconda initially selected the direct solvent extraction route, but later rejected it because it was concerned that the banks and other financial institutions would be reluctant to lend significant sums of money to finance a large-scale project using unproven technology.

The Murrin Murrin flowsheet thus incorporated the standard pressure acid leaching design at the front end of its plant. It is often perceived that larger acid leach scale operations backed by the major would not suffer the small fate of the smaller first stage projects such as Bulong, Cawse and Murrin Murrin.

Ravensthorpe was acquired by BHP from Comet Resources in 1999. The project entailed an upgrade of the ore from 0.8%Ni to 2% feed for processing via a complex flow sheet combining HPAL and atmospheric leaching. A mixed nickel-cobalt hydroxide intermediate was to be produced for refining to metal at Yabulu. Capital cost of the project blew out from an initial \$920million to \$3.2 billion. The closure decision was co-incident with a depressed nickel market and ongoing technical challenges, even after several capital cost escalations. This raises significant questions over other large scale acid leach operations.

Goro was discovered by Inco in 1969 and has been developed slowly. After acquiring Inco Vale reviewed the project and decided to proceed. Capital costs have blown out to US\$4-5bn. Commissioning has been delayed and ramp-up extended over 4 years. Other leaching projects have also been delayed or postponed.

- The 60kt Ambatovy HPAL project in Madagascar has been delayed and the cost estimate raised by more than \$1 billion in February 2009 from its last \$US3.3bn estimate (\$US1.6bn originally).
- Gladstone - Capital costs for the project were estimated in October 2007 to be US\$3.84Bn, with full production of 126ktpa. The refinery is aimed at treating abundant high grade nickel laterite ores from New Caledonia.
- Coral Bay / Rio Tuba second processing plant is due to coming on-line in September 2009. However the later stage expansion of an additional 30ktpa has been delayed.

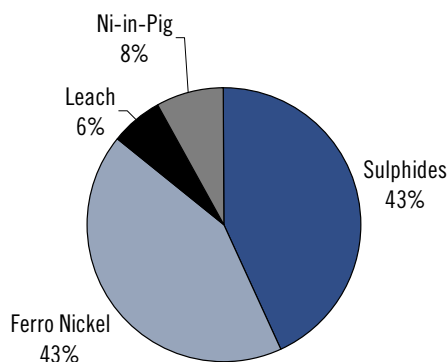
- Kalgoorlie Nickel Project – Vale have completed the pre-feasibility and have yet to decide to move to a BFS.
- BHP Indonesia has dropped plans to develop a \$US4.5bn of nickel laterite resources in Eastern Indonesia in late 2008.
- A decision on Vermelho has been delayed until successful commissioning of Goro. It is possible for the 46 ktpa project to be in production by 2013. Capital costs are expected to be around \$1.9b.
- Ramu capital costs have increased to US\$1.37bn in March 2008 from an original US\$838M. First Production was last scheduled for mid-2009.

Supply potential

Laterites account for the majority of growth in nickel supply and reserves. However questions remain over the viability of Atmospheric and High Pressure Acid Leach (HPAL) Technology and Heap Leaching used to process laterite ores. We examine what the supply side will look like if these technologies fail. Nearly 300kta of mine supply would be cut by 2014.

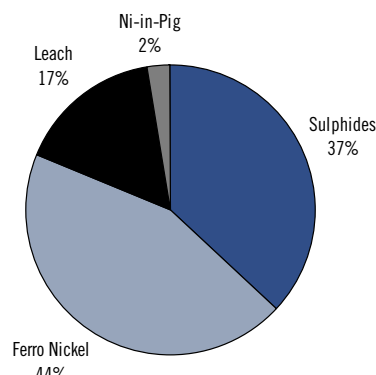
Clearly the outcome of the nickel laterite technology will be crucial in the supply and pricing outlook for the nickel market.

Figure 43. 2009 Nickel Supply



Source: Brook Hunt, Citi Investment Research and Analysis

Figure 44. 2013 Nickel Supply



Source: Brook Hunt, Citi Investment Research and Analysis

Committed HPAL and HL projects will add meaningful supply over the next 3 years.

Figure 45. Probable Projects

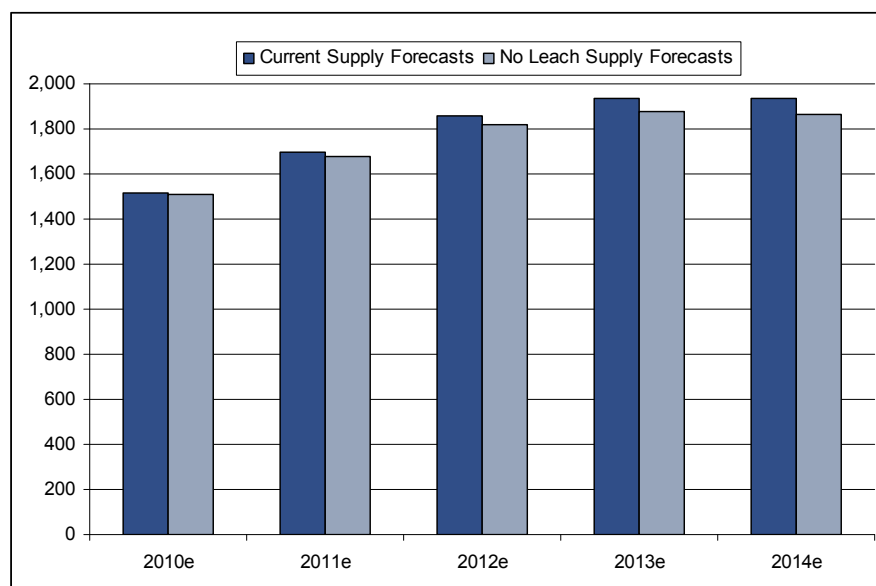
Project	Country	Ore	Process	2010	2011	2012	2013	2014	2015
Avebury	Australia	S	Sulphide				4	8	9
Ban Phuc	Vietnam	S	Sulphide		2	6	6	4	3
Bonao	Dominican Republic	L	FeNi				15	35	42
Eagle	USA	S	Sulphide					15	22
Fenix	Guatemala	L	FeNi					5	9
Lockerby	Canada	S	Sulphide		1	3	4	4	4
Niquelandia	Brazil	L	FeNi		6	9	10	11	11
NorthMet	USA	S	Sulphide				2	6	7
Nunavik	Canada	S	Sulphide			10	16	17	17
Ravensthorpe	Australia	L	PAL			16	29	36	38
Tagoung Hill	Myanmar	L	FeNi		6	14	20	23	23
Trojan	Zimbabwe	S	Sulphide		2	4	5	6	6
Yuanshishan	China	S	Sulphide	2	2	2	2	2	2
			Total PAL	0	0	16	29	36	81
			Total Leaching	0	0	16	29	36	81

Source: Company reports and Citi Investment Research and Analysis

We expect Goro to reach full production in 2014 of ~60 ktpa on a three year ramp-up. The project is ~3 years behind schedule. Capital cost estimates have increased from \$1.5b at inception to US\$4-5b now.

Vermello is Vale's other HPAL project but it has not yet been committed to and a go head is unlikely in the current environment until a successful commissioning of Goro. It is possible for the 46 ktpa project to be in production by 2013. Capital costs are expected to be around \$1.9b.

Figure 46. Change In Nickel Supply If Leaching Fails

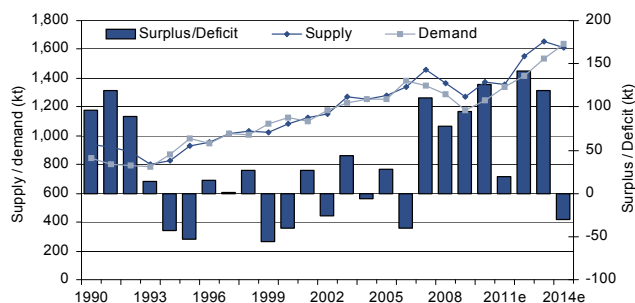


Source: Brook Hunt, Citi Investment Research

If we extrapolate these failures to other laterite leaching projects ~250ktpa is removed from supply by 2014.

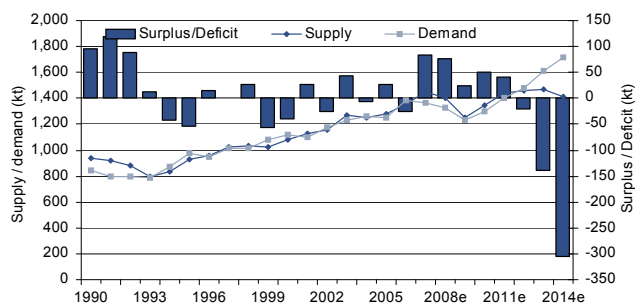
The resulting supply demand balance in the next few years. Large deficits appear in the outer years and hence new projects or dramatically higher Ni-In-Pig production will be required.

Figure 47. Current Nickel Supply Demand Balance (kt)



Source: Brook Hunt, Citi Investment Research and Analysis

Figure 48. Nickel Supply Balance - No Leaching



Source: Brook Hunt, Citi Investment Research and Analysis

The potential for economic failure of laterite leaching technologies is an important upside risk for nickel prices. If all leach projects were to be removed from the supply equation the nickel market would return to supply deficits in 2012 and we believe prices could reach \$US10/lb. This contrasts with our current forecasts which show large surplus until 2014 as shown above.

The failure of laterite leaching not only changes the supply demand balance, but also the cost curve and the competitive landscape

The Laterite Technologies

Nickel is recovered from laterite ores using the one or several following five processes:

- Ammonia leaching (Caron Process)
- Pressure acid leaching
- Heap leaching
- Atmospheric Pressure (VAT) Leaching
- Ferronickel smelting

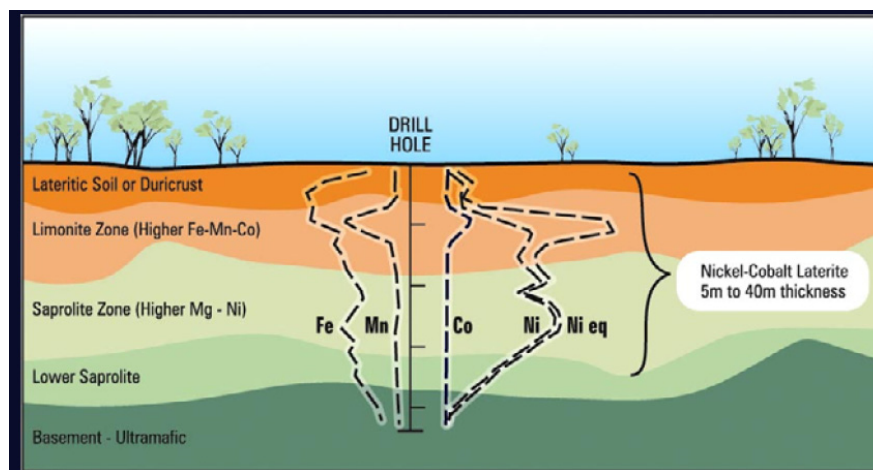
We do not address Ferronickel technologies here given their robust and proven (albeit energy intensive) nature. The two most significant leaching technologies are:

- Ammonia leaching
- Pressure acid leaching

The choice of process is largely dependent on mineralogy.

- Pressure acid leaching is usually only considered for limonite ores which contain low levels of acid-consuming magnesium (5% or less).
- Ammonia leaching is used on limonite ores or mixed limonite/serpentine material, which contain somewhat higher levels of magnesium (up to about 8%) but, at the same time, contain low levels of silica.

Figure 49. Laterite Cross Section



Source: Metallic Minerals

HPAL

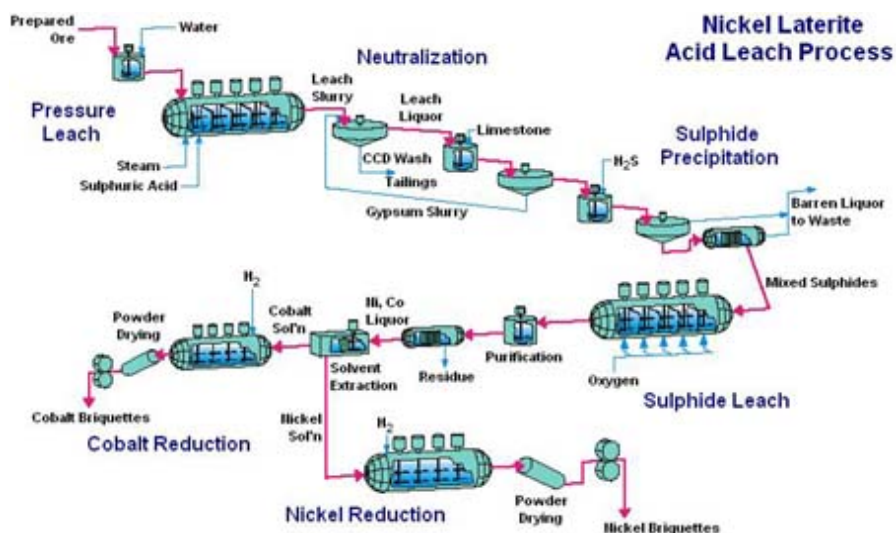
The high pressure acid leach process can be used to treat both limonitic and saprolitic nickel ores. However the process works more efficiently and cost effectively on limonite ores as they have low magnesium and aluminium as this reduces acid consumption.

The process

High pressure acid leaching (HPAL) uses hot sulphuric acid within an autoclave operating at temperatures of 245°C to 270°C and pressure of 5400kPa. These conditions allow the nickel and cobalt in the laterites to be dissolved. After the autoclave process, impurities are removed with the addition of limestone and magnesia is used to precipitate the nickel and cobalt as a hydroxide slurry. The rest of the impurities are driven off using ammonium carbonate. The nickel-rich solution is then purified and nickel and cobalt are separated using solvent extraction (SX). Electro-winning (EW) further refines the nickel targeting 95% nickel and 90% cobalt.

The high pressure and elevated temperatures in this process are required otherwise the extraction of the nickel using sulphuric acid would take a too long. The sulphuric acid is used in preference to other chemicals as it is the cheapest hydrometallurgical reagent and also it does not generate undesirable by-products.

Figure 50. HPAL Process For Nickel Laterites



Source: METSOC

Pros and cons of the technology

Figure 51. Pros And Cons Of Technology

Pros

- Ability to treat both limonitic and saprolitic ore blends
- High extraction rates of nickel and cobalt
- No smelting required making the high moisture content in lateritic ores less problematic

Cons

- High capital and operating costs associated with the high pressure requirements of the process
- New plants normally have numerous teething problems to do with the plant and process
- May only be viable when cobalt can be extracted as this is a valuable by-product

Source: Citi Investment Research and Analysis

Heap leaching

Both nickel sulphide and laterite ores can be leached using this method. Sulphide ores must first be treated with bacteria to break down the sulphide minerals to make them amenable to leaching whereas, laterites can be acid leached directly. Most recent heap leaching studies and developments are focused upon laterites. Limonite and saprolite ores can both be heap and atmospheric leached. However, higher grade saprolite ores are generally preferred over limonite due to their lower iron content. Heap leaching can be a stand alone operation or to supplement an existing HPAL operation.

It is estimated that only around 5-10% of the world nickel deposits are amenable to heap leaching, based simply on suitable geographic location of major laterite deposits. Most of the suitable laterite deposits are located in Australia, given low rainfall and flat topography.

The process

The nickel in laterite is in the form of a chlorite silicate mineral which can be leached preferentially. Heap leach involves irrigating stockpiled ore (based on sealed pads) with acid which is reticulated to leach out the metal into a solution for further processing. Key requirements for a heap leaching operation are:

1. Amenable ores – Not all laterite ore is suitable for heap leaching. The most suitable laterite deposits for leaching are large scale, generally lower grade shallow type structures. The most suitable ore is low in clay and iron (e.g. less than 20%). High clay content in ore prevents adequate contact with and drainage of acid. Coarse agglomerated material is preferable. A low strip ratio is also required (less than 1.2:1).
2. Correct topography – Large open, flat and stable country is beneficial given the requirement for significant stockpiles and irrigation.
3. Low rainfall and ore moisture content is required to prevent acid dilution.
4. Proximity to infrastructure – close proximity to infrastructure and markets is preferable. If close to infrastructure acid can be purchased and trucked to site. If an acid plant is required it is preferable to have access to the power grid, as acid production is exothermic and excess power can be sold back to the grid improving project economics.

5. Acid Plant – A typical Ni heap leach requires 400kg acid / tonne of stockpile ore at 1% Ni grade. Acid can be purchased (at substantial cost) or produced on site for larger scale operations at a capital cost of \$US65m for 600ktpa acid plant.
6. The ability to process or sell an intermediate nickel product for further refining

Current C1 cast cost estimates for laterite heap leaching projects are near the mid point of the cost curve (albeit lower than many existing HPAL laterite operations). If correct, this could see healthy margins for current and future heap leach projects and expansions.

Nonetheless, we cannot foresee substantial new supply from laterite heap leaching with limited reserves in suitable geographic and topographic locations combined with suitable ore geology. Further, suitable ore bodies in suitable locations are required to be at shallow depth, close to infrastructure

Industry average total costs, including capital (C3), have increased at a similar rate to operating costs. Capital costs for new laterite projects average US\$11.33/lb of annual production, sulphides US\$4.50/lb. Indicative capital costs (see Figure 5) for new heap leach projects average ~US\$10/lb for greenfields projects requiring a stand alone acid plant. Importantly capital intensities for expansion of existing HPAL projects, with a heap leach adjunct could be substantially lower given existing acid plant facilities.

Pros and cons of the technology

Figure 52. Pros And Cons Of Technology

Pros

- Increase use of lower grade ore and waste utilization (can process both limonite and saprolite ores)
- Less complex processing than HPAL
- Reduced capital intensity
- Potentially improved viability for small scale operations

Cons

- Large amount of waste material (lower grade ore and lower recoveries generating more than twice the waste of HPAL)
- Acid consumption can vary greatly with mineralogy
- High iron and clay content in ore can present a significant processing issue (only certain ores are suitable)

Source: Citi Investment Research and Analysis

Atmospheric pressure leaching

Atmospheric pressure leaching is another nickel recovery method. This method is not new with trials carried out in the 1980s. The BHP Ravensthorp project was designed to use a combination of pressure acid leaching and atmospheric leaching however due to the high costs this project was put on hold.

The process

Limonite ore is typically processed using this method and is mixed with seawater, sulphuric acid, sulphur dioxide and steam in a leaching vessel at 80-105°C. Nickel and cobalt extraction can be around 90%. The final product from the treatment is usually a mixed Ni-Co precipitate for refining elsewhere.

Pros and cons of the technology

Figure 53. Pros And Cons Of Technology

Pros

- Increase ore utilization (processes both limonite and saprolite ores)
- Claimed to be less complex than HPAL
- Robust and lower maintenance

Cons

- Large amount of waste material (Brook Hunt estimate 1.1 t of waste for every 1 tonne of ore treated)
- Capital intensity
- Ore blend must be precise
- Low iron chemistry and potentially high acid consumption
- Waste product is jarosite (unacceptable for dumping) which can require pressure leaching (increasing operating costs)

Source: Citi Investment Research and Analysis

Direct Nickel

Direct Nickel (DNi) technology owned by Direct Nickel Pty Ltd is a hydrometallurgical process for the treatment of nickel laterite deposits. The technology is still in pilot plant stage and will be at least a few years away from commercialisation.

The process

It is a tank leach process that operates at atmospheric pressure (with the option of mild pressure) and relatively low temperatures. A special reagent package is used to liberate the nickel, cobalt and other metals into solution. The insoluble residue is neutralized and sent to a waste disposal facility. The solution is then sequentially processed to extract the individual metals.

Uses of the technology

To process all lateritic nickel ores at lower cost than current technologies with high recovery rates and reduced environmental impact.

Pros and cons of the technology

Figure 54. Pros And Cons Of Technology

Pros

- Ability to treat full laterite profile from limonitic to saprolitic ores
- Extraction exceeds 95% nickel and 85% cobalt
- Reagent recovery >95% and reagent consumption is as low as 30kg/t of feed material compared to sulphuric acid leaching processes which consume 300 to 1000kg/t
- Low operating costs compared with other processing techniques due to atmospheric pressure and low temperature
- Low technology risk
- Environmental benefits of reduced tailings and process emissions are captured and recycled
- Low capital threshold to entry with the ability to freely scale up from 5ktpa of nickel to any size

Cons

- Still in trial stage so technology risk

Source: Citi Investment Research and Analysis

Caron process leaching

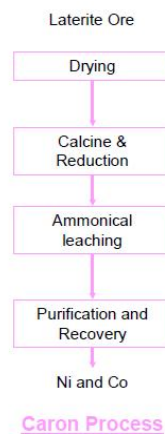
The process

The process involves grinding and drying of the ore. The crushed ore then goes through reduction roasting and then undergoes leaching with ammoniacal carbonate and precipitation to form a nickel carbonate. In the leaching phase cobalt is separated out. Nickel metal is then recovered from the nickel solution.

Recovery of nickel and cobalt decreases with increasing amounts of saprolite as the nickel and cobalt are locked in the silicate matrix which is difficult to reduce at temperatures around 700°C.

Examples include: Yabulu in Australia, Tocantins in Brazil and Punta Gorda in Cuba.

Figure 55. Caron Process



Source: CRCLEME

Pros and cons of the technology

Figure 56. Pros And Cons Of Technology

Pros

- Cobalt recovery (but lower recovery than other processes such as HPAL)
- Able to tolerate higher magnesium in ore than HPAL

Cons

- The front end of the Caron process involves drying, calcining and reduction which are all energy intensive and high cost
- Requires temperatures of ~700°C making high energy costs
- Nickel and cobalt recoveries are lower than for the traditional smelting or the HPAL processes
- The requirement to dry low grade ore
- High costs make it too expensive for limonite ores

Source: Citi Investment Research and Analysis

Other Nickel Processes

Nickel in pig iron

Nickel in pig is a process that took off in 2007 with high nickel prices. China sourced abundant low grade lateritic nickel supplies from Indonesia and the Philippines for feed in unused blast furnaces. The concentrate produced is low in nickel (1-2%). Technology has evolved and improved to reduce the costs associated with this style of nickel processing. Blast furnaces are gradually being replaced with EAF.

The process

Nickel laterite ore is finely crushed then mixed with coke, limestone and other material in mixing machines and transported to the sintering plant. The raw material mix is then placed on a steel conveyor belt in the sintering plant where it is heated by gas fired furnace to form sinter.

The sinter is mixed with coke and limestone and feed into the furnace where hot gas heats the mixture reducing it from metallic oxides to liquid metal. The resultant molten nickel pig iron flowing out of the furnace is cast into moulds and ready for delivery.

The resulting nickel pig iron is then mixed with chromium and other materials to produce 200 and 300 series stainless steel.

An alternative to blast furnaces are electric arc furnaces (EAF). In China, the output from EAF is increasing due to the lower associated operating costs.

Uses of the technology

This is a process for treating low grade nickel laterites. The NPI produced can be used in 200 and 300 series stainless steel.

Pros and cons of the technology

Figure 57. Pros And Cons Of Technology

Pros

- Can treat low grade nickel laterites (0.8% to 2% Ni)
- Can use EAF as a cleaner option to blast furnaces producing 10-25% Ni grades in the NPI
- Cash cost of production of stainless steel 300 series is cheaper using NPI than with primary nickel

Cons

- High production costs
- High impurity concentrations of sulphur and phosphorous
- Produces low grade stainless steel in comparison with primary nickel
- If blast furnaces are used for NPI then relies on coking coal and has high emissions and poor environmental standards

Source: Citi Investment Research and Analysis

Hydrometallurgical Processing

Hydrometallurgical overview

It is estimated that around 80% of the world's total copper production is processed through the smelting process with SXEW production accounting for the remaining 20%.

The smelting process is highly efficient and recent innovations have enabled production of high quality copper while also recovering precious metals and converting sulphur to a saleable sulphuric acid. However, there are many downsides to smelting which include;

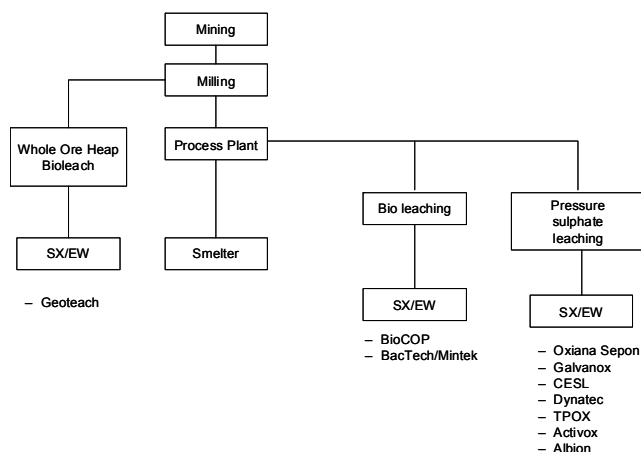
- Very high capital and operating costs
- Long construction times
- Inability to treat oxide ores
- Inability to treat arsenic and bismuth
- Not economical for small operations/throughput

Pure and high grade copper reserves are depleting and many new copper reserves are small and have increased ore complexity or are copper oxide deposits. Concentrates can receive penalties from smelters if they have elevated deleterious elements such as arsenic, bismuth, lead or tungsten. If concentrations of these are above cut off levels then smelters can refuse to take the concentrates. Concentrate producers are therefore required to either source smelters that can blend their concentrate or find alternate processing technologies which can extract out these elements.

Hydrometallurgical processes have a number of key objectives they need to meet in order to be competitive with smelting. These include;

- Produce high quality copper metal
- Convert the sulphur present in chalcopyrite to a marketable form (sulphur or sulphuric acid) or suitable for long term disposal (gypsum)
- Convert the iron present in chalcopyrite to a form suitable for disposal (goethite or hematite)
- Convert impurity metals such as selenium, mercury and lead to a form suitable for long term disposal or recovery
- Allow recovery of gold, silver, platinum group metals and base metals such as nickel, cobalt and zinc sometimes associated with chalcopyrite in marketable forms
- Be able to treat concentrates and/or whole ore sources containing deleterious elements such as arsenic, lead, tungsten and bismuth to an environmentally acceptable form

Figure 58. Main Methods For Treating Copper Concentrates



Source: Citi Investment Research and Analysis

The hydrometallurgical processes above will all have varying economics due to site specific factors:

- Concentrate grade
- Power costs
- Accessibility to existing infrastructure and land
- Labour rates
- Transport rates
- Mineralogical composition
- Process route adopted

However the major economic factor behind hydrometallurgical process is delivering the potential to make new ore bodies produce and maximising productivity and recovery from existing operations with complex mix ore.

Figure 59. Overview Of Hydrometallurgical Processes

Process	Metal focus	Overview	Commercial	Asset
Heap bioleaching	Copper	Micro-cultures are added to the heap pad with the leaching solution to leach out the metal	No	
Activox	Nickel	A combination of fine grinding and pressure oxidation	No	Norilsk Nickel holds patents for the technology
Albion	Nickel	Treats concentrates from refractory ores. Ultra fine grind and active leaching under atmospheric conditions	No	Plant in construction at EnviroGold's Las Lagunas tailings project
CESL	Copper	Oxidation of sulphide concentrates at high temp and pressure with catalytic ions. Impurities get oxidised in the process	No	Trial plant at Vale Copper Facility in Carajas region
Galvanox	Copper	Leaches copper from a mixed copper sulphide through the electrical imbalance of the ore types.	No	
Total Pressure Oxidation (TPOX)	Copper	Use of autoclaves to oxidise sulphide ore bodies	Yes	Kansanshi

Source: Citi Investment Research and Analysis

Supply and demand implications

The different hydrometallurgical processes allow the process of sulphide ores that previously were not suitable for the conventional smelting methods. This will enable a greater supply of base metals including nickel, zinc, copper, cobalt and molybdenum. An exact analysis of how much potential supply can be delivered through these processes is difficult to determine given the need to ascertain the 'type' of ore sitting within a companies resource base.

We do not believe that the hydrometallurgical process will result in an SXEW style revolution that we saw in the 1970's. However the potential is certainly there for some incremental capacity additions.

Codelco's Mansa Mina mine is a case study in the issues of high arsenic. The mine has 500mt of reserves with a copper grade of over 1% (insitu metal of 5mt). The deposit was found to be uneconomical in the late 90's due to the high levels of arsenic. However the Chuqui mill will require sulphide ore feed when it goes underground and the project through developments in hydrometallurgical processing will allow the process of sulphide feed.

If the hydrometallurgical process can increase global supply of copper by 1% (which we believe is an achievable figure) then it has the capacity to add 150ktpa of production which is a similar size to the Lumwana project for Equinox.

Risks

There are a number of factors that have delayed the implementation of hydrometallurgical processing at mine sites.

- Poor technical results when scaling up from pilot plant to mine capacity
- Increased risks associated with the new technologies such as new processes, unique chemistry, processing conditions and equipment
- Costs associated with licensing the new technology

The Technologies

The major hydrometallurgical processes we summarise in this section are

- Heap bioleaching
- Activox
- Albion
- CESL
- Galvanox
- Total Pressure Oxidation (TPOX)
- Bio Leaching

Heap bioleaching

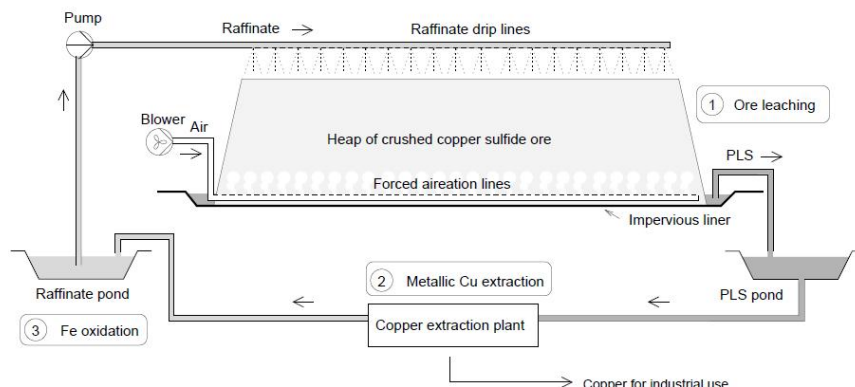
Whole ore heap bioleach process allows for recovery of copper and other base metals from primary and secondary sulphide ores. It is a similar process to conventional whole ore acid heap leaching but has an additional system to maintain biological activity and maximize heat conservation. Sulphide leaching is maximized through maintaining high temperatures within the heap.

The pad is loaded with agglomerated ore in individual panels which is irrigated with a barren leach solution (sulphuric acid) to achieve the desired pH. The microbial culture in solution is then added to start the bio-oxidation process. The microorganisms require temperatures between 30 and 35°C and a pH of 1.3 to 4.5 for optimal growth. Continual monitoring of the temperature, pH and off-gases and the aeration and irrigation rates are required.

The solution pond collects and circulates the copper rich solution to allow for a constant grade. Leaching is followed by SX/EW for further extraction of copper. Sulphuric acid is a by-product of the SX/EW which is re-used in the leaching process.

If there are any deleterious elements present then before the solution undergoes SX/EW then an additional step for purification is required to remove the elements.

Figure 60. Simplified Copper Heap Leaching Process



Source: Citi Investment Research and Analysis

Uses of the technology

Heap bioleach is a low cost method that allows for cost effective treatment of low grade ores that can contain arsenic. It is low cost due to very little ore preparation (crushing only) and minimal energy use.

This could also be a cheap and cost effective method for companies to reprocess waste dumps for extra metal recovery. Material that was once classified as waste as it was uneconomical to treat due to lower copper prices could have metal extracted using this process.

Pros and cons of the technology

Figure 61. Pro's And Con's Of New Technology

Pro's

- Ability to treat low grade ore cost effectively
- Suitable for smaller operations
- Low capital cost requirements
- Can extract arsenic before SX/EW
- Less environmental impact

Con's

- Constant maintenance required to enable running at optimum conditions
- Slower recovery times if optimal temperature is not maintained
- Lower recovery and production rates
- Generally longer than expected start up times

Source: Citi Investment Research and Analysis

Bio leaching

Bioleaching is an alternative technology that is being explored to process and extract base metals. Currently the main disadvantage is that bioleaching is slow in comparison to conventional pyrometallurgical processes and high-intensity hydrometallurgical processes. The major challenge is determining how to operate leaching at temperatures above 60°C where increased leaching rates are achieved. Scientists are searching for bacteria that can withstand these temperatures, can be preserved, transported and used to inoculate the ore successfully, all at a relatively low cost.

The process

BioCOP is used at Chuquicamata where thermophile bacteria is used to oxidize sulphide minerals to metal sulfates and sulphuric acid at atmospheric pressure (100kPa) and temperatures of 65-80°C. The thermophile bacteria together with oxygen are added to a stirred tank reactor with the finely ground ore. The copper is then recovered by solvent extraction and electrowinning (SX/EW).

Another process is Bioleach by BacTech and Mintek. This uses the BACOX bioleaching technology to process arsenic rich mine tailings and oxidize sulphides to eliminate a major source of acid mine drainage. The precious and base metals recovered can be sold to the market. It operates at low temperature (35°C) and atmospheric pressure (100kPa) but required a very fine grinding (5-10µm).

Uses of the technology

The bioleaching processes can be used as an alternative to conventional processing methods for base metals and arsenic. The technology can treat arsenic rich ores without suffering significant penalties.

Pros and cons of the technology

Figure 62. Pro's And Con's Of New Technology

Pro's

- Increased metal recoveries without increasing operational costs
- Ability to treat low grade ore cost effectively
- Reduced leach cycle time and inventory
- Reduced acid and water

Con's

- High capital costs
- Constant maintenance required to enable running at optimum conditions
- Bactech required very fine grinding to enable leaching of chalcopyrite
- BioCOP™ has high oxygen consumption and acid waste

Source: Citi Investment Research and Analysis

Pressure sulphate leaching

There have been a number of new processes developed over the last 5-10 years that demonstrate advances in chemical reaction kinetics for treating copper concentrates that are not suited to smelting. These processes all have variations in grinding size, operating temperatures and pressures depending on the concentrate they have been designed to treat.

Figure 63. Sulfate Processes

Process	Temp (°C)	Pressure (kPa)	Regrind D80 (µm)	Special conditions
Activox	90-110	1000-1200	5-10	Fine grinding combined with high oxygen overpressure overcomes chalcopryrite passivation
Albion	85	100	5-10	Atmospheric ferric leaching of very finely ground concentrate
Galvanox™	150	1000-1200	10-15	Modest regrind combined with surfactants for chalcopryrite leaching
Bactech/Mintek Low Temperature Bioleach	35	100	5-10	Low Temp bioleach requires very fine grinding to overcome chalcopryrite passivation
BIOCOP™ Process	65-80	100	37	High Temp bioleach uses thermophilic bacteria
CESL Copper Process	140-150	1000-1200	37	Chloride catalyzed leach of chalcopryrite producing basic copper sulfate precipitation in the autoclave
Oxiana Sapon Copper process	80 - copper 220-230 - Pyrite	100 3000-4000	100 50	Atmospheric ferric leach for copper from chalcocite. Pressure oxidation of pyrite concentrate to make acid and ferric sulfate for copper leach
Total Pressure Oxidation Process	220-230	3000-4000	30-40	Extreme conditions of T and P designed to rapidly destroy chalcopryrite and other sulphides
High Pressure Acid Leach (HPAL)	>250	3300-5500	30-40	High pressure and temperature process

Source: David Dreisinger, University of British Columbia, Citi Investment Research

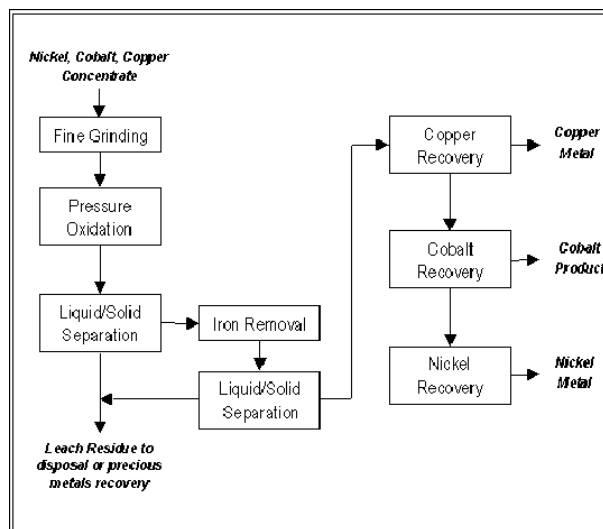
Activox

Activox® is a leaching technology used for treating a variety of metal sulphide concentrates. Western Mineral Technology (WMT) is the developer of this technology

The process

This involves a combination of fine grinding (5-10µm) and pressure oxidation. It operates under moderate pressure of 1000-1200kPa and at elevated temperatures of 90-110°C. Mineral sulphides are broken down when reacted with oxygen. The resulting slurry needs further processing via solvent extraction to recover the metals. The process was demonstrated at a pilot scale on Tati Nickel concentrate in Botswana but has been in care and maintenance since 2007.

Figure 64. Activox® Process



Source: Western Minerals Technology

Uses of the technology

It can be used as an alternative to the smelting process to recover nickel, copper, cobalt and gold.

Pros and cons of the technology

Figure 65. Pro's And Con's Of New Technology

Pro's

- Nickel, cobalt and copper metal recoveries into solution exceed 95%
- Mild oxidation conditions allow the use of low cost materials for plant construction
- Substantial reductions in capital and operating costs
- No acid consumption – generates acid
- Waste heat available for power

Con's

- Poor leaching of chalcopyrite
- Difficult to recover lead or arsenic in a zinc sulphide and gold or silver in a copper sulphide
- End up with higher iron and sulphur content in the concentrate
- Operability issues
- High neutralization requirement

Source: Citi Investment Research and Analysis

Albion process

This technology was developed by MIM (now Xstrata) to treat concentrates produced from refractory base and precious metal ores. Currently the process is jointly owned by Xstrata and Highlands Pacific/OMRD (Japanese consortium).

The process

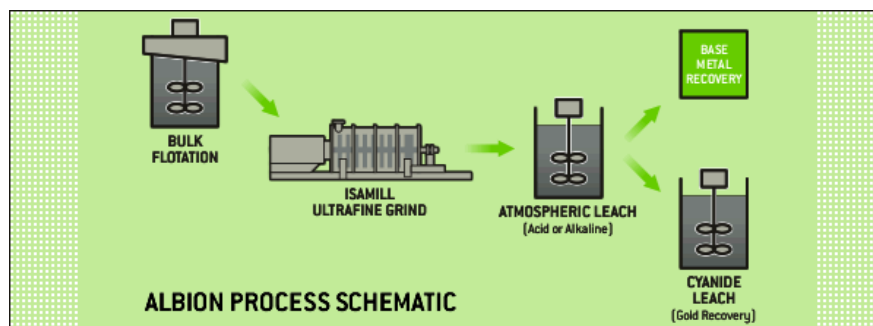
The Albion process is a combination of ultrafine grinding (5-10 μ m) and oxidative leaching at atmospheric pressure (100kPa) and low temperature (85°C). No autoclaves or bacterial cultures are used.

The key is the ultrafine grinding which results in a high degree of strain being introduced to the mineral lattice. This creates defects that “activate” the mineral and helps kick start the leaching and as the grinding increases the minerals’ surface area, the rate of leaching is increased.

The leaching is carried out in agitated tanks operating at atmospheric pressure. Oxygen is introduced to assist with the process.

If there is gold to be recovered then cyanide leaching is carried out after the atmospheric leaching.

Figure 66. Albion Hydrometallurgical Process



Source: Xstrata technology

Uses of the technology

This process is used to efficiently recover high refractory base metals that typically have poor/low recovery rates with traditional pyrometallurgical methods.

Pros and cons of the technology

Figure 67. Pro's And Con's Of New Technology

Pro's

- Lower capital cost
- Oxidative leach at moderate temperature and atmospheric pressure
- Fewer units of operation, leading to simpler plant layout
- Easier to operate and maintain as simple proven units of equipment are used
- Lower cyanide consumption if gold recovery from residues is conducted
- Higher silver recoveries from residues
- For precious metals circuits, the Albion Process is an alkaline leach, and filtration/CCD circuits are not required ahead of cyanidation

Con's

- Higher operating costs than other technologies

Source: Citi Investment Research and Analysis

CESL

The technology was developed by Tech Cominco for: the production of copper and nickel cathode from their respective concentrates, the economical recovery of gold and silver from the residues and the removal of copper from molybdenum concentrate.

The process (Copper)

The CESL Copper Process consists of four main steps:

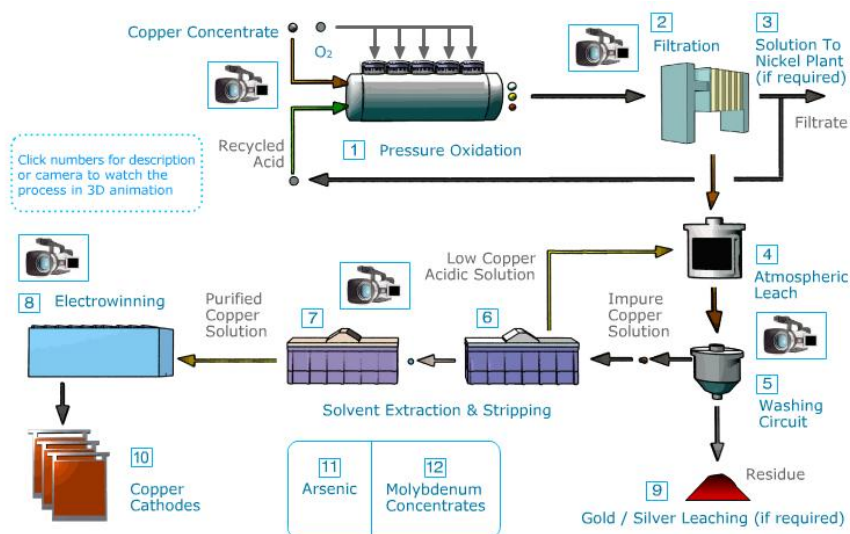
1. copper mineral oxidation,
2. copper leaching from the oxidation residue,
3. solvent extraction to purify the copper leach liquor, and
4. electrowinning to recover copper in a commercial product form

The CESL Copper Process involves oxidation of sulphide concentrates at elevated pressure (1000-1200kPa) and temperature (140-150°C) in the presence of catalytic chloride ions. In addition to copper, impurity metals such as nickel, cobalt, and zinc are oxidized during the pressure oxidation process. Depending on the concentrate metallurgy, it may be economically feasible to recover some of the more valuable impurity metals from the process solution.

The leach filter cake, containing oxidized copper, hematite and elemental sulphur is repulped with recycled raffinate from Solvent Extraction. The pH of the slurry is controlled in order to efficiently leach the copper from the pressure oxidation filter cake.

Impurities are removed from the copper-rich solution by solvent extraction. The purified solution is then electrowon, producing copper cathodes.

Figure 68. CESL Hydrometallurgical Process



Source: CESL Limited

The process (Nickel)

The Nickel Process begins with a pressure oxidation step similar to that used in the Copper Process. Complete dissolution of the nickel, copper, cobalt along with zinc, occurs within the autoclave. If the leach liquor is high enough in copper, it is sent to solvent extraction for recovery. The nickel solution requires purification as it may contain impurity elements. These metals are removed by precipitation. The cobalt can be recovered from the solution as a marketable product through a proprietary purification stage. Nickel is precipitated as a hydroxide or sulphide which may be processed further to metal or sold as an intermediate product. If producing nickel metal, ammonium sulphate is used to leach nickel from the intermediate. The resulting nickel electrolyte is electrowon to produce nickel cathodes.

Uses of the technology

The CESL Processes are applicable to a wide variety of base metal sulphide concentrates and can process bulk, lower grade, or impurity-challenged concentrates which may otherwise incur additional smelting costs.

Pros and cons of the technology

Figure 69. Pro's And Con's Of New Technology

Pro's

- Can recover nickel, cobalt, zinc and molybdenum byproducts
- Applicable to wide variety of base metal sulphide concentrates
- Can process bulk, low grade or impurity rich concentrates
- Environmentally sustainable process with no gaseous emissions and solid by-products are stable leach residues and gypsum
- Successful in pilot plant stage and first commercial plant built at Vale copper facility in Carajas region.
- Can refine "dirty" concentrates containing fluoride, uranium, arsenic, bismuth and other impurities that pose challenges for conventional smelters

Con's

- Multiple solvent extraction circuits are required with several mixer settlers in each circuit
- Less than optimal selectivity for cobalt over nickel at pH=7 rather than pH=5
- Careful operation of the precipitation and purification circuits is required to ensure impurity rejection and hydroxide cake quality

Source: Citi Investment Research and Analysis

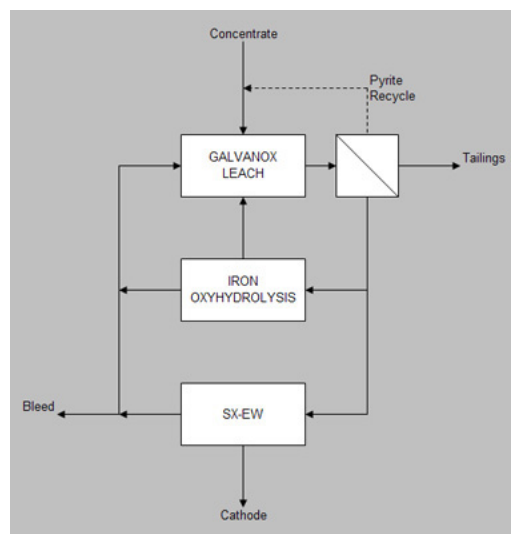
GALVANOX™

Galvanox™ is a method for leaching copper from mixed copper sulphide concentrates. The technology has been developed from the University of British Colombia.

The process

Galvanox™ takes advantage of the electrical energy derived from the chemical reaction between pyrite and chalcopyrite (galvanic couple). This enables rapid and complete oxidation of chalcopyrite under atmospheric, medium temperature (80°C) conditions in an acidic iron sulphate solution without microbes, ultrafine grinding or chemical additives. Chalcopyrite is referentially leached over pyrite thus the pyrite is not creating heat or acid which adds neutralization costs.

Figure 70. Galvanox



Source: University of British Columbia

Uses of the technology

It has the ability to process both primary and secondary copper concentrates that contain arsenic and gold. It can treat arsenic levels above the smelting cutoff grade of 0.3%. The arsenic is able to be separated from the recovered copper into an environmentally stable form.

Pros and cons of the technology

Figure 71. Pro's And Con's Of New Technology

Pro's

- Can be used on a variety of copper sulphides
- No fine grinding required
- Able to treat arsenic rich concentrates and convert it into a stable compound
- Copper recovery of 98% in less than 12 hours
- Ability to recover >90% of the gold in a CIL/CIP circuit
- Fully compatible with conventional SX-EW
- Inexpensive to build and simple to operate
- Conventional materials used for construction
- Only small portion of the ore uses the autoclave reducing high capital and operating costs compared with TPOX

Con's

- To enable high recovery of copper in less than 24 hours, the following must be maintained; stirring speed of 1150rpm, pyrite to chalcopryrite ratio of 4, temperature of 85oC and initial sulphuric acid concentration of 45g/L

Source: Citi Investment Research and Analysis

Total Pressure Oxidation (TPOX)

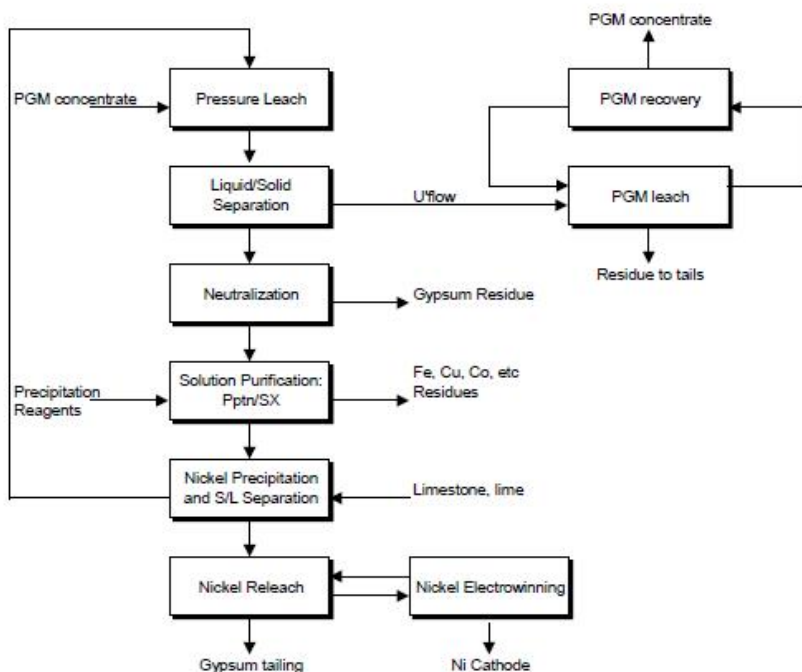
This process has successfully been commercialized at Phelps Dodge Baghdad plant in Arizona and First Quantum's Kansanshi Copper Operation in Zambia.

The process

This involves the use of high pressure (3000-4000kPa) and temperature (220-230°C) autoclaves with low acidity and low to moderate salinity to oxidize all sulphide minerals. In this process iron is precipitated as hematite. A single autoclave is used to leach the concentrates which then proceed onto flashing (return slurry to atmospheric pressure), slurry cooling, counter current decantation (CCD) washing and then copper SX/EW. The acid from the autoclave process is recycled for further use in the stockpile leach giving an acid credit.

If precious metals are present, the neutral residue from autoclave washing can be used for cyanide leaching.

Figure 72. TPOX Process



Source: Phelps Dodge

Uses of the technology

This is an alternative method for the processing of copper ore. It is particularly suitable when the acid from pressure leaching can be used in other parts of the process.

Pros and cons of the technology

Figure 73. Pro's And Con's Of New Technology

Pro's

- Can get extremely high recovery of copper (>99%) into solution
- Ideal for operations that have an excess of sulphuric acid produced by the process of oxidizing all the sulphide feed into the autoclave
- Proven technology and can easily be scaled up in size if required

Con's

- High operating costs when compared to other alternate technologies due to the high purity of oxygen addition required and the need for limestone/lime to neutralize the residues

Source: Citi Investment Research and Analysis

High pressure acid leach (HPAL)

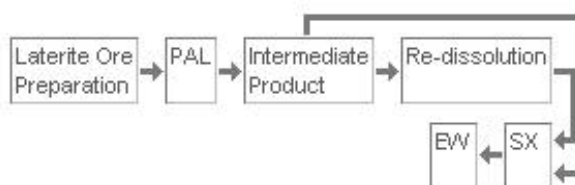
This process is currently used to process lateritic nickel deposits that are refractory and unable to be treated using conventional pyrometallurgical methods such as smelting or heap leaching. It is very similar to current acid leach processes except that it uses higher temperatures and pressures to improve and maximize copper recoveries.

The process

The sulphide material is firstly subject to normal grinding and floatation which extracts 40-45% Cu then HPAL is conducted to increase copper extraction up to 98% (normally 85% with heap leach).

The acid leaching of the ore is conducted at temperature above 240°C and at high pressures.

Figure 74. HPAL Process



Source: SGS group

Uses of the technology

HPAL can be used as an alternative to smelting for the recovery of Cu from complex ore types. Due to the high capital and operational costs this process will be vulnerable at times of low commodity prices.

Pros and cons of the technology

Figure 75. Pro's And Con's Of New Technology

Pro's

- High Cu recovery of up to 98%
- Recovery of Cu from complex ore types

Con's

- High capital and operating costs

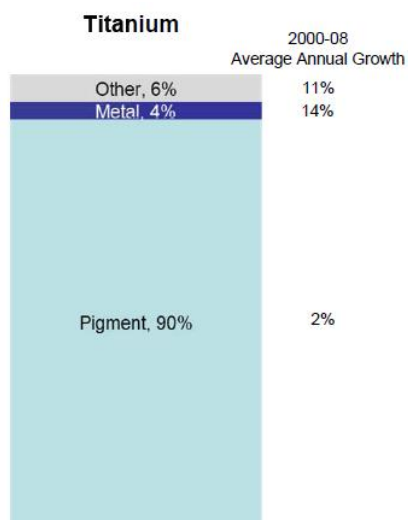
Source: Citi Investment Research and Analysis

Titanium Metal

The technology

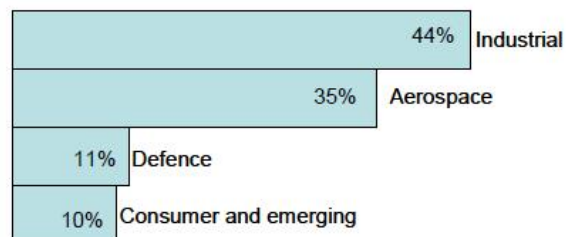
Titanium is an important material used in commercial aerospace (fastest growing segment) and in defence and industrial applications. Titanium metal has the highest strength-to-weight ratio making the metal highly desirable in aerospace applications whilst its high corrosion resistant properties makes it suitable for industrial applications in highly corrosive environments. Titanium metal makes up approximately 5% of end consumption demand for TiO_2 raw material.

Figure 76. Titanium Use



Source: Iluka Resources

Figure 77. Titanium Metal Use



Source: Iluka Resources

High grade TiO_2 is the feed source for the manufacture of titanium metal with the lower grade feedstock typically used for pigments.

Titanium metal is produced using the Kroll process which involves extraction, purification, sponge production, alloy creation and forming and shaping. This process is both costly and time consuming which multiple possibilities for process bottle necking. New technologies to replace the Kroll process are being investigated to reduce the costs associated with metal production.

New titanium metal technology

There are a few titanium processing technologies which have the aim of reducing the cost and increasing efficiency of titanium metal production. Two processes which have received some attention are the Armstrong process and TiRO^{TM} process.

Figure 78. Titanium Technology Overview

Technology	Final product	Issues	Titanium sheet production cost comparison(US\$/lb)	Current Supply (kt)
Kroll	Titanium	High cost and large quantities of waste material produced	15-50	150
Armstrong process	Titanium powder	Yet to be commercialized	7	0
TiRO process	Titanium powder	Yet to be commercialized and still in trial phase and therefore risks associated with the technology to deliver cost reductions	n/a	n/a

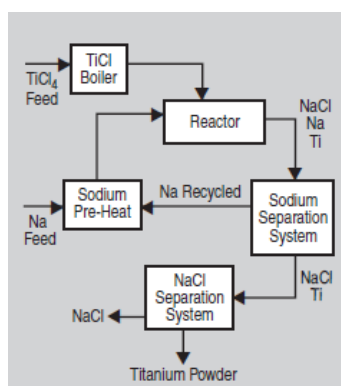
Source: Citi Investment Research and Analysis

Armstrong process

Titanium tetrachloride is injected into a stream of molten sodium. The excess sodium cools the reaction products and carries them to separation stages where the excess sodium and salt are removed. The reaction product is a continuous stream of powder. With simple modification of the process it can be possible to make vanadium/aluminium titanium alloys.

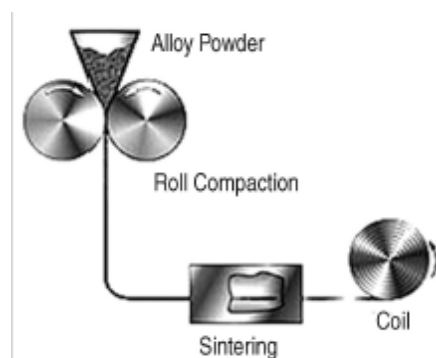
The Armstrong process is a patented technology owned by Cristal US and construction of the Ottawa facility is in progress with commissioning expected by the end of 2010. This will be the first commercial scale titanium powder production facility in the world. The titanium powder undergoes roll compaction to create titanium sheets. The technology was trialed with a 1800 tonne per annum pilot plant where the government provided US\$700,000 in assistance to support the project.

Figure 79. Armstrong process



Source: Cristal US

Figure 80. Roll compaction for titanium sheets



Source: Cristal US

TiRO process

TiRO uses a new two step method to enable direct production of titanium metal power.

- Titanium tetrachloride is reduced with magnesium (Kroll process currently used)
- Continuous reduction of the titanium tetrachloride using a fluidized bed reactor

- The fluidized bed reactor uses argon and eliminated potential contamination with oxygen and nitrogen and also minimizes contact between the titanium feedstock and the reactor vessel reducing possible iron contamination
- The process is run continuously rather than in batches reducing operating costs
- The titanium feedstock is further treated using chloride separation which can control product size and shape (to suit consumers), energy efficient, minimizes iron contamination and has the advantage of producing magnesium chloride in which magnesium metal can be recovered

The TiRO process has been developed by the CSIRO and is still at pilot plant scale with a capacity of 2 kg per hour of titanium. The technology is deemed to be scalable to commercial production facility size of 100 tonnes per annum.

Figure 81. Pros And Cons Of New Titanium Technologies

	Armstrong process	TiRO process
Pros	<ul style="list-style-type: none"> ■ Production costs of US\$7/lb (roll compacted titanium sheet) compared with the ~US\$15-50/lb using the current Kroll process ■ no requirement to produce a sponge or melt-to-produce ingots ■ reduction in the production time, energy consumption, manufacturing costs and environmental impact ■ product classed as commercially pure grade 1 titanium due to less than 0.05% oxygen 	<ul style="list-style-type: none"> ■ Produces high quality titanium with low level contaminants (Fe, Mg) ■ Can produce a range of grade of powder depending on downstream specifications ■ Less capital intensive as re-melting is not required (unlike current process) ■ Can be fully automated ■ Claim that production costs are 50% less than the current Kroll process
Cons	<ul style="list-style-type: none"> ■ Still in construction and potential operational risks associated start up ■ Potential for ramp up delays depending on plant start up 	<ul style="list-style-type: none"> ■ Still in research stage and may not be suitable for commercialization ■ Long lead time from research of technology to plant construction and commercialization ■ Oxygen content in titanium above 0.25% requiring additional work to lower these levels

Source: Citi Investment Research and Analysis

Costs

Current capital and operating costs of titanium metal are high due to the remelting, forming and machining required to turn the titanium into sheets, plates and bars. The high cost of parts production inhibits expansion into new markets. Commercialization of low cost technologies will help eliminate the barriers to growth as titanium becomes affordable and competitive with aluminium and magnesium alloys.

Figure 82. Cost of Titanium – A Comparison (US\$/lb)

Item	Steel	Aluminium	Titanium (Kroll)	Titanium (Armstrong)
Ore	0.06	0.01	0.27	0.27
Metal	0.10	1.1	5.44	3.00
Ingot	0.15	1.15	9.07	
Sheet	0.30 - 0.60	1.00 - 5.00	15.00 - 50.00	7.00

Source: JOM

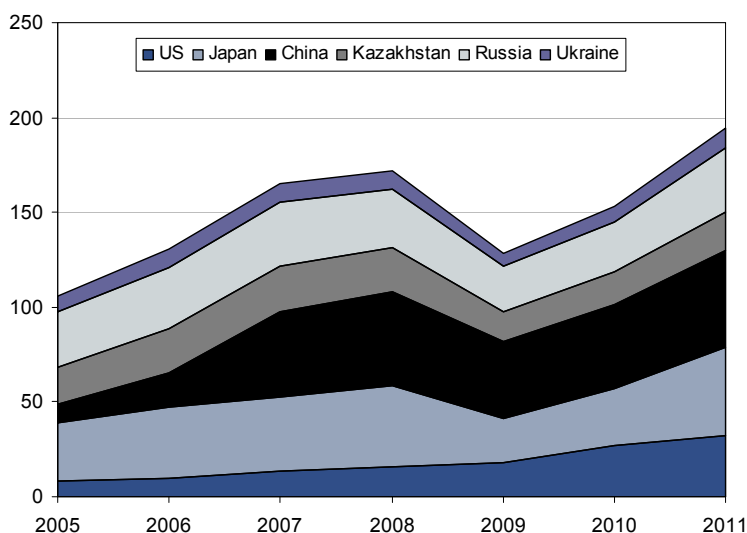
Supply potential

Titanium has enormous potential yet continues to struggle due to high costs, volatile prices, processing difficulties and supply issues. In recent years, titanium suppliers have worked hard to develop new markets for titanium however with a tightening of supply due to increased aerospace demand, prices are driven up. The new markets as a result are unable to obtain the titanium needed cost effectively thus dampening enthusiasm.

With reduced barriers to growth due to lower cost titanium technologies supply of the metal is likely to increase which in turn provides relief of titanium metal prices and opening up of new markets globally.

The new technologies have the added benefit of continuous titanium processing and are easily scalable. Titanium output from processing plants as a result will likely be increased and more accurate titanium supply forecasting can be implemented which is currently difficult due to the batch processing techniques.

Figure 83. World production of titanium sponge (000s tonnes)



Source: TZMI

Current R&D projects

There are numerous projects underway looking at alternative titanium processes. The Armstrong process is currently the most commercially advanced.

Figure 84. Titanium Research And Development Projects

Process name/Organisation	Country	Process	Output
TiRO / CSIRO	Australia	Chemical	Powder
Armstrong / International Titanium Powder (ITP)	US	Chemical	Powder
EMR / MSE (University of Tokyo)	Japan	Electrolysis	Powder
FFC Cambridge	UK and US	Electrolysis	Powder
Idaho research foundation	US	Chemical	Powder
Idaho titanium technologies	US	Chemical	Powder
MER corp	US	Electrolysis	Powder
OS (Kyoto university)	Japan	Other	Powder
Peruke (pty) Ltd	South Africa	Chemical	Powder
Preform reduction (University of Tokyo)	Japan	Chemical	Powder
SRI International	US	Other	Powder
Vartech	US	Chemical	Powder
BHP Billiton polar titanium	Australia	Electrolysis	Liquid titanium
CSIR	South Africa	Other	Liquid titanium
GTT S.R.I	Italy	Electrolysis	Liquid titanium
QIT (rio tinto)	Canada	Electrolysis	Liquid titanium
Tresis International	US	Chemical	Liquid titanium
MIR-Chem	Germany	Chemical	Other
South African titanium	South Africa	Other	Other

Source: Australian Government

Marine Technology

Technology Overview

The second to last frontier in mining is access to under water deposits (the last frontier being the massive copper deposits on Mars and the Moon). The process of seafloor mining is being developed by Nautilus Minerals which is focusing Seafloor Massive Sulphide (SMS) deposits. SMS deposits form on the ocean floor and contain appreciable concentrations of copper, zinc, gold, silver and other trace metals. Copper grades are in excess of 5% and gold grades are generally greater than 5g/t.

Figure 85. Nautilus Resource Statement

Class	Domain	Tonnes (kt)	Grade				Contained Metal (in 000s)			
			Cu (%)	Au (g/t)	Ag (g/t)	Zn (%)	Cu (lbs)	Au (oz)	Ag (oz)	Zn (lbs)
Indicated	Massive Sulfide	870	6.8%	4.8	23	0.4%	130,425	134.3	643.3	7,672
Inferred	Chimney	80	11.0%	17.0	170	6.0%	19,401	43.7	437.3	10,582
	Lithified Sediment	2	4.5%	5.2	36	0.6%	198	0.3	2.3	26
	Massive Sulfide	1,200	7.3%	6.5	28	0.4%	193,125	250.8	1,080.3	10,582

Source: Citi Investment Research and Analysis

The process relies heavily on technology derived and processes derived from deep sea oil and gas drilling. Whilst it is very early stages for the concept, and there are no commercial applications, successful development could open up new avenues of future production for the industry. The concept is for a single mining vessel to produce c95ktpa of copper a year from 1.5mtpa of ore mined. To put that in to context, Prominent Hill produces 110ktpa of copper from a 10mtpa of ore. So if the concept is viable, the potential for the delivery of new supply is massive.

The process

Exploration of SMS requires deep ocean electromagnetic geophysics for target generation of drilling. Drilling is carried out using specially designed remote operated vehicle (ROV) drills. They are deployed on the seafloor and can drill up to 80m into the seafloor.

The rig is compact, easy to deploy, operate and recover without the need of specialized and expensive surface vessels or platforms. The ROV drills can work at depths up to 3000m below sea level. ROVs are unmanned submarine robots with umbilical cables used to transmit data between the vehicle and researcher for remote operation in areas where diving is constrained by physical hazards. ROVs are fitted with video and still cameras as well as mechanical tools for specimen retrieval and measurement. Grab sampling gives a guide to the grade on the seafloor which also helps with drilling targeting.

The largest risk in the entire process lies with mining of the resource. Nautilus has developed a production plan which includes a sustainable recovery system and ways of minimizing environmental and ecological impacts. The Papua New Guinea government needs to approve the mining lease application before the project is granted access to move into mining stage.

The system design draws extensively upon technology used in the subsea oil and gas sector, and combines this with rock cutting and materials handling technologies used in land-based mining operations. To ensure reliability, dual redundant systems are employed on critical subsystems such as the cutting tools.

The Production Support Vessel (PSV) is a key component of the recovery system and is to be fitted out with the Subsea Mining Equipment. The ore will be cut and transported through a horizontal pipe as slurry. The ore will be lifted to the ship via a subsea pumping and pipe-works system, where it will be de-watered, and the resulting deep sea water returned to the same water depth from where it was extracted. The de-watered ore will then be barged to PNG, where it will be temporarily stored, and then transferred to large ocean going bulk carriers for shipping to an existing concentrator facility. Concentrate will be sold to the smelting markets.

Figure 86. Seafloor Production System



Source: Nautilus Minerals

Nautilus plan to utilize single mining vessels to deliver production. The plants are anticipated to mine c1.5mtpa of ore per annum and deliver gold production of c200koz and copper production of 95ktpa.

Capital costs for the plants is expected to be in the vicinity of US\$400m.

On simple calculations if the project were to deliver a ROIC of 15% at a \$3/lb copper price, then the cost of production could creep up to \$2.50/lb. So clearly the technology is profitable in high copper price environments.

Key issues to profitability will be control of capital costs, volume processed and the prevailing metal prices.

Pros and cons of the technology

Figure 87. Pro's And Con's Of New Technology

Pro's

- Ability to tap in to high grade base metal deposits that historically have not had the technology available

Con's

- Continuity of mining
- Environmental issues associated with sub sea mining
- Higher capital and operating cost when compared to conventional mining techniques

Source: Citi Investment Research and Analysis

Who will be affected

There a number of companies that will benefit if SMS mining is financially viable and all approvals are granted.

- Seafloor Geoservices, the manufacturers of the ROV will benefit from approval of SMS mining as their product has been specially designed for the purpose of seafloor exploration. There will also be a flow on to suppliers of materials.
- Soil Machine Dynamics (SMD) has contracts to build remote operated seafloor mining tools. They specialize in the design and manufacture of ROV's and seabed trenching systems.
- Technip are an integrated group providing engineering, procurement and construction management on the Nautilus project, including the Riser and lifter system (RALS). Technip are used extensively in the oil/gas and petrochemical industry.
- Ocean Floor Geophysics is in the process of developing and then testing new deep-ocean electromagnetic technology used for exploration of SMS systems.
- Fugro is a service provider in the collection and interpretation of data and provides operational support for subsea ventures. They provide specialist vessels, ROV's and subsea engineering capabilities relating to subsea exploration and development.
- GE Oil & Gas are a leader in advanced technology equipment and services and have contracts to build subsea slurry pump for the RALS using their Hydril Pressure Control subsea pumping technology.

Shale Gas

Technology Overview

Shale gas deposits are unconventional natural gas deposits and can be difficult to characterize but generally have lower resource concentration, more dispersed over large areas and require well stimulation or some other extraction or conversion technology. The shale acts as both the source and reservoir for the natural gas. The chemical makeup of the shale gas is typically a dry gas primarily composed of methane.

The rapid development of shale gas particularly through the US is primarily due to the increase in natural gas prices over the last few years (supply and demand driven) with developments in horizontal drilling and fracturing making this possible.

In the US, there are the Barnett and Woodward shale's and in Canada the Horn River basin. Exploration is underway in Europe (Hungary and Poland) and China. In Europe there are many factors that will cause slow development of unconventional natural gas including subsurface geology, services in terms of supply chain, land access and access to infrastructure issues, government regulations and environmental restrictions. Currently it is not known whether the shale can support economic development.

China and the US have recently formed an alliance and formed a set of agreements on clean energy, energy efficiency and environmental improvement. This will allow China access to the technological developments in the US regarding shale gas.

The process

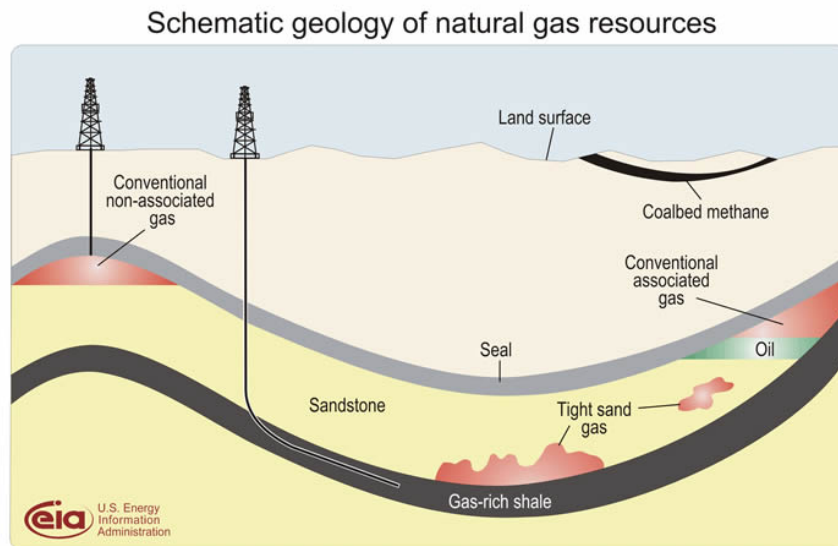
Shale formations that host economic quantities of gas have a number of common properties:

1. Rich in organic material (0.5% to 25%)
2. Mature petroleum source rocks in the thermogenic gas window, where high heat and pressure have converted petroleum to natural gas
3. Sufficiently brittle and rigid enough to maintain open fractures.

Exploration conducted to target potential shale rich areas and then extraction techniques use the same procedures as those for conventional oil and gas. The major difference is in the drilling of the shales to maximize flows. The gas produced in shale is held in natural fractures, pore spaces and some is absorbed within organic material. Typically the gas flows are low due to the impermeability of these rocks.

Gas is recovered by drilling vertically to intersect the shale then horizontal drilling is conducted within the shale to maximize the drillhole surface area within the formation. Water, chemicals and sand are injected into the shales under great pressure. The pressure fractures 'fracs' the rock and the sand holds the resulting cracks open so the gas can flow out. After the initial surge of gas after 'fracing' the flow decreases and the process must be repeated.

Figure 88. Natural gas Resources



Source: U.S Energy information administration

Uses of the technology

Natural gas including shale gas will play a leading role in reducing greenhouse-gas emissions and replacing older, inefficient coal plants with highly efficient combined cycle gas generation. Shale gas can be used for power generation and domestic use such as cooking and heating.

Pros and cons of the technology

Figure 89. Pro's And Con's Of New Technology

Pro's

- Natural gas emits 50% less carbon than coal and 30% less than diesel and gasoline
- Natural gas development from shale uses the least amount of water for the energy it produces compared with nuclear energy and conventional oil

Con's

- Production costs are higher than those for conventional gas
- Shale formations generally need 'fracing' to get high flows of gas which is high cost and success is not always guaranteed

Source: Citi Investment Research and Analysis

Supply and demand implications

In terms of gas demand, India is limited by its access to gas supplies based on domestic production and imports availability. If India is able to produce more gas then this should reduce their need for coal imports which will be more environmentally friendly.

China has recently signed a cooperation pact with the US government for the facilitation of transfer of technology for gas shale production.

If increased supply continues long term then this will keep the price of natural gas low and as it can be a replacement for coal for power generation then the reducing the demand for thermal coal.

Who will be affected

The flow on effect of low natural gas prices will most likely be the increased use for gas power generation. This will have a positive impact on specialist companies that provide the drilling and 'fracing' services. There will possibly be a negative impact on coal companies who specialize in thermal coal due to reduced demand for coal. Operators of environmentally unfriendly coal fired power plants will be most probably be the most impacted due to the push towards greener and cleaner energy sources.

Uranium Oxide

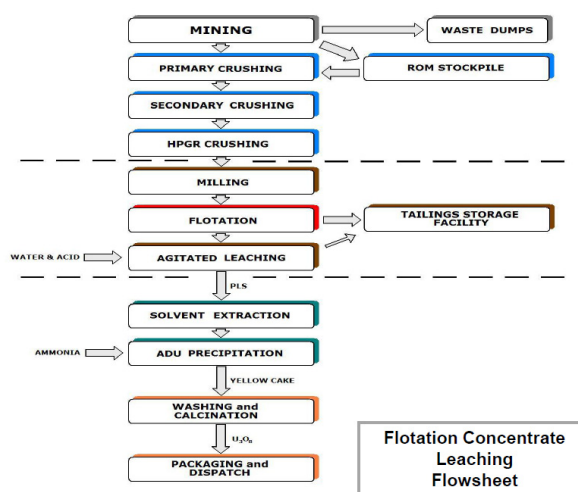
Uranium oxide processing

Traditionally uranium has been extracted from oxide ores through a process of heap or tank leaching as it is a cheap option for the relatively low uranium concentrations. The downfall with these processing techniques is the recovery of uranium is fairly low at around 80%.

Research has tested flotation as an additional step prior to tank leaching, a process not usually applied to oxide ores. The use of flotation in this situation is unproven on a commercial scale however initial results are promising.

The ore goes through steps of conventional crushing but then requires grinding and milling to reduce the particle size for successful flotation. The ore undergoes the flotation, agitated tank leaching of the high grade flotation concentrate and solid/liquid separation. This increases the recovery of the uranium from ~80% to ~91%. Then the normal process of solvent extraction or ion exchange, precipitation and drying is carried out.

Figure 90. Flotation And Tank Leaching Flowsheet



Source: Bannerman Resources

Costs

Tank leaching of uranium oxide deposits has average cash costs around \$25-30/lb. By adding flotation to the tank leach process costs increase to +\$40/lb which is reclaimed with the higher recovery of uranium.

Supply potential

If flotation becomes economically and metallurgically successful when applied to uranium oxides then this has the potential to increase recoveries of uranium and also deposits which may have had concentrations too low for extraction could become economically viable.

Companies exposed to the technology

The use of flotation and tank leaching is being investigated by Bannerman Resources at their Etango deposit.

Supply Demand Balances

Iron Ore – Supply Demand Balance

IRON ORE SUMMARY SHEET

IRON ORE Supply Demand Balance

Mt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Seaborne Imports							
Japan	115	133	142	148	148	148	148
Korea	42	52	56	59	62	65	68
Taiwan	12	18	14	14	14	14	14
China	628	611	637	675	714	736	758
EEC	56	99	133	128	128	128	128
USA	4	7	7	9	9	9	9
Total Seaborne Imports (incl. minor markets)	877	959	1,020	1,063	1,105	1,130	1,156
Seaborne Exports							
Australia	362	417	450	478	522	610	682
Brazil	266	298	314	326	343	375	409
India	115	100	95	70	65	65	65
Canada	28	23	25	25	25	25	25
S.Africa	45	48	47	54	61	64	69
Other	54	77	77	77	77	47	48
Total Seaborne Exports	870	964	1,008	1,030	1,094	1,187	1,298
Surplus/Deficit	-6.8	4.7	-11.4	-32.8	-11.4	57.2	142.7

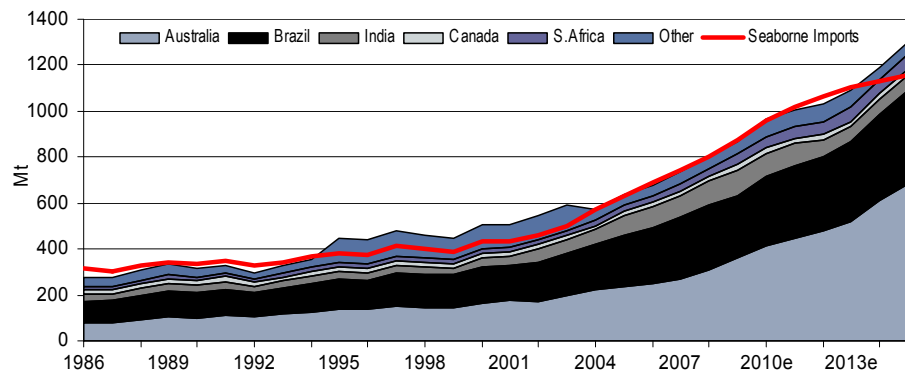
Source: Tex Report; Citi Investment Research and Analysis

China's Crude Steel Production & Iron Ore Supply

Mt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Crude Steel Production	568	626	650	687	721	743	765
Pig Iron Production	544	601	624	660	692	713	735
China Imports (Mt iron ore @63%)	628	611	637	675	714	736	758
China Imports (Contained iron)	396	385	406	429	450	464	478
Inventory	67	72	65	60	60	60	60
Domestic Production (Contained iron)	153	219	219	264	208	207	206

Source: Tex Report; Citi Investment Research and Analysis

Suppliers to the Seaborne Iron Ore Market



Source: IISI, Citi Investment Research and Analysis

Last updated: 06-Nov-10

Pig Iron Production in Major Seaborne Markets

Mt	YTD Prod. Sep-10	Annualized	Prod. Sep-10	% chg ytd	% chg yoy month
Japan	61.6	82.1	6.9	31.5%	13.4%
Korea	23.2	31.0	2.8	17.1%	11.7%
Taiwan	6.7	9.0	0.8	19.3%	39.0%
China	445.2	593.6	45.7	10.8%	-4.6%
Total	536.7	715.6	56.1	13.2%	-1.6%

Source: WSA

Asian Iron Ore Imports

Mt	YTD Sep-10	Annualized	Imp. Sep-10	% chg ytd	% chg yoy month
Japan	99.7	133.0	10.1	38.0%	-7.0%
China	457.9	610.5	52.6	-2.5%	-18.5%
Total	557.6	743.5	62.7	-3.8%	-21.9%

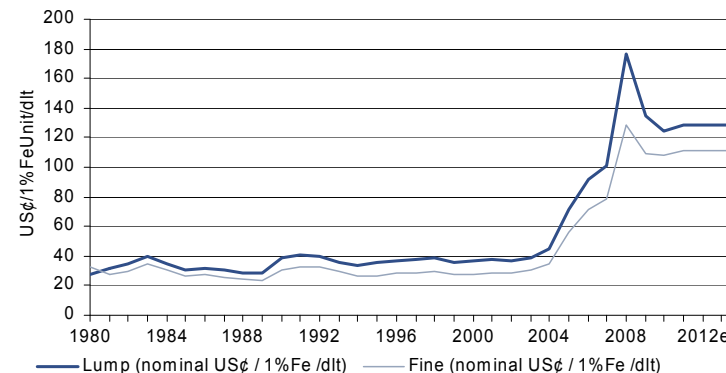
Source: Tex Report

Key points

- iron ore prices have doubled and further rises are in prospect.

- Market in deficit but surpluses loom beyond 2013.

Price Forecast - Lump & Fines



Source: Citi Investment Research and Analysis

Coking Coal – Supply Demand Balance

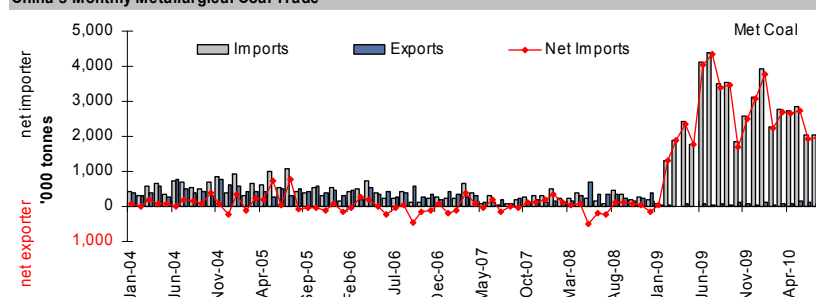
METALLURGICAL COAL SUMMARY

METALLURGICAL COAL Supply Demand Balance

Mt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Imports							
Japan	49.4	58.6	63.9	66.5	66.5	66.5	66.5
South Korea	19.4	25.8	25.3	26.6	27.8	29.2	30.6
Taiwan	4.0	4.4	4.5	4.6	4.7	4.7	4.6
India	24.6	39.1	54.9	66.7	74.8	97.8	104.0
EC	28.4	35.2	44.4	46.6	46.6	46.6	46.6
China	30.5	31.4	40.0	30.0	30.0	30.0	30.0
Brazil	12.5	12.9	18.0	18.8	19.7	20.5	21.5
Other	17.3	22.0	25.0	30.0	30.0	30.0	31.0
Total	186.2	229.4	275.9	289.8	300.1	325.4	334.7
Exports							
Australia	135.0	158.2	160.0	173.0	190.0	192.0	192.0
US	33.9	50.2	50.0	50.0	50.0	50.0	50.0
Canada	19.9	27.5	27.5	27.5	25.0	25.0	25.0
China	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Russia	11.3	10.0	12.0	12.0	12.0	12.0	13.0
Mozambique	1.0	0.0	4.4	6.0	10.0	12.2	12.2
Other	1.3	2.5	3.0	3.0	3.0	3.0	3.0
Total	202.0	249.1	257.5	272.1	290.6	294.8	295.8
Balance	15.8	19.7	-18.4	-17.6	-9.5	-30.6	-38.9

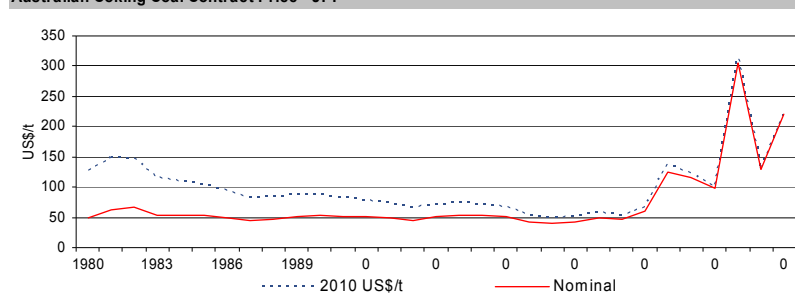
Source: The Tex Report; Citi Investment Research and Analysis

China's Monthly Metallurgical Coal Trade



Source: Antaike

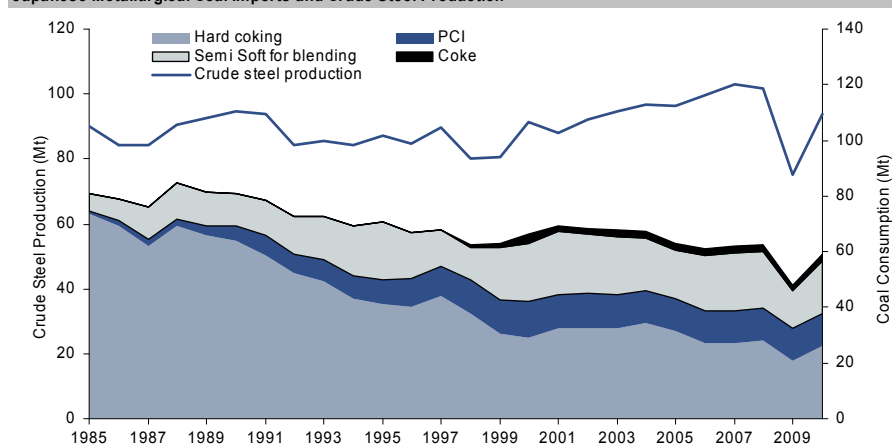
Australian Coking Coal Contract Price - JFY



Source: The Tex Report; Citi Investment Research and Analysis

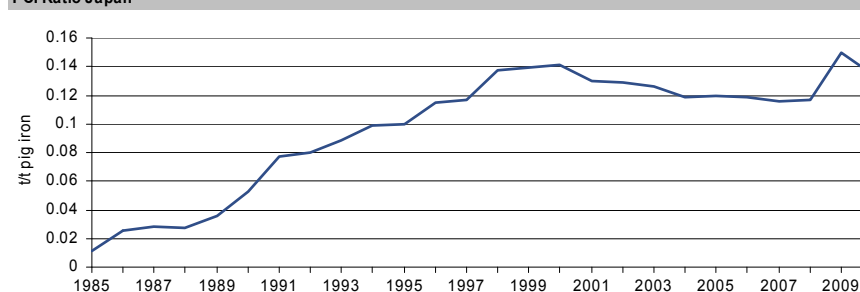
Japanese Metallurgical Coal Imports and Crude Steel Production

Last updated: 06-Nov-10



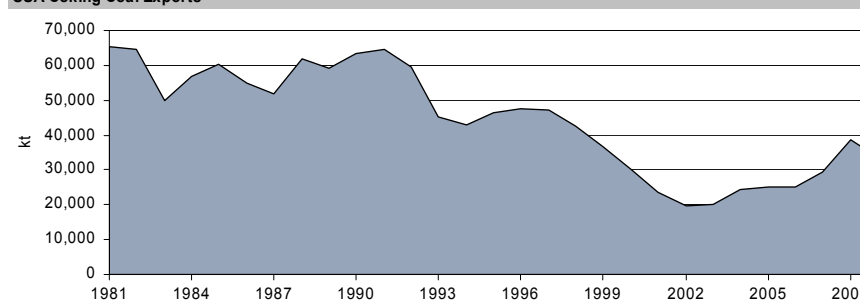
Source: The Tex Report, IISI; Citi Investment Research and Analysis

PCI Ratio Japan



Source: The Tex Report; Citi Investment Research and Analysis

USA Coking Coal Exports



Source: ICR

Thermal Coal – Supply Demand Balance

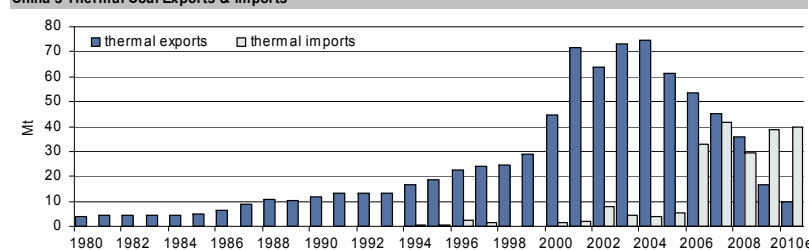
THERMAL COAL SUMMARY

THERMAL COAL Supply Demand Balance

Mt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Imports							
Japan	108.3	118.6	123.1	123.7	124.3	126.1	127.8
S.Korea	80.5	87.7	91.1	94.9	98.6	102.4	135.0
Hong Kong	12.3	9.5	12.0	12.0	12.0	12.0	18.0
Taiwan	48.6	51.6	62.4	62.4	62.4	62.4	62.4
India	48.2	56.9	62.9	75.0	80.0	85.0	90.0
USA	14.3	12.3	12.3	12.3	12.3	12.3	12.3
EC	96.7	90.0	95.0	100.0	100.0	100.0	100.0
China	92.1	113.2	100.0	100.0	100.0	100.0	100.0
Others	74.1	61.8	110.0	110.0	110.0	110.0	110.0
Total	575.1	601.5	668.7	690.3	699.6	710.1	755.5
Exports							
Australia	139.0	138.0	160.0	175.0	192.0	192.0	212.0
South Africa	65.7	70.0	75.0	80.0	80.0	80.0	80.0
Indonesia	234.3	260.0	280.0	300.0	300.0	310.0	320.0
US	11.6	11.0	15.0	15.0	15.0	15.0	15.0
China	16.9	14.5	15.0	15.0	15.0	15.0	15.0
Columbia	67.9	62.0	67.0	62.0	62.0	62.0	62.0
Canada	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Russia	16.2	14.0	16.0	16.0	16.0	16.0	16.0
Vietnam	23.7	24.0	20.0	14.0	14.0	14.0	14.0
Venezuela	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Total	586.4	604.7	659.1	688.1	705.1	715.1	745.1
Balance	11.3	3.1	-9.6	-2.2	5.5	5.0	-10.4

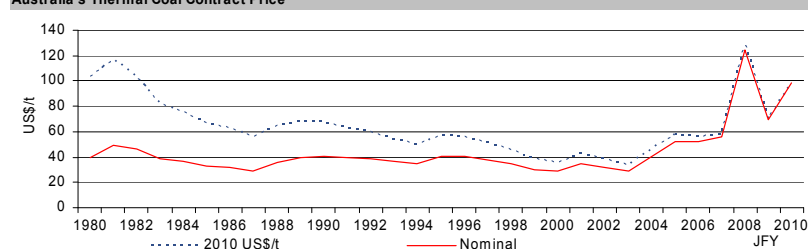
Source: Citi Investment Research and Analysis

China's Thermal Coal Exports & Imports



Source: The Tex Report

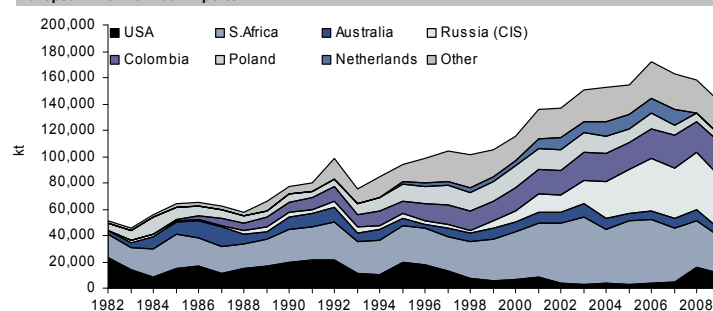
Australia's Thermal Coal Contract Price



Source: Global Coal

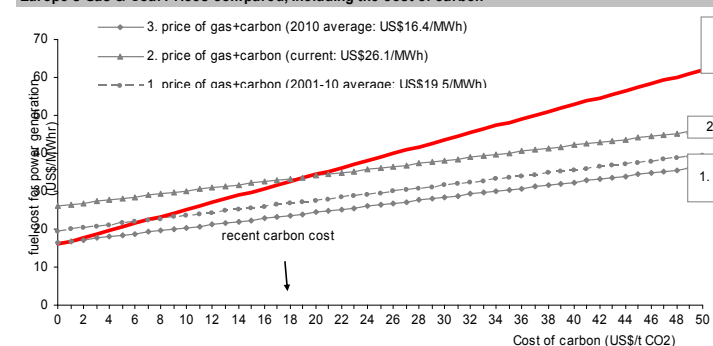
European Thermal Coal Imports

Last updated: 06-Nov-10



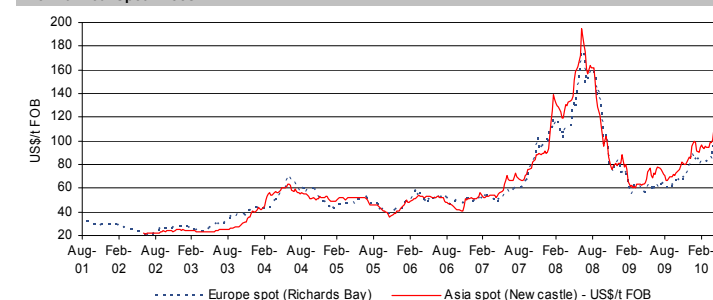
Source: ICR

Europe's Gas & Coal Prices compared, including the cost of carbon



Source: Barlow Jonkers, Bloomberg; Citi Investment Research and Analysis

Thermal Coal Spot Prices



Source: Global Coal

Copper – Supply Demand Balance

COPPER SUMMARY SHEET

WORLD COPPER Supply Demand Balance							
	Current Price: US\$/lb 382.6						
kt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Mine Production (Concentrates)	12,476	12,927	13,030	13,803	14,705	15,296	15,574
Concentrate Stock	112	120	120	120	120	120	120
Concentrate Stock Change	-26	8	0	0	0	0	0
Concentrate Available	12,501	12,919	13,030	13,803	14,705	15,296	15,574
Secondary Supply etc. (incl losses)	1,295	906	1,257	1,437	1,632	1,784	2,467
Smelter Capacity	17,362	17,746	18,317	19,794	20,946	21,897	23,739
Smelter Production	13,796	13,824	14,287	15,239	16,338	17,080	18,041
Smelter Utilization (%)	79.5%	77.9%	78.0%	78.0%	78.0%	78.0%	76.0%
Mine Production (Electrowon)	3,330	3,341	3,672	4,115	4,435	4,431	4,318
High Grade Scrap	1,528	2,022	2,000	1,500	1,500	1,500	1,500
Mine Production (Total)	15,805	16,267	16,702	17,917	19,141	19,727	19,893
Refined Production (Total)	18,654	19,186	19,959	20,854	22,273	23,011	23,860
% Change	0.6%	2.9%	4.0%	4.5%	6.8%	3.3%	3.7%

Consumption/Demand	18,238	19,354	20,168	20,905	21,936	22,926	23,950
% Change	0.6%	6.1%	4.2%	3.7%	4.9%	4.5%	4.5%
Surplus/Deficit	416	-168	-209	-51	337	84	-91
Stock Change	279	-168	-209	-51	337	84	-91
Stocks	1,095	927	718	666	1,003	1,088	997
Stock:Consumption Ratio (wks)	3.1	2.5	1.9	1.7	2.4	2.5	2.2
Price (US\$/lb)	241	339	414	400	360	320	272

CHINA - Supply Demand Balance

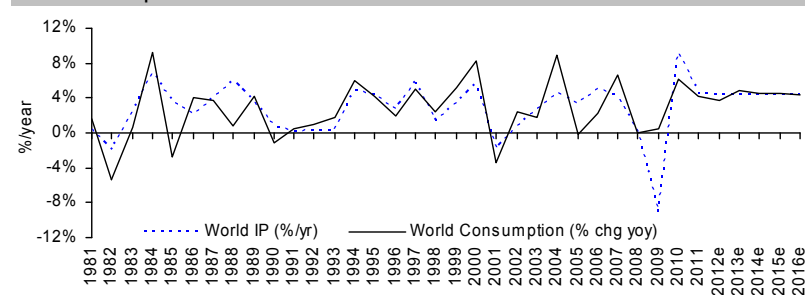
kt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Mine Production	961	1086	1180	1256	1287	1290	1281
Refined Production	4,110	4,400	5,907	6,881	7,644	7,974	8,174
Consumption	7,144	7,547	8,155	8,582	9,294	9,956	10,644
Consumption (%/yr)	38.7%	5.6%	8.1%	5.2%	8.3%	7.1%	6.9%
Conc+Scrap Surplus/Deficit	-3,148	-3,314	-4,727	-5,626	-6,357	-6,684	-6,893
Metal Surplus/Deficit	-3,035	-3,147	-2,248	-1,701	-1,650	-1,982	-2,470

Source: WBMS, LME, CRU, Citi Investment Research and Analysis

Consumption, by country/region		Consumption, by end-use	
USA	9%	Building wire	27%
Japan	5%	PowerTrans	3%
Europe	17%	Telecom	8%
China	39%	Winding wire	8%
Korea	5%	Other wire	11%
Other	25%	Tube	11%
	100%	Sheet+Strip	7%
		Brass	18%
		Other Alloy	7%
			100%

Source: Brook Hunt; Citi Investment Research and Analysis

World - Consumption & IP



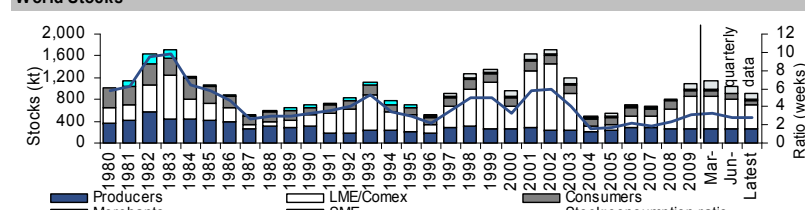
Source: Datastream; Citi Investment Research and Analysis

Consumption Forecast by Country

(% ch yoy)	2009	2010e	2011e	2012e	2013e	2014e	2015e
World	0.6%	6.1%	4.2%	3.7%	4.9%	4.5%	4.5%
USA	-18.3%	7.0%	3.0%	2.8%	2.8%	2.8%	2.8%
Japan	-21.9%	10.0%	-0.5%	1.1%	1.1%	1.1%	1.1%
Europe	-18.9%	4.0%	3.1%	1.5%	1.5%	1.5%	1.5%
China	38.7%	5.6%	8.1%	5.2%	8.3%	7.1%	6.9%
Korea	14.2%	3.0%	7.9%	7.9%	7.9%	7.9%	7.9%

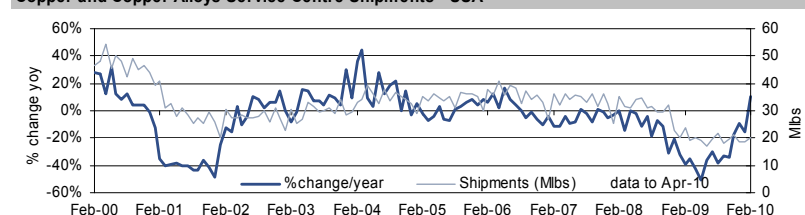
Source: WBMS; Citi Investment Research and Analysis

World Stocks



Source: WBMS, LME; Citi Investment Research and Analysis

Copper and Copper Alloys Service Centre Shipments - USA



Source: Copper & Brass Service Center Association

Source: WBMS; LME; Citi Investment Research and Analysis

Zinc – Supply Demand Balance

ZINC SUMMARY SHEET

WORLD ZINC Supply Demand Balance	Current Price:		US\$/lb	110.1			
kt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Mine capacity	11,278	12,243	13,021	14,867	15,390	15,842	16,215
Mine production	11,337	11,874	13,021	14,867	15,390	15,842	16,215
Direct chemical use	4	4	4	4	4	4	5
Conc stock change	137	-479	78	967	331	137	292
Available concs	11,197	12,350	12,939	13,896	15,055	15,701	15,918
Concs required	11,197	12,350	12,939	13,896	15,055	15,701	15,918
Metal production	11,430	12,577	13,256	14,156	15,271	15,886	16,093
Smelter Capacity	11,187	13,017	13,954	14,902	16,074	16,722	16,940
Avg smelter util (%)	94.2%	97.3%	95.0%	95.0%	95.0%	95.0%	95.0%
Primary prodn	10,679	11,779	12,341	13,254	14,360	14,975	15,182
Secondary prodn	751	798	915	902	911	911	911
Supply	11,430	12,577	13,256	14,156	15,271	15,886	16,093
Supply (%)	-2.5%	10.0%	5.4%	6.8%	7.9%	4.0%	1.3%
Consumption	11,163	12,100	12,945	13,777	14,618	15,457	16,350
Consumption (%)	-3.2%	8.4%	7.0%	6.4%	6.1%	5.7%	5.8%
Surplus/Deficit	267	477	311	380	653	429	-257
Reported stock change	288	477	311	380	653	429	-257
Total stocks	1,005	1,481	1,792	2,172	2,825	3,254	2,997
Stocks (wks)	4.7	6.4	7.2	8.2	10.0	10.9	9.5
Price (US\$/lb)	79	99	112	109	103	98	91

Source: ILZSG; LME; CRU; Citi Investment Research and Analysis

CHINA - Supply Demand Balance

kt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Mine Production	3,092	3,465	3,328	3,476	3,516	3,542	3,543
Metal Production	4,357	4,984	5,836	6,286	6,518	6,518	6,593
Consumption	4,888	5,162	5,489	6,079	6,667	7,241	7,856
Consumption (%/yr)	17.9%	5.6%	6.3%	10.7%	9.7%	8.6%	8.5%
Conc Surplus	-1,265	-1,519	-2,508	-2,810	-3,001	-2,976	-3,050
Metal Surplus	-532	-179	346	207	-150	-723	-1,264

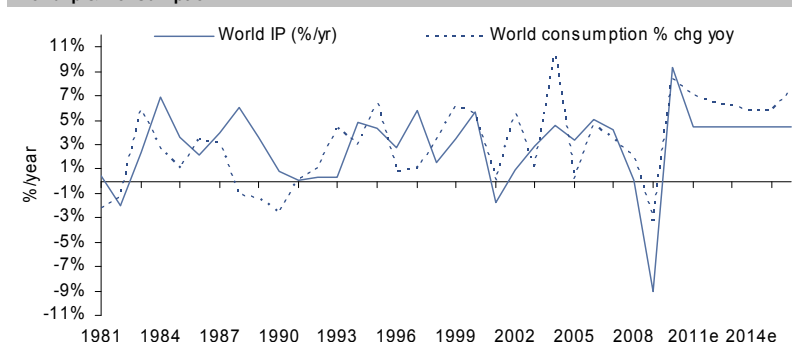
Source: ILZSG; LME; CRU; Citi Investment Research

Consumption, by country/region		Consumption, by end-use	
USA	8%	Galvanising	60%
Japan	4%	Rolled & Extruded Products	2%
Europe	17%	Brass Semis & Castings	5%
China	44%	Die-casting Alloys	26%
rest of Asia	17%	Oxides & Chemicals	7%
other	11%	Miscellaneous	1%
	100%		100%

Source: ILZSG; CRU; Citi Investment Research and Analysis

Last updated: 06-Nov-10

World IP & Consumption



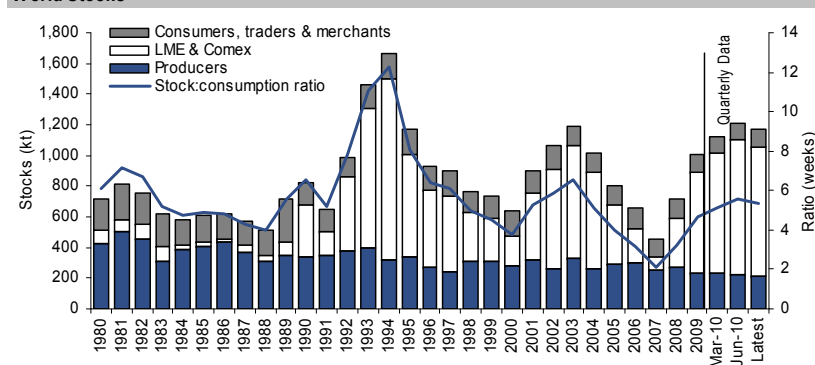
Source: Citi Investment Research

Consumption Forecast By Country

(% ch yoy)	2009	2010e	2011e	2012e	2013e	2014e	2015e
World	-3.2%	8.4%	7.0%	6.4%	6.1%	5.7%	5.8%
USA	-7.8%	-2.9%	1.2%	1.0%	1.0%	1.0%	1.0%
Japan	-23.2%	16.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Europe	-22.9%	13.6%	3.7%	1.8%	1.8%	1.8%	1.8%
China	17.9%	5.6%	6.3%	10.7%	9.7%	8.6%	8.5%
Korea	-19.7%	13.7%	7.9%	7.9%	7.9%	7.9%	7.9%

Source: ILZSG; Citi Investment Research and Analysis

World Stocks



Source: ILZSG; Citi Investment Research and Analysis

Nickel – Supply Demand Balance

NICKEL SUMMARY SHEET

WORLD NICKEL Supply Demand Balance				Current Price: US\$/lb		10.65	
kt	2009	2010e	2011e	2012e	2013e	2014e	2015e
Mine production	1,355	1,372	1,704	1,900	2,039	2,084	2,116
Refined capacity	2,096	2,127	2,185	2,259	2,279	2,279	2,279
Metal production	1,327	1,408	1,584	1,767	1,896	1,938	1,968
Change in Norilsk Stockpile							
Supply	1,327	1,408	1,584	1,767	1,896	1,938	1,968
Supply (%)	-2.1%	6.1%	12.5%	11.5%	7.3%	2.2%	1.6%
Consumption/Demand	1,291	1,413	1,573	1,688	1,772	1,854	1,910
Consumption (%)	0.3%	9.4%	11.3%	7.3%	5.0%	4.7%	3.0%
Surplus/Deficit	35.6	-4.3	11.4	78.7	124.2	83.3	58.1
Reported stocks	163.6	159.3	170.7	249.4	373.6	456.9	515.0
Stock change	8.1	-4.3	11.4	78.7	124.2	83.3	58.1
Stocks (wks)	6.6	5.9	5.6	7.7	11.0	12.8	14.0
Price (US\$/lb)	6.74	9.90	11.29	10.74	9.69	8.64	7.37

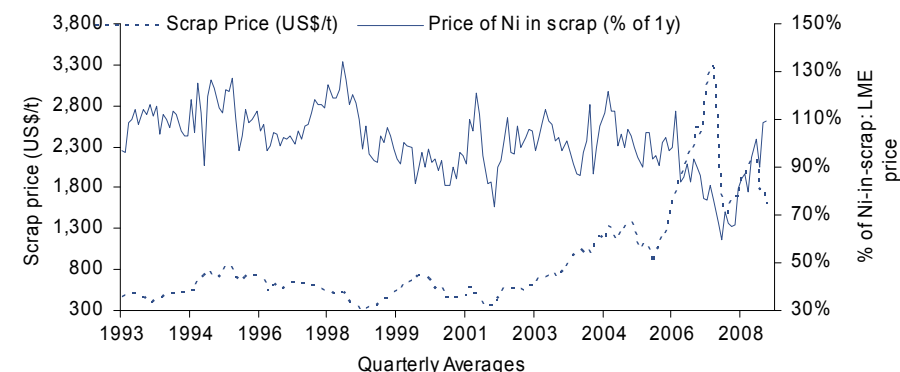
Source: INSG; CRU; Citi Investment Research and Analysis

Consumption, by country/region

Europe	18%	stainless steel	64%
China	42%	alloy steels	5%
Japan	11%	non-ferrous alloys	14%
U.S.A.	7%	plating	7%
South Korea	7%	batteries	3%
rest of world	15%	other, incl foundry	8%
	100%		100%

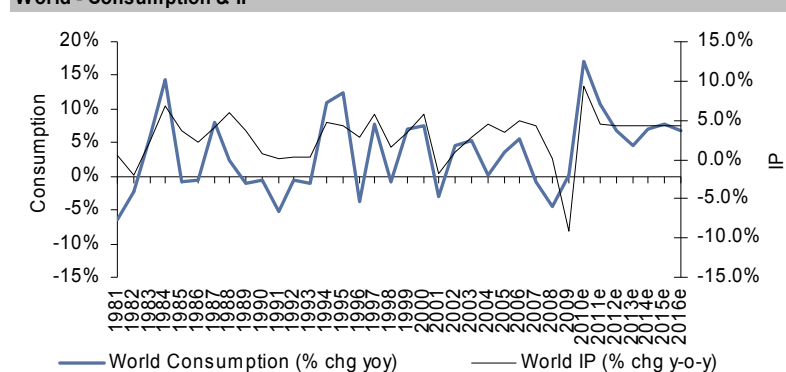
Source: INSG; CRU; Citi Investment Research and Analysis

Stainless Steel Scrap Price & the Ni-in-Scrap : LME Price ratio



Source: Metal Bulletin; LME; Citi Investment Research and Analysis

World - Consumption & IP



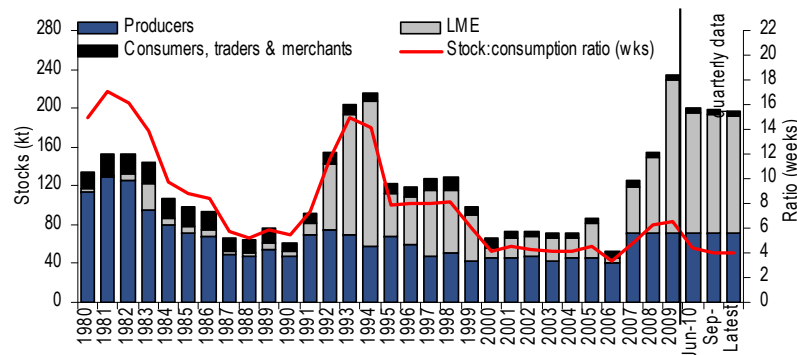
Source: INSG; Citi Investment Research and Analysis

Consumption Forecast by Country

(% ch yoy)	2009	2010e	2011e	2012e	2013e	2014e	2015e
World	0.3%	17.1%	10.6%	6.9%	4.7%	7.1%	7.8%
USA	-27.5%	53.8%	-0.6%	0.5%	0.8%	2.3%	2.7%
Japan	-20.3%	16.6%	3.6%	0.9%	0.1%	4.0%	1.8%
Europe	-39.0%	45.1%	1.6%	2.4%	-0.1%	1.6%	1.1%
China	77.4%	6.8%	12.1%	12.2%	9.4%	11.6%	14.1%
Korea	22.7%	-12.0%	5.1%	5.5%	-1.7%	7.0%	3.0%

Source: INSG; CRU; Citi Investment Research and Analysis

World Stocks



Source INSG; Citi Investment Research and Analysis

Appendix A-1

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