PANORAMA 2010

a look at ...

Are Li, Ni, Pt and Pd "critical" metals?

Heavily dependent on petroleum, the transport industry is seeking technological solutions to lessen this reliance and reduce its CO_2 emissions, such as hybrid or electric vehicles or fuel cells cars. But these solutions are in turn dependent on a few metals that have some of the same characteristics as hydrocarbons, e.g. they are finite resources present in geographic concentrations. For how long will lithium, nickel, platinum and palladium be available for our use? Will the importance of their applications and the implications of their geographic distribution make them critical in the world economy?

Transport is one of the sectors responsible for emitting the largest quantities of CO_2. A number of trends have emerged due to increased awareness that economic growth must be made more environmentally sustainable. For instance, catalytic converters have come into general use to limit toxic gas emissions and vehicles running on hybrid, electric and fuel-cell systems have been developed.

Lithium (Li), nickel (Ni), platinum (Pt) and palladium (Pd) have applications in:

- batteries (nickel, lithium),
- fuel cells (platinum),
- catalytic converters (platinum and palladium),
- refining (nickel is a component of some catalysts).

The energy mix of the future is shaping up as being more sustainable. Ni, Li, Pt and Pd are expected to play key roles. Will the geological resources of these metals suffice to cover future requirements?

With the exception of lithium, these metals are traded on the commodity futures market just like oil, natural gas and other metals (Zn, Cu) that in recent years have shown significant variations.

Resources and reserves

There exists a number of classifications, more or less detailed, based on the many geological, technical and economic criteria involved in deciding whether or not to undertake operations in an area containing a concentration of one or more metals. The financial markets oblige mining operators to use strict terminology. The Australian Joint Ore Reserves Committee Code (JORC) serves as the reference. Two key definitions apply:

- a mineral resource is a concentration or occurrence of material of intrinsic economic interest... in such form and quantity that there are reasonable prospects for eventual economic extraction,
- a mineral reserve is the economically mineable part of a resource demonstrated to be technically and economically viable at a given point in time.

Nickel

Reserves and resources (nickel)

Nickel is naturally found in combination with other elements, forming various minerals of which two large classes can be mined:

- sulfide minerals, especially pentlandite: $(Ni, Fe)_9S_8$,
- oxide minerals, a class that includes garnierite: $(Mg, Fe, Ni)_3Si_2O_5(OH)_4$.

According to the USGS (US Geological Survey), current world nickel resources are estimated to be 150 Mt[1] (million metric tons). Close to half of them are recoverable and counted as reserves, which amount to an estimated 70 Mt and break down as follows:

- 40% sulfide minerals, mostly located in large mountain ranges formed of magmatic rocks. They are extracted from underground mines, have a nickel concentration ranging from 0.2 to 8% and account for 55% of

(1) The "tons" in this paper must be understood as metric tons

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present-day nickel production. They form the largest known deposits (e.g. Kambala and Mount Keith in Australia, Sudbury in Canada and Norilsk in Russia).

- 60% oxide minerals, formed by the weathering of surface rock (laterization) in a humid tropical environment. They can be exploited by means of open-pit mining. The oxides are not as rich in nickel (0.4 to 3%) as the sulfides but often form large accumulations. They are expected to become more important in the next few years: major advances have been made in the processing of oxide ores. Oxide minerals now represent 45% of world production and are typically found in New Caledonia, the Dominican Republic, Cuba, Papua New Guinea and Australia.

Nickel is also found in concentrations of 0.5 to 1.3% in polymetallic nodules located at the bottom of the sea. Although their quantities are thought to be on the same order of magnitude as the terrestrial resources, they are not counted owing to the legal uncertainties as to their ownership and the technical difficulty of recovering them.

As for their geographic distribution, 72% of nickel reserves (70 Mt) is concentrated in five countries: Australia, France (New Caledonia), Cuba, Russia and Canada (Figure 1).

Supply and demand (nickel)

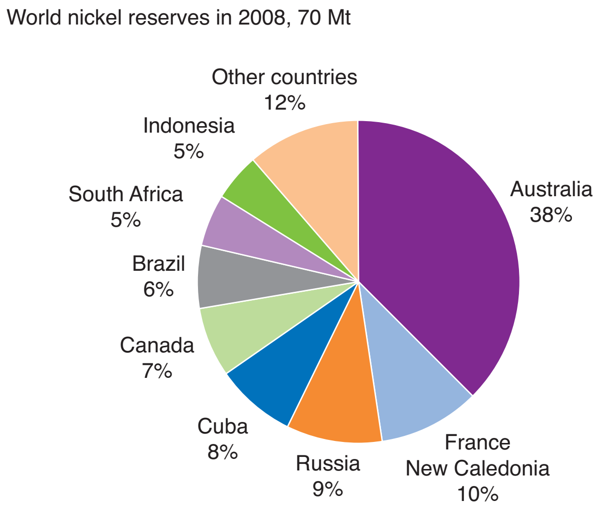
In 2008, nickel production totaled 1.6 Mt of which 63% was concentrated in five countries (Figure 2), namely, Russia, Canada, Indonesia, Australia and France (New Caledonia). At the current level of production, these reserves would last for about 44 years. The projects already underway should boost capacity by at least 0.24 Mt/yr by 2012, an increase of about 15%. They mostly concern oxide ore from New Caledonia and Indonesia. Mention should be made of the Goro and Koniambo projects in New Caledonia undertaken by Vale Inco and Xstrata, respectively, and the Weda Bay project (Eramet) in Indonesia.

At the industrial level, five companies control 63% of world nickel production: Norilk Nickel (Russian, 18%), Companhia Vale do Rio (Brazilian, 17%), BHP Billiton (Australian, 11%), PT Anaka Tambang (Indonesian, 9%) and Xstrata (Swiss, 9%).

Nickel is mainly used in alloy form (Figure 3), especially in (austenitic) stainless steels. It is also used to protect (plate) metals that do not resist corrosion as well as it does. Finally, it is used in the rechargeable nickel-metal hydride batteries (NiMH) used in most of the existing hybrid vehicles, including Toyota’s. Nickel also enters into the composition of certain refining catalysts.

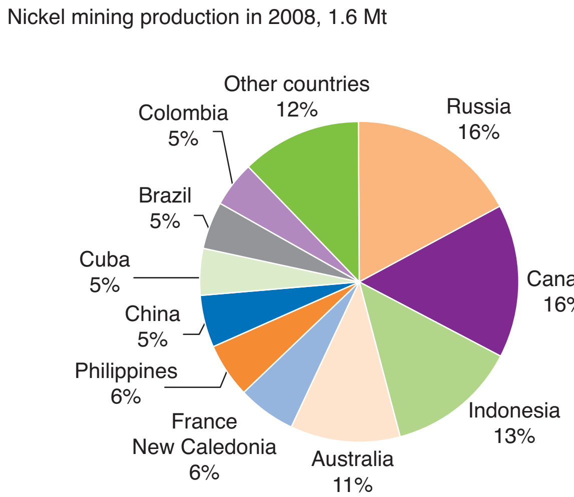
Between 2000 and 2007, nickel production rose by 30%, driven up by demand from China and India whose economic growth generated a rising need for stainless steel, mainly for construction. China alone accounted for one-quarter of world nickel consumption in 2008. The economic and financial crisis occurring at the end of 2008 put the brakes on this frenetic growth, leading to a drop in nickel demand. In early 2009, the producers adjusted production, revising it down by about 9%. Some mining operations were shut down, e.g. at Jinchuan in Zambia and Ravensthorpe in Australia, run by BHP Billiton. However, projects already underway to open new mining sites remained status quo.

Fig. 1 - World nickel reserves in 2008



Source: USGS

Fig. 2 - Nickel mining production in 2008



Source: USGS

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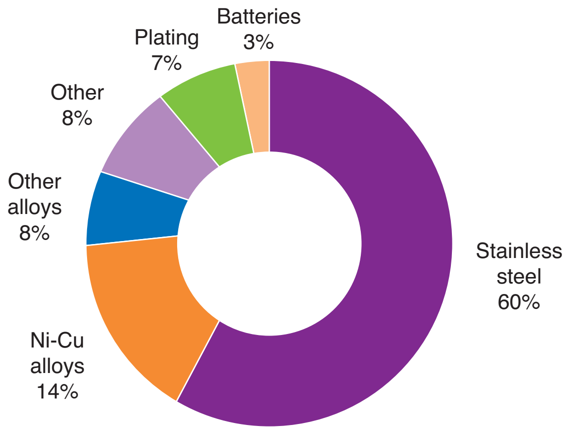
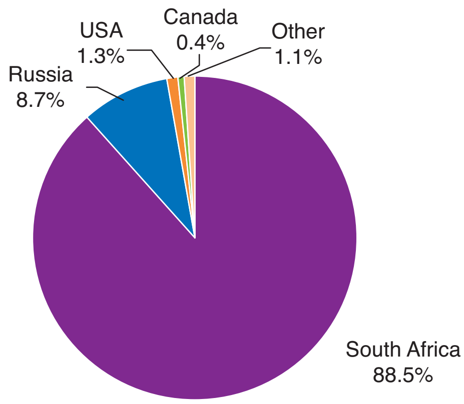
Fig. 3 - End uses of nickel



Source: based on information from various sources

Fig. 4 - World PGM reserves in 2008



Source: USGS

For most applications, nickel is used in alloy form. What is recycled is the alloy, not Ni by itself. This is also true for stainless steel, specialty alloys and refining catalysts. Specialized recycling companies produce ingots from an alloy of known composition that can then be used as a raw material.

Platinum and palladium

These two metals belong to the "Platinum group metals" (PGM) along with iridium (Ir), rhodium (Rh), ruthenium (Ru) and osmium (Os). These elements are found fairly often in combination at deposits and their applications are relatively similar. Platinum and palladium are the main representatives of this group. Platinum is one of the densest, heaviest metals and is also very malleable whereas palladium is the least dense and least malleable of the PGM. Platinum and palladium offer superior oxidation and corrosion resistance at high temperatures. Platinum – and, to a lesser extent, palladium – is a powerful catalytic agent.

PGM reserves and resources

The largest deposits in the world have been formed in an ultrabasic magmatic environment in which the PGM combined with other metals such as gold, nickel or copper. According to USGS data, world PGM resources come to about 80,000 tons, most of which are recoverable today and count as reserves. The latter amount to 71,200 tons 90% of which are in South Africa (Figure 4) at the Bushveld magmatic complex, where the Pt content is on the order of 5g/t. The Stillwater mine in Montana (United States) and the Lac des Iles mine in Ontario (Canada) are the other prominent platenoid mines. PGM may also be obtained as by-products from Cu-Ni mines, e.g. at Noril'sk in Siberia (Russia) or Sudbury in Canada. At the current level of extraction, PGM reserves could cover mining production for more than 200 years.

PGM supply and demand

Both platinum and palladium have a close connection to the motor industry, because more than half of consumption goes towards their use in catalytic converters. Palladium, steadily coming to replace platinum in gasoline vehicles, is seeing increased use in catalysts for diesel engines.

Demand

Half of world platinum demand is generated by the automotive sector. It is used to manufacture catalytic converters for diesel vehicles (Figure 5). Future emissions standards (Euro 6 and Euro 7) will be increasingly stringent, which will drive up demand for platinum and palladium. The largest market is Europe, whose fleet is dominated by diesel vehicles. 2008 saw auto-related platinum demand drop for the first time since 1999, as a result of the current economic slump. European carmakers cut back on platinum purchasing because the production of light-duty vehicles was down, despite the fact that the use of diesel particulate filters is on the rise.

Platinum is also used in other sectors – jewelry, chemicals, electronics and glass (flat LCD screens) – and refining (catalysts). Finally, financial investments represented 6% of demand in 2008, a higher percentage than in previous years. One reason was the sharp price increase early in the year.

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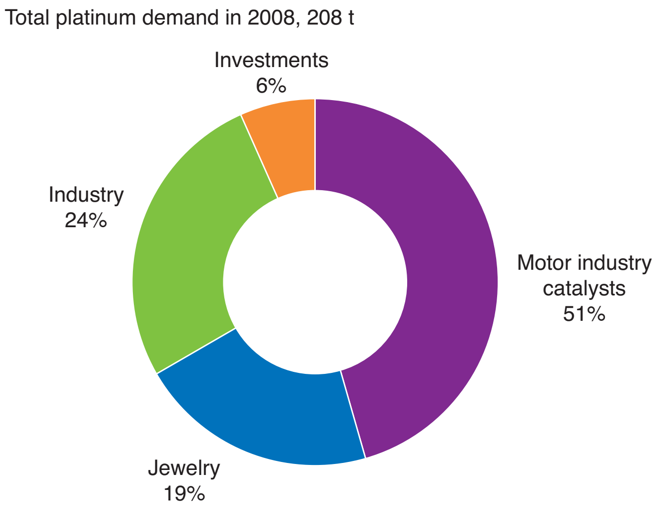
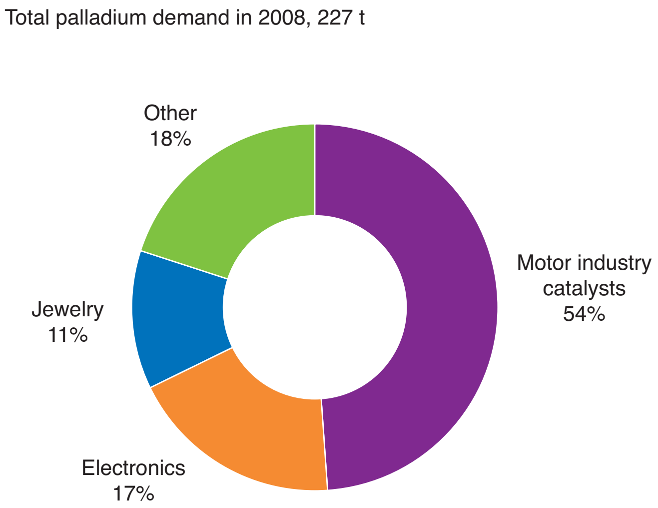
Fig. 5 - Total platinum demand in 2008



Source: Johnson Matthey, Platinum 2009

Fig. 6 - Total palladium demand in 2008



Source: Johnson Matthey, Platinum 2009

In 2008, world platinum demand fell by about 5% to 208 tons as a result of depressed demand from the automobile industry.

More than half of world palladium demand is generated by the motor industry, which mainly uses palladium to manufacture catalytic converters for gasoline vehicles (Figure 6). The biggest market is North America, where gasoline vehicles are dominant. With the economic slowdown in 2008, auto production fell in this region and brought palladium demand down with it. In Europe, the advent of catalytic converters for diesel vehicles that relied on a platinum-palladium alloy instead of platinum alone, brought a rise in palladium demand, even though new vehicle production was falling. This significantly affected the respective prices of platinum and palladium (Figure 12). The price of platinum was significantly lower than that of palladium.

Palladium is also used in electronics, a field in which demand has been growing steadily for seven years. This mainstream trend is due to the increasingly complexity of electronic equipment, which is such that the consumption of components is always on the rise.

Palladium is also used in the jewelry sector to replace gold or platinum when their prices are very high. Furthermore, it serves as a catalyst in the chemical industry, has applications in the field of dentistry and is used as a long-term financial investment.

Demand was up by about 2% in 2008. The downswing in the motor industry was more than offset by the upswing in the electronics, jewelry and financial investment sectors.

Supply

The platinum supply stood at 198 tons in 2008, broken down as follows:

- 170 tons extracted from mines,
- 28 tons produced by recycling catalytic converters.

Since demand amounted to 208 tons, about 10 tons had to come from stocks to achieve market equilibrium in 2008.

The palladium market was supplied with 240 tons, as follows:

- 75% extracted from mines (180 t),
- 14% obtained by recycling catalytic converters (33 t),
- 11% from the sale of Russian state stocks (27 t).

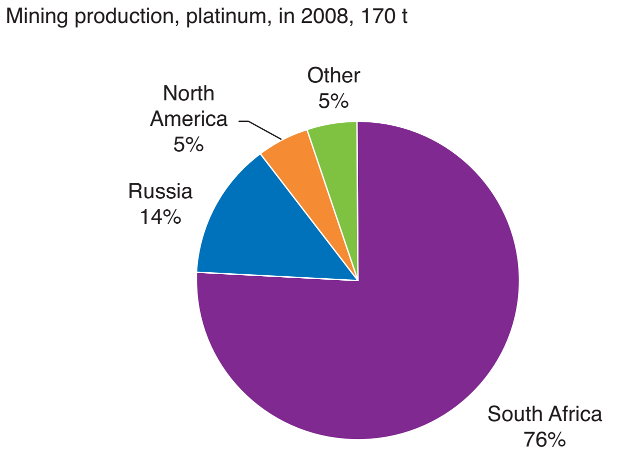
Demand came to about 227 tons, leaving the palladium market with a surplus of about 13 tons in 2008.

Mining production

From the standpoint of geographic distribution, PGM mining production is highly concentrated: South Africa accounts for 56%, Russia 29% and North America 10%. South Africa alone supplies three-quarters of the world's extracted volumes of platinum (Figures 7 and 8).

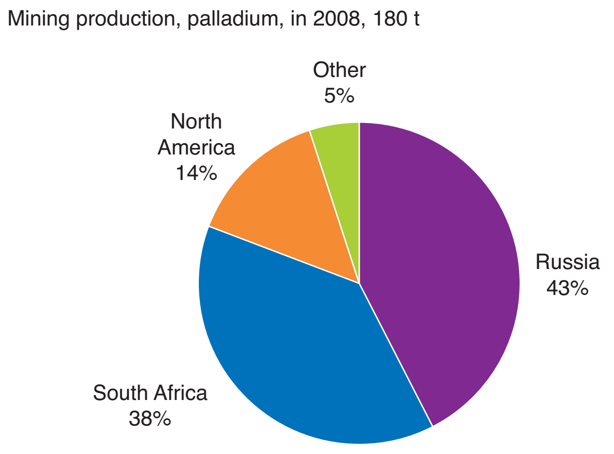
In 2008, the platinum and palladium outputs were down by approximately 10%, mainly because there was an energy crisis in South Africa during which the national operator had to ration electric power. The situation was aggravated by a series of occurrences (e.g. floods), a lack of qualified personnel and shutdowns for reasons of safety. Although few sites were actually closed,

Fig. 7 - Mining production, platinum, in 2008



Source: Johnson Matthey, Platinum 2009

Fig. 8 - Mining production, palladium, in 2008



Source: Johnson Matthey, Platinum 2009

investment budgets were drastically reduced and a number of projects that were under consideration in early 2009 were put off, often indefinitely. The structural nature of this domestic energy crisis led to fears of a considerable slowdown in development of additional capacities. Elsewhere, the industry was forced to react to lower prices by reducing supply. In North America, for example, mining operations were temporarily shut down (e.g. at the Lac des Iles mine run by North American Palladium).

In Russia, PGM production also fell by about 10%, mainly due to particularly harsh weather conditions, but also to a decrease in ore quality.

As for the future, the situation in South Africa and that in Russia are giving rise to fears that it will be difficult to increase supply over the short and medium term.

As for the mining companies, concentration was also the rule. Two companies accounted for more than 60% of PGM mining production: Anglo Platinum (32%), whose production (mostly platinum) is located in South Africa and Norilsk Nickel (29%), which mainly produces palladium (and nickel) and operates in Russia. Impala Platinum and Lonmin, with operations in South Africa, represent 13% and 9% of PGM mining production, respectively.

Recycling

An estimated 28 tons of platinum was recycled in 2008. This quantity covered 13% of total demand and one-quarter of demand from the automobile sector. Recycled palladium supplied 14% of total demand and 30% of motor industry demand.

The increase in recycled volumes is a mainstream trend, because the proportion of end-of-life vehicles equipped with catalytic converters is rising in all regions of the world. In 2008, recycled volumes were up 7.5% compared to 2007, even if the onset of the economic crisis at year-end resulted in a sharp downturn in the price level and in the number of vehicles scrapped.

The bulk of recycled platinum and palladium in 2008 came from North America (62% and 53%), Europe (24% and 31%) and Japan (6%). Consequently, these countries are slightly less dependent on mining producers.

Lithium

Reserves and resources (lithium)

Lithium does not occur naturally in its metallic form, because of its great reactivity. It is found mainly in the form of:

- chlorides (LiCl), in combination with the salts of other alkali metals, present mainly in the brine of intracontinental salt lakes,
- silicates such as spodumene ($LiAl(Si_2O_6)$) or petalite ($Li(AlSi_4O_{10})$), which is found in pegmatite, a crystalline rock close to granite,
- a member of the clay mineral group, hectorite $Na_{0,4}Mg_{2,7}Li_{0,3}Si_4O_{10}(OH)_2$ is the product of the alteration of certain types of volcanic rock,
- a borate mineral, jadarite, $Li\ Na\ Si\ B_3\ O_7\ (OH)$.

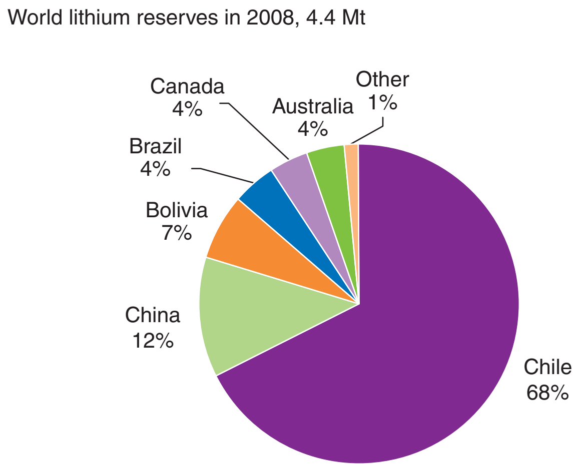
For the *Bureau de recherches géologiques et minières* (BRGM) in France, the debate over the estimation of world lithium resources reveals that it is necessary to gain more detailed geological knowledge of the many minerals and metals critical to the development of environmentally friendly technologies. Estimates of lithium resources vary between 11.4 Mt (USGS) and 56 Mt (Sociedad Quimica y Minera de Chile or SQM), broken down as follows:

- lithium chloride, found in certain salt lakes where the evaporation of water leaves high salt concentrations. The salt lakes of the Andes and Tibet constitute the largest deposits of lithium salts currently under exploitation. These surface deposits are considered to have a high Li concentration, ranging from 0.034% for the Salar de Rincon in Argentina to 0.3% for the salt lakes of Chile. The extraction of lithium salts involves evaporating the residual water to obtain a lithium concentration of up to 6%. The Salar de Atacama in Chile is currently the largest producing site in the world. The Bolivian salt lakes, especially the Salar de Uyuni, hold a large proportion of the world's lithium resources. The latter are not under industrial exploitation at the present time, but the situation could change,
- deposits of silicates, usually found in combination with pegmatites, exist in the United States, Canada, Africa, Russia, China and Australia, for the most part. The extraction of the ore often involves underground or open-pit mining (Greenbushes) as well as acid ore-washing operations. These deposits are much smaller and less profitable than those of lithium chloride. Historically, the earliest deposits to be exploited (in Australia, the United States and Canada) were silicates. However, when production sites in Chile started operating more recently at much lower cost, these mines were often closed,
- hectorite: a deposit of this type has been identified and is under assessment by Western Lithium: the McDermott caldera complex, located in the state of Nevada (U.S.). It may hold resources in excess of 2 Mt of lithium,
- jadarite: the only known deposit is in Jadar (Serbia). Under assessment by Rio Tinto, its resources are currently thought to be superior to 2 Mt of lithium.

Moreover, sea water contains lithium chloride in a concentration that may be low (about 0.17 parts per million) but, given the volumes involved, this would represent about 230,000 Mt of additional lithium! Today, these volumes are not counted, because a profitable method of recovering lithium has not been found.

According to the USGS, current world reserves of lithium are estimated to be 4.4 Mt (40% of resources). The BRGM in France thinks this number could rise substantially in the next few years, because there are still many possibilities for discovering new deposits. In addition, some countries produce lithium but their reserves are not included in these figures. Argentina is a case in point and, to a lesser extent, so is Portugal.

Fig. 9 - World lithium reserves in 2008



Source: USGS

The salt lakes of Chile account for 68% of the reserves counted in the USGS estimate (Figure 9). China ranks second with 12%, followed by Bolivia (7%). The latter currently leads the world for resources, but estimates of its reserves are still far from complete; the figure cited should be taken as the minimum.

Supply and demand (lithium)

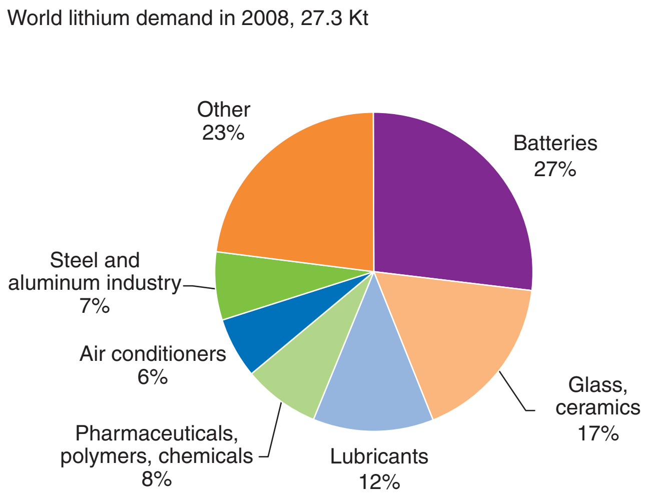
Lithium is generally used in the form of a lithium carbonate (Li_2CO_3) or a lithium silicate, especially spodumene.

In the last few years, the most important application for lithium has been batteries (Figure 10). This segment has been driving world consumption of lithium. Until now, growth has been due to the rise of rechargeable batteries for use in electronic equipment: 90% of all laptops and cellular phones contain a lithium battery. In future, it is anticipated that growth will be driven by the automobile sector, as hybrid and electric vehicles equipped with lithium-ion batteries arrive on the market. Among them are four electric models that Renault plans to bring out starting in 2011. In 2005, batteries accounted for 19% of lithium demand compared to 27% in 2008.

The glass and ceramics industries rank second for demand. They use lithium to increase the impact resistance of materials. The glass industry is highly dependent on demand in the building sector, which slowed significantly this year.

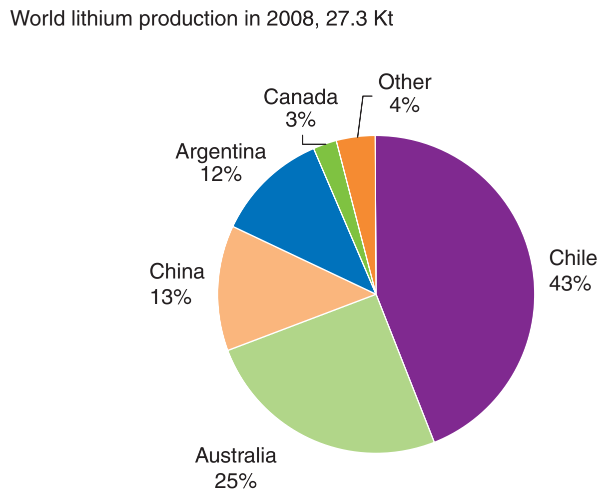
In 2008, world lithium production reached 27,300 t, 93% of which took place in four countries: Chile, Australia,

Fig. 10 - World lithium demand in 2008



Source: USGS

Fig. 11 - World lithium production in 2008



Source: USGS

China and Argentina (Figure 11). Output was up by 28% since 2005, driven by strong demand for batteries. Current known world reserves could cover more than 160 years of consumption at the present level.

A handful of market players control the production of lithium: SQM represents 30% of the world market and is based in Chile; Chemetall (28%) operates in Chile and the United States, where it is the only producer; and FMC (19%) works in Argentina.

Used to make batteries for hybrid and electric vehicles, lithium is currently a much-coveted commodity. The market expects to see demand for hybrid and electric vehicles increase substantially, generating very high demand for lithium. The race for lithium is on. A number of mining development projects are in the works. First of all, let's look at Bolivia, whose large resources are not under exploitation. In September 2009, the Bolloré Group submitted a plan to the Bolivian government concerning the development of the Salar de Uyuni, thought to contain 300,000 tons of recoverable lithium. The lithium extracted will be used, in a few years, to manufacture the Group-developed batteries that are to be incorporated into the Bluecar, an electric car expected to reach the market in 2010. Other Japanese and South Korean companies have also expressed interest in the Bolivian resources.

In the United States, the government is determined to reduce national dependence on oil and gas. One priority is the electrification of transport systems, which has given fresh momentum to the lithium industry. Exploration operations have been undertaken (e.g. the Kings Valley project conducted by Western Lithium at the McDermott caldera in Nevada) and new permits obtained (e.g. Ashburton Resources in Nevada). Furthermore, the U.S. Department of Energy (DoE) is providing dedicated grants for projects intended to produce materials for lithium-ion batteries. For instance, Chemetall is going to develop its Silver Peak production site in Nevada. Canada, the neighbor and foremost trading partner of the United States, is also giving lithium exploration a boost (e.g. Linear Metal at Seymour Lake, Ontario and Lithium One at James Bay, Quebec).

In Asia, Australian Galaxy Resources, financed by the Chinese investor Creat Group, has finalized the feasibility study for the Mt Cattlin project (Western Australia). Production should start by year-end 2010. In China, the company has also undertaken a feasibility study bearing on the production of lithium carbonate (Li_2CO_3).

Outlook and conclusion: Should one expect a tight market for these metals?

Since 2003, the price of metals has seen spikes and great volatility fueled by underlying financial speculation. In 2008, a severe market correction occurred. Nickel, platinum and palladium felt the impact of the world economic and financial crisis to varying degrees (Figure 12).

The lithium price has been rising steadily for a few years, up from \$300/ton of lithium carbonate in the 1990s to \$5,000/ton in 2008. The number of market players is small, so the producers set the price in sales contracts. Lithium is not quoted on international markets. As a result, little information concerning price volatility is available.

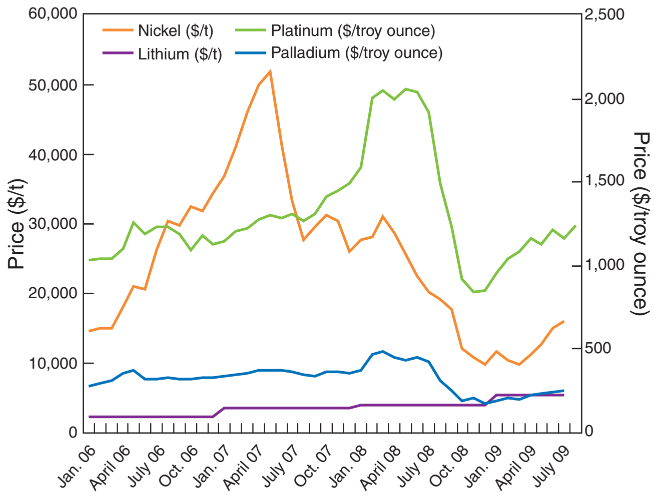
The nickel price peaked at more than \$50,000/t in the second-half of 2007 before plunging to \$10,000/t in early

2009. The prices of most mineral and metal commodities began to rise in 2002, triggered by rapid growth in China and its massive imports of minerals and metals. This economic fundamental was greatly amplified by speculation. The nickel price started to fall in mid 2007, which was early compared to the economy as a whole. The reason was that production increased simultaneously in Canada, Australia and New Caledonia. In parallel, the high price level encouraged consumers to replace stainless steel with substitute alloys. This reduced their nickel requirement and pushed the price down. In late 2008, by which time the price had stabilized, the economic and financial crisis triggered another steep decrease in demand, bringing the price down with it.

The prices of platinum and palladium followed parallel trend curves and reached historic highs in early 2008 ($2,275 and 585/troy ounce, respectively) in a very tight market. There was a shortage of supply due to conditions in South Africa (power outages and flooding). The end of 2008 was marked by a global economic slowdown with a substantial decrease in vehicle production and industrial demand. On the other hand, the lower prices revived interest in Pt and Pd in the jewelry and investment sectors, which supported prices in 2009.

Eventually, each kWh produced by a Li-ion battery will consume 100 g of lithium instead of 140 to 200 g today. An electric vehicle (EV) with a lithium-ion battery whose capacity is 20 to 30 kWh will have the equivalent of 2 to 3 kg of Li on board. According to a study by Meridian International Research, an estimated 8,500 tons of produced lithium will be available for automobile applications by 2020. Based on these quantities, between three

Fig. 12 - The price of metals for automobile batteries and catalytic converters



Source: LME and other sources

and five million of these EV batteries could be put on the market by 2020, limiting the proportion of EV vehicles to less than 8% of the world market.

Today, identified reserves represent 160 years of consumption and 60% of resources are not counted as reserves. The problem with lithium is not related to the level of resources, but rather to their exploitation and geographical concentration. The latter could create tensions, because 80% of lithium is found in South America, especially in two countries, Chile and Bolivia. However, as new types of unconventional deposits come to light (e.g. hectorite in Nevada and jadarite in Serbia), the market may see the development of geographical diversity to some extent.

In this respect, the recycling of lithium appears to be a key factor. Today, recycling is practiced on an insignificant scale. Lithium is usually incinerated, because it is present in very small quantities and hard to separate from other constituent components. Nonetheless, recovery processes do exist, such as those marketed by Toxco or Sony-Sumitomo, which make it possible to recover more than 95% of the lithium. Other processes are being developed, among them the Récupyl process supported by the French agency for the environment and energy management (ADEME).

The consumption of nickel should increase in step with the growing proportion of hybrid vehicles in the fleet. A nickel-metal hydride battery consumes between 1 and 2 kg of nickel per kWh. According to the IFP, putting one million vehicles equivalent to the Toyota Prius on the market would require the production of close to 3,000 tons of additional nickel (0.2% of current production). Given the current outlook for relevant mining development projects, this should not create any major tensions. Current reserves represent 44 years of production but, since the latter is expected to grow, the life span of reserves will rapidly decrease. The latter should last long enough to find new volumes and bring them under exploitation.

The platinum consumed today amounts to 2 g per diesel vehicle. This figure could rise to 4-8 g in future, with the ever-increasing quantities of transport pollutants wich will have to be removed. A fuel cell also requires a lot of platinum (about 0.8 g/kW today and, it is hoped, 0.2 g/kW in future). IFP expects that nearly 10 tons of platinum (6% of current production) will be consumed per million vehicles powered by fuel cells. The potential effects might be to limit the number of vehicles available on the market, boost the platinum price and generate geopolitical tensions because the bulk of reserves are located in South Africa.

Are Li, Ni, Pt and Pd "critical" metals?

PGM reserves represent 88% of the resources, which means that the vast majority of known volumes are recoverable today. The reserves are thought to cover more than 200 years of consumption at the current level, which is fairly comfortable. It would take targeted exploration to increase platinoid reserves, but resources do not pose any vital problems. The fact that reserves are very heavily concentrated could be a source of tension: 89% of them are in South Africa.

The extent to which the metals Li, Ni, Pt and Pd become critical to the world economy will depend on whether advances are made in geological knowledge, the exploitation of resources is feasible and the effort to reduce the quantities of materials used for different applications is continued. Once again, research is the key to the future.

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