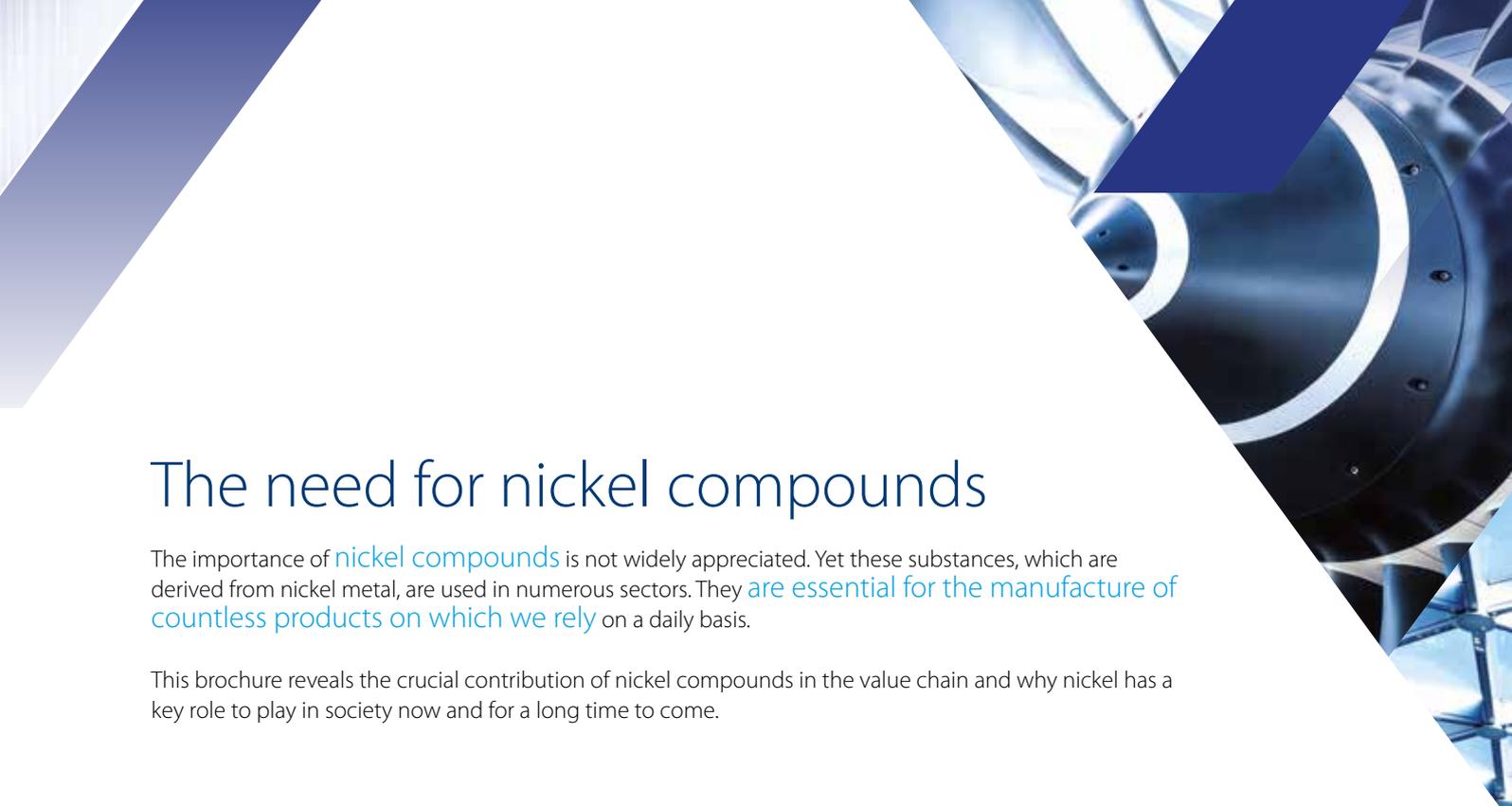




**Nickel**  
**Compounds**  
the inside story...





# The need for nickel compounds

The importance of [nickel compounds](#) is not widely appreciated. Yet these substances, which are derived from nickel metal, are used in numerous sectors. They [are essential for the manufacture of countless products on which we rely](#) on a daily basis.

This brochure reveals the crucial contribution of nickel compounds in the value chain and why nickel has a key role to play in society now and for a long time to come.

## Nickel in a nutshell

Nickel is a naturally occurring, lustrous, silvery-white metallic element used by humankind for some 2,000 years. It was only identified as an element in the 18<sup>th</sup> century. It then came to prominence in plating and in alloys.

Stainless steel was discovered in the early 20<sup>th</sup> century and nickel was found to have a beneficial role. Alloys based on nickel have excellent corrosion and heat resistance, making them ideal for uses in harsh environments such as chemical plants, jet engines and desalination facilities.

While nickel metal is the most important form of nickel by volume, nickel compounds nevertheless have critical uses. They are essential to a wide range of industrial sectors including transport, aerospace, marine and architectural applications and for the manufacture of many consumer goods. [Nickel compounds also play a key role in environmentally-friendly technologies.](#)

[Most people do not realise the importance of nickel compounds in the functioning of everyday products](#) like cars and electronics because, when they are used in manufacturing processes, they are transformed into metal, other substances or integrated into products. Nickel compounds are never directly accessible to the user.

### **Metals, compounds and alloys explained**

*Most metals, nickel included, do not occur as such in their natural state. They are found as minerals in ores, which are then processed.*

*Compounds are made of at least two elements chemically bonded together (e.g. nickel chloride).*

### **Metals vs Compounds**

- 1. Metals conduct electricity and heat, while compounds do not.*
- 2. Metals and compounds both have high melting and boiling points.*
- 3. Nickel, once refined into nickel metal, is often supplied as cathodes, briquettes or other rounded forms, while nickel compounds are usually granules, powders or liquids.*

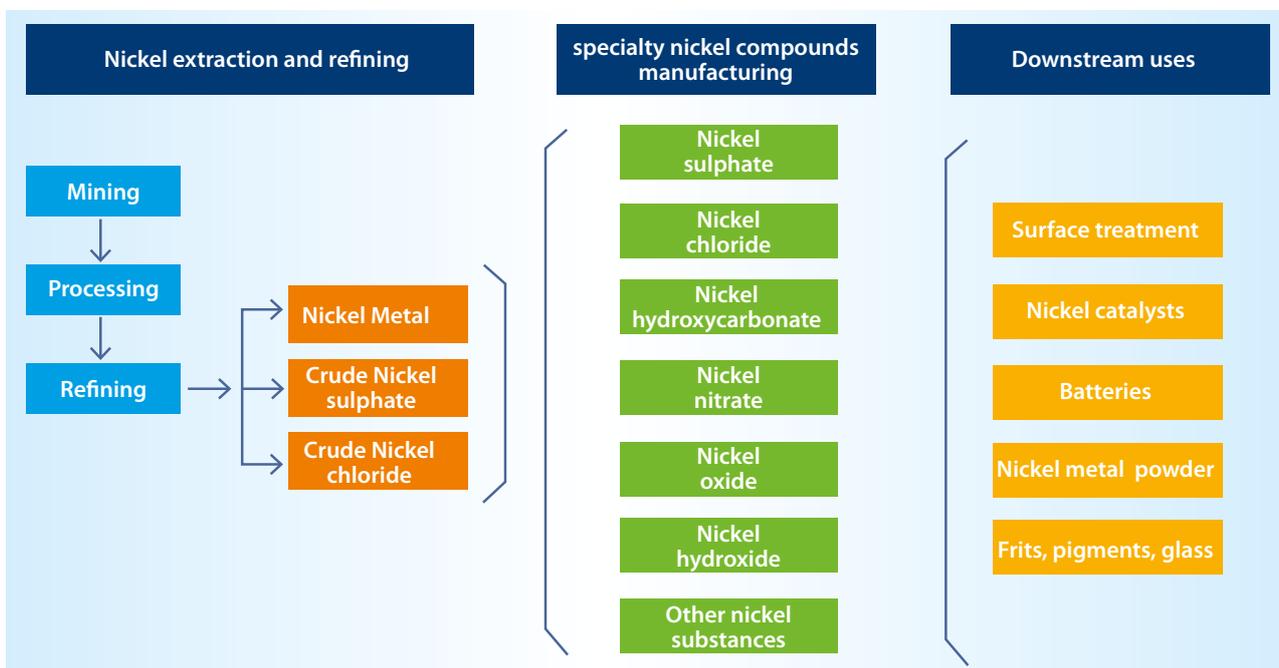
### **What are alloys?**

*Alloys are metallic materials consisting of two or more elements combined in such a way that they cannot be readily separated by physical means. In this way they are not so much mixtures as solid solutions of the different alloying elements. More than 90% of metals are used to form alloys. Alloys represent an enormous family of engineering materials that provide a wide range of products with distinct and useful properties such as resistance to corrosion, ability to withstand extreme temperatures, strength or formability.*



# Characteristics of nickel compounds

Processing of nickel ores leads to nickel metal and nickel compounds such as nickel sulphate and nickel chloride which are the basic ingredients for making other nickel compounds.



## **Safe use, with proper handling**

*Nickel compounds have different hazard classifications because of their intrinsic properties. Due to these classifications, the manufacturing, use, storage and transport of nickel compounds are regulated. Their production and use is strictly controlled to protect the environment.*

*With proper handling, nickel compounds are safe to use. And, because of the nature of the technologies in which they are used, consumers are not exposed to nickel compounds.*

The most important nickel compounds and their main uses are listed below.

On a global scale, there are a great many industries which depend on nickel compounds for critical applications such as plating, batteries and catalysts, even though they make up a relatively small portion of the total tonnage of nickel used every year.

### Nickel compounds and their main uses

			 Automotive	 Aircraft	 Electronics	 Batteries	 Plastics	 Paints	 Ceramics	 Fuels
<b>Nickel sulphate</b>	$\text{NiSO}_4$	Metal surface treatment, battery cathodes	●	●	●	●	●			
<b>Nickel chloride</b>	$\text{NiCl}_2$	Metal surface treatment, catalysts	●	●	●					●
<b>Nickel sulphamate</b>	$\text{Ni}(\text{H}_3\text{NO}_3\text{S})_2$	Metal surface treatment	●	●	●					
<b>Nickel oxide</b>	$\text{NiO}$	Catalysts, pigments, frits, glass						●	●	●
<b>Nickel hydroxycarbonate</b>	$\text{CH}_2\text{O}_3\text{Ni}$	Metal surface treatment, catalysts, pigments and frits	●	●	●		●	●	●	
<b>Nickel nitrate</b>	$\text{Ni}(\text{NO}_3)_2$	Metal surface treatment, catalysts, battery cathodes	●	●	●	●				●
<b>Nickel diacetate</b>	$\text{Ni}(\text{OCOCH}_3)_2$	Metal surface treatment	●	●	●					
<b>Nickel hydroxide</b>	$\text{H}_2\text{NiO}_2$	Metal surface treatment, battery cathodes, pigments	●	●	●	●	●	●	●	
<b>Nickel sulphide</b>	$\text{NiS}$	Catalysts								●
<b>Nickel subsulphide</b>	$\text{Ni}_3\text{S}_2$	Catalysts								●

# How nickel compounds are used

## Nickel compounds in plating

Nickel compounds are widely used for plating of metals and coating other base materials such as plastics. **Nickel plating provides a unique combination of corrosion and wear resistance**, as well as excellent adhesion properties for subsequent coating layers. Because of this, nickel is often used as an undercoat for other coatings, like chromium.

Plating or surface treatment involves applying a thin layer of metal or metal alloy. Its function is to change the technical or physical properties, like electrical conductivity, or to improve durability. Plating is also used for decorative purposes, such as for bathroom taps where a bright, shiny appearance is combined with resistance to corrosion and wear.



### Did you know?

#### 'Less' is more when it comes to electroless nickel plating

Electroless nickel plating combines wear and corrosion resistance with excellent adherence to all metals. This includes light metals such as aluminium which is increasingly important in the automotive and aerospace industry, due to its light weight.

In electroless nickel plating, a nickel coating is deposited on a surface using a controlled chemical process, or 'reduction', which is not based on electricity. This is why electroless nickel coatings are extremely uniform, even when applied to items with a complex shape.

Electroless nickel coatings are the first choice when it comes to protecting critical materials against corrosion in harsh environments, such as in automotive fuel systems, turbochargers, transmission parts and braking systems. In aircraft, electroless nickel is used for coating electro-hydraulic servo valves, compressor blades, engine mounts and landing gear, and other essential applications.



### Did you know?

#### Finished products do not contain nickel compounds

Nickel compounds are used in metal surface treatment. During this process nickel compounds are converted into metallic nickel. Therefore, nickel compounds as such are not present in the final product.



### Did you know?

#### Electroforming is an important industrial technology

which relies on nickel sulphamate and nickel chloride. Electroforming is an 'additive manufacturing' process which creates an object by electrodeposition of a metal onto a pre-formed pattern or mould known as a mandrel. Applications include security printing such as bank notes, postage stamps and official documents, stampers for CDs, DVDs and holograms, rotary textile printing screens, nickel foams for batteries, radar wave guides and many other uses.



### Case in point

#### Nickel plating used in coinage

Bright and durable "silver" coinage – usually nickel-plated steel – signals value to citizens. In addition, governments appreciate the low cost and long life of plated coinage. Mints appreciate how nickel surfaces take an impression from dies for sharp definition and detail that will last for decades of hard use. Vending machine makers and operators depend on the magnetic signature from the nickel to validate the coinage and allow only legitimate sales. And when the coins are at the end of their life, the nickel comes back with the steel for recycling and a new beginning.



## Nickel plating in the automotive industry

Plating and coating is particularly important for the car industry, where innovation in coating solutions is advancing rapidly and for which **nickel is indispensable for safety and longevity**. Plating on plastics and aluminium provides key benefits of esthetics and durability. Other important plating techniques are electrolytic zinc-nickel and electroless nickel plating.

Zinc-nickel plating is especially effective for corrosion protection, for example against salt spray, and thus is in high demand for automotive bolts, fasteners and components.

Similarly, electroless nickel plating is a well-known technique for protection against wear. It is used in hydraulic systems, shafts in different engine parts, in parking brakes and in automatic gearboxes.



### Did you know?

#### Zinc-nickel plating facts

Zinc-nickel plating is the standard for bolts and fasteners used in the automotive and aerospace industries. It consists of a zinc-surface treatment and a post treatment to improve corrosion performance based mostly on a chromium conversion coating followed by a sealer.



### Did you know?

#### Nickel is vital for plating on plastics

Deposition on ABS plastic mouldings provides durability for automotive, consumer products, builders hardware, taps, electronic products and many other applications where bright or satin coatings are required.



### Case in point

#### High performance coating for the car industry

The car industry is extremely demanding when it comes to selecting the right coatings to provide the best possible protection against corrosion and wear.

Zinc-nickel plating is used for applications requiring the highest corrosion and heat resistance with the lowest deposit thickness. This is why it is the only choice for high performance coatings of bolts, fasteners and brake parts in the automotive industry.

Typically, a zinc-nickel coating contains between 12-15% nickel. Zinc-nickel can also be applied to aluminium and magnesium substrates, both of which are gaining in importance in cars.





## Nickel plating in the aerospace industry

The aerospace industry has the most demanding technical requirements in terms of safety and reliability. The sector operates under strict standards for all materials, coatings and maintenance procedures for aircraft components, which are subject to detailed evaluation and testing before use.

Nickel-based plating combines unique functional properties that make it important for aerospace applications, thanks to its excellent adhesion, corrosion protection, hardness, wear and erosion resistance, as well as uniform layer thickness, even on complex components. This is why **nickel, zinc-nickel and electroless nickel coatings are all increasingly used in the aerospace industry, for safety and performance.**

### Case in point

#### **On-site aircraft maintenance**

Brush plating is a specialised technique that enables machine parts to be electroplated on-site. Brush plating can be applied using mobile devices that can be brought to the site of the aircraft, instead of dismantling and transporting the parts to an industrial plating location. This can represent a significant cost advantage for aircraft maintenance. The technique is accepted as standard by the aerospace industry, particularly for maintenance of landing gear.

## Nickel plating in electronics

Today, we depend on electronics for almost everything. They are particularly critical in applications where reliability is essential and failure would have dramatic consequences, such as in cars, aeroplanes, trains and the energy sector. Materials used in electronics for these purposes must meet the highest technical requirements.

**Nickel plating is widely used in electronic parts**, such as connectors, contacts, microprocessors and integrated circuits, **where it contributes to ensure functionality and reliability.** Because the requirements for such components are very demanding, nickel plating has a crucial role in the electronics industry. It provides corrosion resistance, solderability, a barrier layer to avoid the migration of metals and also mitigates 'whiskers' that can create short circuits.

### Case in point

#### **No more whiskers**

Whiskers are unpredictable crystalline growths of very thin metal wires that can cause short circuits. Tin whiskers are frequently observed, but other metals such as silver or zinc can also produce whiskers. Whiskers are a problem for all types of electronics. Of particular concern is when failure (short circuit) could have dramatic consequences, such as in satellites, hospital equipment or aircraft.

It is well known that tin-lead generates very few whiskers, because lead inhibits this type of crystalline growth. With the phase-out of lead in the electronics industry due to health and environmental concerns, the risk of whiskers formation increased.

Because nickel is also effective in reducing whisker formation it plays an increasingly important role in mitigating whiskers today.





## Nickel compounds in catalysts

Catalysts are essential in chemical production as they enable a reaction to take place faster and at lower temperatures and pressures, saving energy and increasing efficiency. Industrial catalysts are often metals or metal compounds that catalyse specific chemical reactions due to their inherent properties. Examples of metal used in catalysts are nickel, copper, cobalt, molybdenum and platinum.

The production of fuel, fertilisers and fine chemicals all require nickel-based catalysts to catalyse specific process steps.

Catalysts are designed for particular processes. An example of a core process where nickel catalysts are crucial is 'steam reforming', which is the main industrial process for the production of hydrogen. Hydrogen is mainly used in refineries and is essential for the production of cleaner fuels.

Another important process catalysed by nickel compounds and other metal catalysts is hydrotreating. This process is used in oil refineries to pre-treat oil fractions and remove sulphur, nitrogen, oxygen, metal and aromatics. The process is essential to reduce sulphur emissions and achieve environmental targets.



### Did you know?



#### Catalysts in fuel refining

Hydrotreating is a basic pre-treatment process in oil refining in most parts of the world and relies on nickel molybdenum (Ni-Mo) or nickel tungsten (Ni-W) catalysts.

Removing the sulphur reduces the sulphur dioxide emissions when fuel is used in cars, aircraft, railroad

locomotives, ships and power plants. Today, sulphur removal is essential for refiners to meet increasingly stringent environmental regulations.

This has ensured that the annual emission of sulphur dioxide from diesel vehicles in the EU has been reduced by a factor of 100 since 1993 despite a doubling in demand for diesel fuel. These gains have resulted in significant improvements in key environmental impact categories such as acidification, smog creation and impacts related to human health.

In terms of volume, hydrotreating is the largest chemical engineering catalytic unit operation with an estimated 2200 units worldwide. It is also the third largest industrial use of catalysts and the demand for Ni-Mo and Ni-W hydrotreating catalysts is increasing. This is primarily due to an increasing global demand for fuels, more and stricter environmental legislation and the fact that light crude oils are running out and heavier crude oils have to be used.



### Did you know?

#### Catalysts in vegetable oil production

Nickel catalysts are used in hydrogenation of fats and oils, which is an important process in producing vegetable tallow, vegetable fats and margarines. Hydrogenation is used to increase the stability of the oil. Highly unsaturated oil is susceptible to autoxidation and thermal decomposition, which can affect the flavour. Partial hydrogenation of vegetable oil improves its utility by changing the softening and melting characteristics to correspond to user needs.

Components for the cosmetics and chemical industries, such as emulsifiers, soaps, creams, and pastes, are also produced by hydrogenation with nickel-based catalysts. The choice of catalyst for hydrogenation greatly affects the properties of the final product. The nickel compound is firmly embedded in the catalyst which remains behind in the industrial process.

Spent catalysts are recycled and have a significant economic value.



## Nickel compounds in pigments, frits and glazes

Nickel oxide is used as a raw material in the manufacture of inorganic pigments and frits, which are in turn used in the production of glazes and enamels. Frits are similar to glass and are employed to give enamels and glazes certain qualities and colour. Nickel oxide is also used to improve adherence properties in ground coat enamels and as a colorant agent.

These glazes and enamels are applied to decorate and protect the surfaces of final products such as tableware, floor and wall tiles, artistic ceramics and enamelled steel parts. The use of **nickel oxide** in certain inorganic pigments **provides unique shades and subtle colour hues** not otherwise obtainable.

It is important to note that because the nickel is chemically bound in the material, there is no risk of it being released.



### Did you know?

#### **Pigment Yellow 53**

Nickel oxide is applied to various complexes to achieve blue, pink or yellow pigments. Pigment Yellow 53 (antimony nickel titanium oxide) is used for plastics, ceramics, building materials and as a pigment in coatings.

Pigment Yellow 53 is characterized by excellent weather-fastness and is therefore used in coil metal coating, for coating car shells and signposts as well as wall paint. It also has excellent heat resistance and is stable under harsh environmental conditions, making it particularly suitable for coating plastic products. Nickel is strongly bound in the pigment complex and cannot be released, making it suitable for use in plastics and ceramics.



### Did you know?

#### **Frits in ceramic glazes**

Frits are the main component of nearly all ceramic glazes and are available in many compositions.

A frit is a ceramic composition that has been fused (pre-heated) in a special fusing oven, quenched (rapidly cooled) to form glass, and granulated.

A glaze is usually made up of one or more frits together with pigments and salts to obtain the required properties and colour.

## Nickel compounds in glassware production

Nickel oxide is also used in the production of certain types of glass, including crystal glass, black light blue glass and ophthalmic glass. In sunglasses, nickel is used as a colorant, giving a brown tint to absorb sunlight and hence protect the eye against UV radiation.

Small amounts of nickel oxide are used for colouring certain crystal glass products shades of purple. In higher amounts, nickel compounds produce a range of specific colours from greyish to blue, violet, or even black glass, depending on the concentration of nickel.

A specialised use of nickel oxide is in the manufacture of black light blue (BLB) glass for fluorescent lamps. The BLB bulb is a fluorescent lamp emitting long wave UV radiation for detection and analysis purposes in archaeology, money checking, forensic science, food industry, medicine, mineralogy and philately as well as for special effects in night clubs, theatres and sign lighting.



## Nickel compounds in batteries

Several nickel compounds (nickel dihydroxide, nickel dinitrate, nickel sulphate and lithiated nickel oxides) and nickel metal are used in the manufacture of different types of rechargeable batteries. These include nickel-cadmium (Ni-Cd), nickel-metal hydride (NiMH) and most lithium-ion (Li-ion) batteries.

We depend on rechargeable batteries in our daily lives for portable electronic devices like mobile phones, laptops and tablets. NiMH and Li-ion batteries are both in general use for such mobile devices, while Li-ion batteries are also used in electric and hybrid vehicles, as well as for energy storage and in satellites.

Ni-Cd batteries, known for their excellent reliability, long life (often exceeding 12 years) and robustness, are the preferred choice for important, dependable and efficient emergency backup systems, such as in hospitals, aircraft and trains.

Hybrid cars with NiMH batteries produce up to 50% less pollution and greenhouse gases than comparable gasoline cars.

At the end of their life, these batteries are recycled. Nickel compounds extracted in this process are reused as secondary raw materials to manufacture new batteries or other industrial products. Flexible battery-based power solutions will continue to become increasingly important in future, as demand grows for lighter, more autonomous and longer-lasting devices. **Nickel will continue to play a key role in battery technology** in the future.



### Did you know?

#### Li-ion batteries used for storage of renewable energy

Energy storage technology plays a key role in integrating renewable energy into the energy grid. Batteries are used to improve grid stability by acting as an active power provider to compensate for the intermittent nature of renewable energy sources, such as wind and solar.

These batteries need to react very quickly and charge and discharge at high rates over a period of 15 to 20 years. Lithiated nickel oxides are the material of choice for the intensive demands of energy storage batteries because of their excellent structural stability and good electronic conductivity.



### Did you know?

#### Nickel-containing battery technology is important for the development of electric vehicles

As an example, the Tesla Model S 85kWh battery pack contains 7,104 nickel-containing cells which give a driving range of 500 km at a sustained speed 90kph. This battery powered car can achieve a speed of 100kph in just 5.6 seconds.



# The need for nickel will grow

By 2050, the world's population will have increased to an estimated 9.6 billion people<sup>1</sup>. Providing enough food, housing, transport, energy and water for the planet's population will require a concerted drive for new and improved technologies.

Nickel is an essential material used in or supportive of virtually all technologies.

The best-known properties of nickel - toughness, malleability and enhanced corrosion resistance - allow **superior performance in difficult environments** and at extremely high temperatures. These properties are why nickel-containing materials play such an important role in providing energy, transport, food and clean water, and why they will continue to contribute to a durable and sustainable economy and society.

Because of their inherent and often unique properties, **nickel compounds** in particular **play important roles in the development of solutions** and innovations to address some of the most pressing challenges, such as energy storage and supply, sustainable, recyclable products and green transport. Their electrochemical qualities are vital for battery technologies. They also give strength and corrosion resistance to plated products and provide catalytic properties for food production and environmentally friendly technologies.

Nickel-containing materials have the further advantage of being **ideally suited for recycling** because they have end-of-life value, are easily identified and can be turned into new high quality materials with less energy. Future decades will see continuous progress in the design of processes and products so that materials can be easily identified, separated and recovered. This increasing emphasis on design for the environment will influence not only the way products are used, but also how they are managed at the end of their useful lives. Ever higher percentages of materials in products, including the nickel contained in batteries, electrical systems, phones and hundreds of other products, will be diverted from landfills and recovered for recycling. Thanks to its economic value and its ability to be restored to its original properties, there will be financial as well as regulatory and ethical reasons for making the effort to recover nickel.

**New applications of nickel will be in millions of parts and processes, making contributions out of all proportion to the small amounts used.**

The numerous qualities of nickel will continue to contribute to innovation and breakthroughs in science as well as sustainability, to meet present and future challenges.

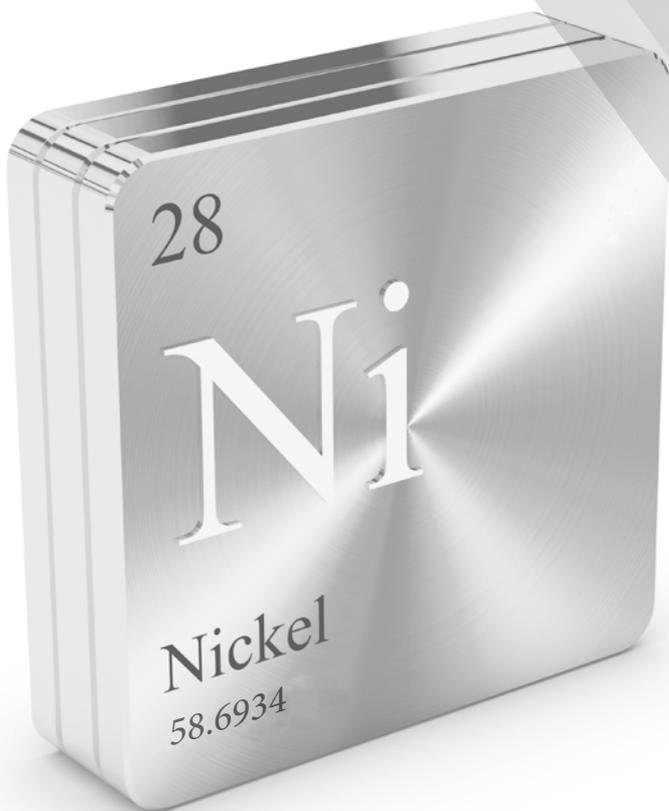
<sup>1</sup> United Nations, World Population Prospects, 2012

# About the Nickel Institute

The Nickel Institute (NI) is the global association of the world's primary nickel producers who together account for approximately 85% of worldwide annual nickel production outside China.

Our mission is to promote and support the use of nickel in appropriate applications. NI grows and supports markets for new and existing nickel applications, including stainless steel; and promotes sound science, risk management, and socio-economic benefits as the basis for public policy and regulation. Through our science division, NiPERA ([www.nipera.org](http://www.nipera.org)), we also undertake leading-edge scientific research relevant to human health and the environment. NI is the centre of excellence for information on nickel and nickel-containing products and has offices in Asia, Europe and North America.

[www.nickelinstitute.org](http://www.nickelinstitute.org)



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