NICKEL

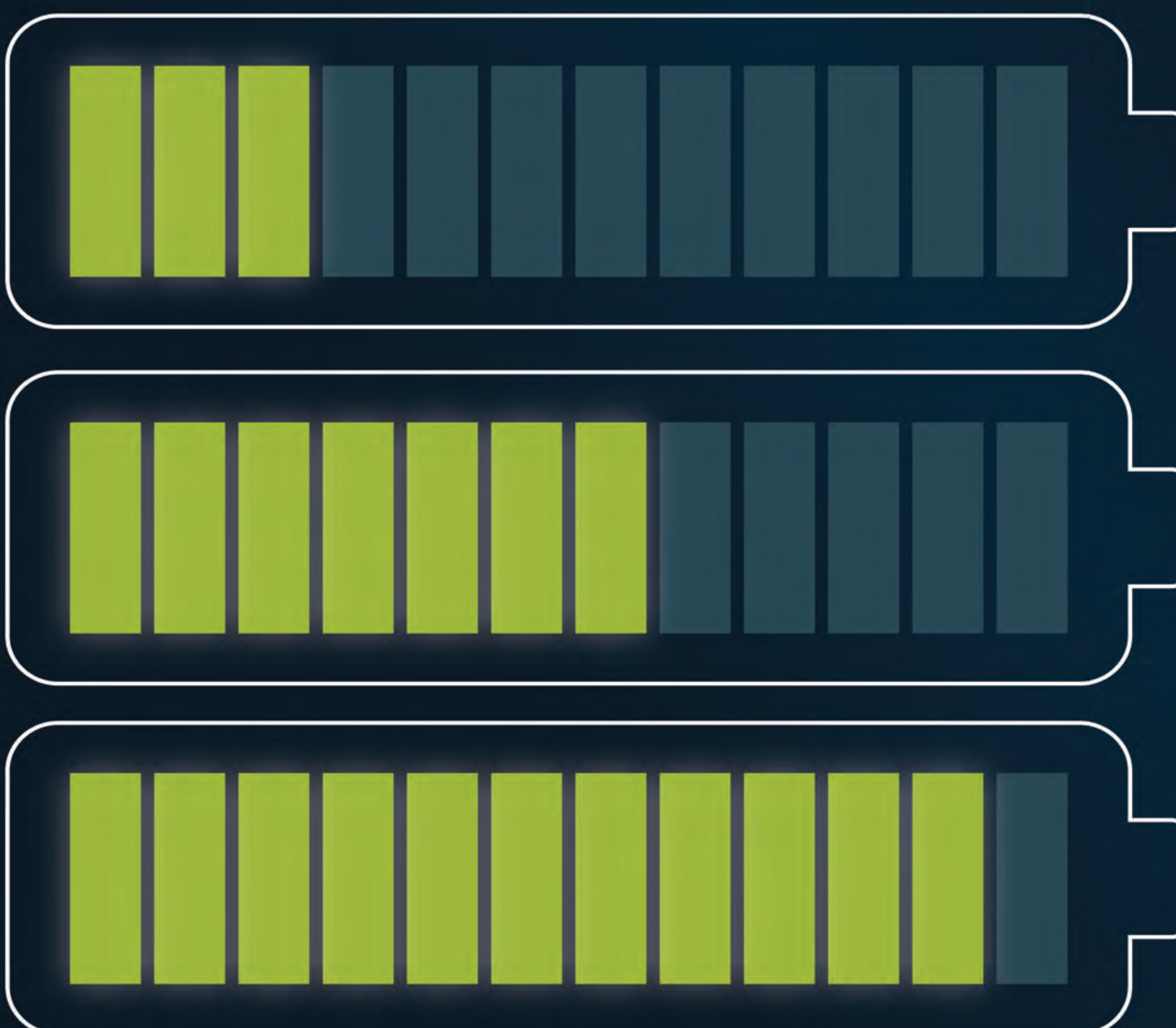
THE MAGAZINE DEVOTED TO NICKEL AND ITS APPLICATIONS

Managing the grid—
demand and response

Batteries underground
making mines safer

Battery storage
off the grid

May 2017, Vol. 32, No.1



Battery technology

past, present and future use of nickel

© SOLAR IMPULSE | REVILLARD | REZO.CH

△Solar Impulse 2 flying over Switzerland during test flights in 2014

© SOLAR IMPULSE | MERZ | REZO.CH

△ Solar Impulse 2 on the airfield in Payerne, Switzerland in 2014

CASE STUDY 09
SOLAR IMPULSE 2

Flying day and night using only stored solar energy, the Solar Impulse 2 (Si2) defied odds and made history when it circumnavigated the world without any fuel. Taking turns in the single-seater cockpit, co-founders Bertrand Piccard and André Borschberg covered 43,041km in 17 legs, crossing Asia, the Pacific Ocean, the USA, the Atlantic Ocean, the Mediterranean Sea and the Middle East.

When designing the plane, Piccard and Borschberg knew that they had to construct an ultra-light form that had a large wingspan to reduce drag and an ample surface to insert enough solar cells to reserve maximum energy to fly throughout the night on batteries. "The aircraft structure uses the most advanced technologies and has stimulated scientific research in the fields of composite structures, lightweight materials, electric propulsion and methods for managing and storing energy," said André Borschberg.

Borschberg set a record for flying five consecutive days and nights over the Pacific Ocean from Japan to Hawaii. And Bertrand Piccard achieved the first crossing of the Atlantic Ocean in a solar airplane. A total of 19 world records were set or are still pending by the World Air Sports Federation (FAI).

"We had to make maximum use of every single watt supplied by the sun, storing any surplus in our batteries. We tracked down every possible source of energy efficiency," said Borschberg.

Si2 used batteries based on Kokam Co., Ltd's advanced Ultra High Energy Lithium Nickel Manganese Cobalt Oxide (NMC) battery technology. The battery was chosen for its high energy density and efficiency, along with its ability to operate over a wide range of temperature, humidity and pressure conditions.

With four 38.5kWh Ultra High Energy NMC battery packs with 150Ah cells, totaling 154kWh of energy storage, Si2's 17,248 solar cells produced 11,000kWh of electricity, much of which was stored in its NMC batteries and then discharged to power the plane at night.

The Ultra High Energy NMC batteries feature an energy density of approximately 260 watts hours per kilogram (Wh/kg). This high energy density enables the Si2 to store more energy without increasing the plane's weight or size. In addition the batteries have a 96% efficiency, meaning less energy is wasted when the batteries charge or discharge. Ni

SOLAR IMPULSE 2 FACTS:

- 17,248 solar cells built into the wings that power the four batteries (38.5kWh per battery) that in turn power the four electric engines (13.5kW each) and the propellers
- Single-seater aircraft made of carbon fiber
- Unpressurised and unheated cockpit of 3.8m^3
- Wing span: 72m (larger than a Boeing 747: 68m)
- Length: 25m
- Weight: 2,300kg (similar to a large family car)
- Cruising Speed: 45-55km/h (25-30 KIAS (Knots-Indicated Air Speed) at sea level)
- Max. Altitude: 8,500m Flight Level: 280 (28,000ft.)
- The propulsion system is 93% efficient i.e. only 7% energy loss

NICKEL, VOL. 32, NO. 1, MAY 2017

NICKEL

The Magazine Devoted to Nickel and its Applications

Nickel magazine is published by Nickel Institute
www.nickelinstitute.org

David Butler, President
Clare Richardson, Editor

Contributors: John Chapman, Parul Chhabra, Gary Coates, Peter Kelly-Detwiler, Carly Leonida, Geir Moe, Kim Oakes, Marcel Onink, Kristina Osterman, Nigel Ward

Design: Constructive Communications

Nickel Institute can be contacted at:
Rue Belliard 12
Brussels 1040, Belgium
Tel. +32 2 290 3200
communications@nickelinstitute.org

ISSN 0829-8351

Printed in Canada on recycled paper by Hayes Print Group

Cover: Constructive Communications
Cover image: Constructive Communications

TABLE OF CONTENTS

Case Study
Solar Impulse 2........................2

In Focus
Editorial...............................3

Feature
Batteries past, present & future..........4-5
Importance of nickel......................5
Battery storage to power the grid...6-7
Demand side response systems.........8-9
Battery recycling..................10-11

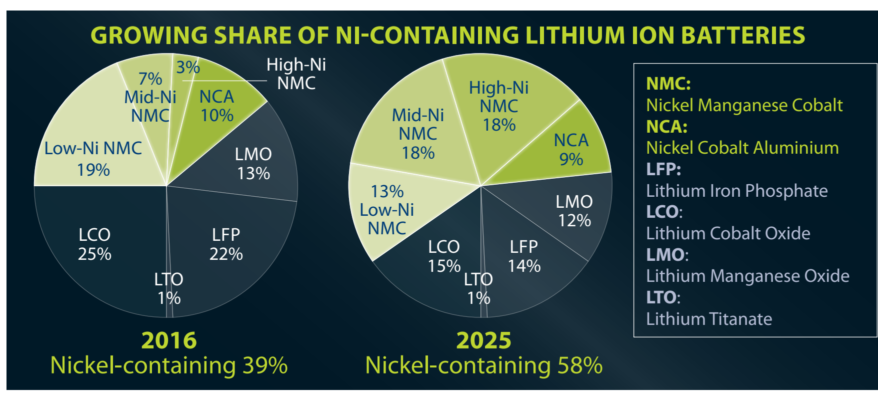
In Use
Underground mining 12-13
Nickel plated steel for batteries.......15
Chevy Bolt..........................16

In Brief
Storing solar energy..................14
Earthquake-resilient bridge...........14
Web links 15

ISTOCKPHOTO.COM © LILIBOAS

POWERING THE FUTURE

The battery market is on the move both literally and metaphorically. Concern over climate change, the drive towards energy efficiency and the adoption of carbon dioxide emissions targets by governments are all helping to increase the adoption of hybrid and electric cars. Add to this the heightened interest in renewable energy technologies involving batteries and energy storage, as well as the global consumer demand for longer lasting batteries to power electronic equipment, smart phones and electric bicycles. It's a dynamic scene!



SOURCE: ROSKILL

Electric vehicles (EVs) currently account for a small proportion of global automobile production but their share is growing. While growth forecasts for EVs vary, all are showing strong increases. The proportion of EVs on the road is currently below 1%. Recent estimates suggest the share will increase to between seven and 11% by 2025 and many of these vehicles will be powered by nickel-containing lithium ion batteries.

New nickel-containing battery technology is also set to play a role in energy storage systems linked to renewable energy projects. Wind turbines or solar voltaic panels generate electricity when the wind or sun is available, and battery technologies are enabling energy to be stored for use when required.

After being talked of for years as a significant technology for the future of the electricity system, major international brands—such as Nissan and Tesla—are getting involved. Tesla announced in early 2015 its entry into the energy storage market with a lithium battery featuring a nickel alloy cathode.

In this issue we look at the past, present and future of battery technology and the role of nickel. As it's such an extensive topic, we have dedicated most of this issue to it. The picture is complex. Different applications require different technologies and no single battery technology will ever emerge as the "winner". Nickel has been used in batteries for over a century, and for the foreseeable future will continue to have an important role to play in this fast-moving sector.

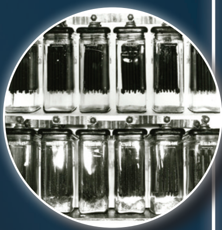
Clare Richardson
Editor, *Nickel* magazine

Nickel Institute
knowledge for a brighter future

BATTERIES: GOOD TODAY AND FAR BETTER TOMORROW

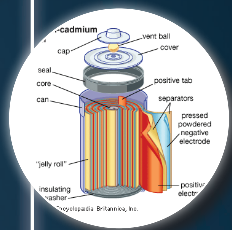
◁ **1748**
Benjamin Franklin
uses the term "battery"
—United States

1799 ▷
First battery with
continuous current:
Voltaic Pile
Alessandro Volta
—Italy



◁ **1859**
First rechargeable battery
Lead acid
Gaston Planté
—France

1899 ▷
First NiCd battery
Waldemar Jungner
—Sweden



◁ **1959**
First alkaline batteries
Lewis Urry
—Canada

1967 ▷
NiMH battery invented
Battelle-Geneva
—Switzerland

◁ **1980**
Lithium ion
cobalt-oxide cathode
—United States

2014 ▷
Lithium ion
solid state battery
—United States

From lead acid to Li-ion, over the course of the past 50 years or so, batteries have undergone a remarkable transformation. Back then, we used batteries in limited applications: to start cars, and power our toys, remote controls, and flashlights. Lead acid has long been the choice for gasoline-powered cars, while your typical alkaline batteries did the trick for devices in the home.

Then along came the nickel-based rechargeables: nickel cadmium (NiCd) and the longer lasting nickel-metal hydride (NiMH). These changed the way we worked and lived, charging power tools and early digital cameras. NiMH then made the big leap into transportation in the mid-90s, as the supporting technology for the Toyota Prius. This changed driving technology forever, leading to today's electric vehicles. However, the density was still lacking for what people wanted in cars, tools, cameras, and other emerging devices.

Lithium ion emerges

So lithium ion (Li-ion) emerged commercially onto the scene (most versions of which contain nickel) in 1991, making its way into early camcorders and eventually into our smartphones, laptops, and other portable devices we use today. Li-ion was also incorporated into the next generation of automobiles, as its superior power density became critical for moving vehicles over long distances.

In a half-century, we have transitioned from a point where batteries were mostly peripheral in our lives, to the point where we have them in our pockets and purses all day long (and some of us literally have them inside us in our pacemakers). One need only look around an airport lounge, with people always on the prowl for power outlets, to see how critical they are to our daily lives.

The near-term future looks good for nickel

As with many technologies, the more we use them, the better we want them to be. Batteries are no exception. We want cellphones and laptops to last for days on a charge. We want electric vehicles to go as far as a car on a tank of gas (and to 'fill it up' in less than ten minutes). And increasingly, we want batteries to support our massive and complex electric power grids.

We desire batteries that are lighter, denser, more powerful, and faster to charge. The question now arises, how will we get them? Will this involve continuous tweaks to existing technologies? Or is there something revolutionary lurking around the next corner, and if so, how long will it take to get it?

Further out the view gets hazy

First, let's look at the improvements to existing lithium ion chemistry. One trend is the migration towards nickel manganese cobalt cathodes, which offer more energy density and lower costs per energy delivered. There is also a move towards super dense lithium air batteries (Tesla has patents in this area, and other researchers are making considerable progress). At the same time, costs of lithium ion batteries continue to fall considerably as supply chains become more efficient (and China ramps up its massive production capabilities). Many observers see costs falling by as much as 50% over the next several years.

Further out, the view gets hazy: what about the next generation of lithium game-changers? Where will they come from, if at all? And when might they arrive? One possible candidate is the solid state battery, which is safer, denser (up to twice as much energy in the same space), longer-lasting, and also a lot more expensive at present. These batteries will likely have to find a beachhead in certain devices before they can reach economies of scale that facilitate price reductions. They are probably four or five years away from making their way into your smartphone.

Lithium sulfur is another candidate, owing to its four-fold density advantage over lithium ion and lower cost of materials. Significant technical and safety issues remain to be resolved here, though progress is being made.

The process of battery innovation will accelerate

Long-term, battery technology is all about materials science. It's about combining various elements on the periodic table to see how they will perform. Today, we are able to investigate chemistries in ways that were impossible a few years ago. High-performance super-computing allows us to perform over a quadrillion calculations per second, to combine various elements into compounds in the virtual world and rapidly see how they may perform. Do they transmit light and electricity? Are they malleable or brittle? Virtual compounds can be turned into actual compounds and tested further in the real world. Researchers now think they can cut the time required to bring a product to market in half.

Better battery technologies

Within five years, super-computers are expected to begin to perform 'what if' calculations, bringing more human-like reasoning to the table. As the US Department of Energy notes in a review on research and technology, "a combination of physical theory, advanced computer models, and vast materials properties databases to accelerate the design of a new material with application-specific properties by optimizing composition and processing to develop the desired structure and properties."

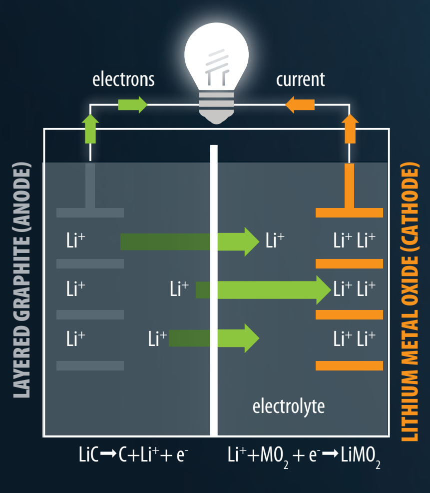
This promises to accelerate the process of bringing new battery technologies to market far more rapidly than today. We are likely to see far better battery technologies within the coming decade, with technologies that are as yet unclear.

In recent decades, nickel has played a key role in supporting our battery-powered lives. And for the foreseeable future, nickel will continue to do so. Ni

The importance of nickel in rechargeable battery technologies

An electric battery is a device consisting of one or more electrochemical cells, which is comprised of two electrodes—an anode and a cathode, and an electrolyte. When the two electrodes are linked by an electrical pathway, electrons can flow. When a battery is supplying electric power, the anode is the source of electrons that when connected to an external circuit will flow and deliver energy to an external device.

▽ *Lithium ion (NMC) rechargeable battery discharge mechanism*



Electrolytes are able to move as ions within, allowing chemical reactions to be completed at the separate electrodes and so deliver energy to the external circuit. It is the movement of those ions within the battery which allows current to flow out of the battery to provide power.

Batteries come in two classifications, based on whether the electrodes can be regenerated and thus the battery recharged. These classifications are: Primary (single-use or disposable) and Secondary (rechargeable) batteries.

Secondary (rechargeable) batteries come in different varieties, such as the well-known lead-acid battery found in automobiles, NiCd (Nickel Cadmium), NiMH (Nickel Metal Hydride) and Li-ion (Lithium ion). Nickel is an essential cathode component of many Secondary battery designs, including Li-ion, as shown in the table below. Ni

BATTERY TYPE	CATHODE	ANODE	ELECTROLYTE
Alkaline (P)	Manganese dioxide (MnO_2)	Zinc	Aqueous alkaline
Lead-acid (S)	Lead dioxide (PbO_2)	Lead	Sulphuric Acid
Nickel-Cadmium(NiCd) (S)	Nickel oxyhydroxide (NiOOH)	Cadmium	Potassium hydroxide
Nickel Metal Hydride (NiMH) (S)		Hydrogen-absorbing alloy	Potassium hydroxide
Lithium ion (LCO) (S)	Lithium cobalt oxide ($LiCoO_2$)	Carbon based, typically graphite	Lithium salt in an organic solvent
Lithium ion (NMC) (S)	Lithium-nickel-manganese-cobalt oxide ($LiNiMnCoO_2$)		
Lithium ion (NCA) (S)	Lithium-nickel-cobalt-aluminum ($LiNiCoAlO_2$)		

(P) = Primary, (S) = Secondary

MORE POWER TO THE LOW CARBON GLOBAL GRID

ISTOCKPHOTO.CAOM © PETMAL

TESLA.COM

ISTOCKPHOTO.COM © 4X-IMAGE

The market for batteries to support global power grids is set to surge

Lithium ion (Li-ion) batteries (many of which employ nickel) will play an integral part in supporting power grids in a global shift to become cheaper and cleaner.

This move is largely due to a significant increase in renewable energy resources, primarily wind and solar. In the US, wind and solar made up more than half of the new generating capacity over the past three years. Asia and Europe have invested billions in renewables and are on the way to creating a trillion-dollar sustainable power grid.

The problem is, the wind doesn't always blow, and the sun doesn't always shine. That's why batteries are being recruited to help stabilise our complex and far-reaching electricity infrastructure.

What's in storage?

Recent numbers from the Energy Storage Association showed that energy storage is increasing rapidly. In fact, total US installation almost tripled in size in 2016. But that's just the beginning.

In 2017, US storage numbers are expected to increase by nearly another 50%. Three installations in California in January of this year—all lithium ion and containing nickel—were equal to 15% of all US storage installed last year.

Other countries are also pushing stationary storage—Li-ion batteries—into their grid quite rapidly. Korea Electric Power Corporation, for example, is planning on 500MW of NMC batteries for fast-reacting storage facilities for grid stability. Japan has recently injected hundreds of millions of dollars of storage projects into its power grid as well.

Economies of scale make Li-ion the dominant technology

This is a result of both the long history of Li-ion in the market for consumer electronics and the enormous recent scale of investments in Li-ion manufacturing—much of it devoted to supporting the electric vehicle (EV) industry.

Tesla's famous Gigafactory in Nevada, for example, is expected to manufacture 35,000 megawatt-hours (MWh) by 2018. That single US factory will produce the equivalent of all the lithium ion batteries produced worldwide just four years ago. Approximately one-third of Tesla's factory output will be devoted to electric grid storage.

WWW.TESLA.COM

△ *Tesla's Advanced Microgrid Solutions aims to facilitate a flexible, adaptive electic grid through its energy storage technology.*

Tesla is not alone, however, and it may not even be the biggest kid on the Li-ion block.

China is in the driver's seat

China will drive global economies, pushing prices down and demand up.

The growth trajectory for battery grid storage is going to be very steep. China already owns the lion's share of global production.

If China can do with batteries what it has done with solar modules, it may dominate the market. By promoting electric vehicles (EVs), the country is driving demand for Li-ion batteries, resulting in manufacturing economies of scale. Some analysts expect that increased volumes and supply chain efficiencies will reduce costs as much as 40% in the next year.

The biggest Chinese company in the sector, Amperex Technology, tripled its Li-ion battery output over the past year and has overtaken LG Chem, one of the world leaders. At production of roughly 8,000 megawatt-hours (or 8-gigawatt hours – GWh) today, it plans to burgeon to 50GWh by 2020 (or half again as large as Tesla).

Good news for nickel

This is good news for nickel demand in the long run. Global suppliers of Li-ion battery cathode material are increasing production capacity of nickel-manganese-cobalt (NMC, with a typical ratio of 33% for each of the elements).

Much of this output will be devoted to EVs, but stationary grid storage will have its place as well. In grid storage, the NMC technology is rapidly gaining traction over other competing lithium technologies such as lithium iron phosphate and becoming the cathode of choice for developers.

A world of possibility

Stationary grid storage is still in its early days, and future projections as to the size of the market vary widely. For the visible future, EVs will drive new demand for lithium ion batteries and the nickel contained inside them.

The role of stationary energy storage will be quite significant in the very near future, as costs fall and business models get refined. It is quite likely that stationary storage will complement the millions of solar arrays already on people's houses. At the grid level, leading storage companies such as AES Energy Storage already see Li-ion storage as cost-competitive with new peaking generation plants and a significant part of the future global grid architecture.

What is clear, is that nickel will play a critical role in the low-carbon power grid of the future. Ni

Demand side response and battery


ISTOCKPHOTO.COM © 4X-IMAGE

The demand for energy is continually increasing; at national levels, within communities and in households. The traditional method of meeting this demand has been to increase production on the supply-side.

In recent times, however, attention has started to focus more on the demand-side, i.e. on the consumers themselves. The intention has been to adjust demand at peak times, for example by offering consumers financial incentives to use power at an off-peak time.

An alternative that is gaining significant momentum to meet this increased demand is to provide 'local' ways of storing energy produced off-peak so that it's available for use when needed.

With this latter approach to demand-side-response (DSR), peak demand is not reduced, but managed so that energy—stored in batteries, many lithium ion and containing nickel—is available at critical times of the day.

The DSR advantage

For national grids, an automated DSR system can react to a surge in demand faster than traditional methods such as thermal plants and hydroelectric generators. Furthermore, as it is based on distributed technology, it has no single point of failure. When linked to battery storage systems, frequently based on lithium ion technology, the DSR stockpiles energy from renewable sources so that the off-peak balance between supply and demand can be maintained.

This use of energy storage systems (ESS) is particularly important because 21 gigawatts (86%) of the EU's new energy capacity built in 2016 was from wind, solar and other renewable sources which are intermittent in nature. This more effective use of renewable energy sources helps reduce carbon emissions.

The UK National Grid is just one energy supplier that is investing more in this combination of DSR and battery storage systems. In the response to the UK's latest Capacity Market Auction, some 500 megawatts will be supplied by such new storage projects as the move to wind and solar generation continues.

Greater flexibility for all

This increased use of battery energy storage systems is not limited to national grids as there is also considerable activity in industrial and commercial markets. Open Energi, a UK-based technology company, supplies solutions based on DSR and energy storage.

David Hill, Director, Open Energi, stated "Combining behind-the-meter battery energy storage systems and demand side response is key to unlocking the total value of consumer flexibility and can lengthen battery lifespan by reducing throughput. It enables businesses to optimise the cost and carbon savings across their asset base and has the potential to transform how our electricity system operates."

As DSR grows, the demand for nickel will grow along with it, strengthening the versatility of energy delivery systems around the world. Ni

storage systems rise to the challenge

DSR IN ACTION

The installation of a DSR capability linked to energy storage systems means improved flexibility and reliability, together with an increase in the use of cleaner renewable energy sources. These industry case studies, in the USA and Italy, show how proven energy storage systems can help to meet all of these objectives.

NEXTERA / DEMOSS PETRIE SUBSTATION SYSTEM

△ *NextEra substation system*

Case Study—TEP / NextEra (lithium ion batteries – NMC)

Tucson Electric Power (TEP) is a utility company that provides electricity to over 400,000 customers in southern Arizona.

As part of its drive to enhance the resiliance of the local electric grid, TEP has worked with a subsidiary of NextEra Energy Resources of Juno Beach, Florida to install a 10 megawatt Lithium Nickel Manganese Cobalt Oxide (NMC) energy storage system. It is now helping to maintain a reliable service for customers during periods of high energy demand.

Interestingly, TEP is also participating in a two-year research and development project with Chicago-based IHI Energy Storage to study how efficient use of battery energy storage systems can improve the reliability of electricity supply in Arizona's hot, dry climate.

The NextEra system uses NMC batteries, that typically contain about one third each of nickel, manganese and cobalt chemicals; they have a long life span and are well suited for connectivity with a microgrid for off-peak storage.

According to TEP spokesperson Joe Barrios, "the company looked for cost-effective, proven energy storage systems that would improve reliability while enabling it to explore how innovative technologies like these might help TEP expand the use of renewable resources." TEP's current renewable portfolio has a capacity of about 530 megawatts, which is enough to power more than 110,000 homes for a year.

UNIVERSITY OF GENOA

△ *FIAMM sodium-nickel batteries were chosen for the energy storage system.*

Case Study—Siemens/FIAMM (sodium-nickel batteries)

In 2012, the Savona Campus of the University of Genoa decided to introduce a more efficient method of energy supply and management.

As part of the 'Energia 2020' project, the University elected to install an intelligent energy management system based on microgrid technology.

This system helps satisfy the Campus' electrical and thermal demands by local generation, reducing the amount of electrical energy purchased from the external network.

The objectives were to increase the use of renewable energy sources, minimise energy consumption and reduce the Campus' CO_2 emissions and energy costs.

Renewable energy is captured via a concentrated solar power system and a photovoltaic facility. The microgrid went into production in 2014, with the installation being managed by Siemens.

According to the University's Dr. Mansueto Rossi, "FIAMM sodium-nickel batteries were chosen for the energy storage system as they do not need a complex cooling system; they are extremely resilient to adverse environmental conditions and are ideal for charging during the day and discharging at peak times." Ni

BATTERY RECYCLING IN A BUZZING INDUSTRY

The worldwide battery industry ramps up with demand

ISTOCKPHOTO.COM © BET_NOIRE

Major investment into R&D and new production facilities is taking place in the lithium battery sector, directly linked to the development of electric vehicles (EVs). This has caused a shift in predominant battery chemistries. Hybrid electric vehicles (HEVs) generally use NiMH batteries, while plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) use Li-ion batteries because of their higher energy density and other advantageous properties.

Preparing for the future

Once PHEVs and EVs become mass-market vehicles, the impact on the battery recycling industry will be massive. Battery recycling companies are presently investing and preparing for future needs of much larger scale recycling facilities, able to process Li-ion batteries from these types of vehicles. When battery performance declines below acceptable levels for vehicular use it may still be suitable for secondary use in utility storage. Eventually its performance will be insufficient and will require disposal. Recycling is needed for environmental reasons but also because of the valuable and recyclable materials the batteries contain. The economic incentive in battery recycling is the value of the lithium metal oxides used in the cathodes of these batteries: cobalt, nickel, manganese, combinations of these, or phosphorous and iron. Copper, aluminium and steel are also components of the cell structure. Battery attributes vary with cathode material and there are many different chemistries used.

Important cathode materials in Li-ion batteries are Nickel Manganese Cobalt (NMC) and Nickel Cobalt Aluminum (NCA), which have a content of 33-80% nickel chemicals. NMC is used in a variety of electronic devices and in EVs. NCA is used in 18650 Panasonic cells in Tesla cars and as a blend with Lithium-Manganese-Oxide (LMO) in other EVs. Additional key cathode materials are $LiCoO_2$, $LiMn_2O_4$ and $LiMPO_4$.

Newer recycling processes

Depending, however, on the cathode composition and the recycling process, the value of the cell materials recovered will differ. Most of the Li-ion batteries available today contain cathodes that are primarily cobalt oxides, and the recovery of elemental cobalt drives the process economics. Batteries with lower cobalt content, such as many of those now being built for vehicles, are less attractive for recycling by current methods. Newer recycling processes are under development to recover active cathode materials (including the lithium they contain) that could be reused in batteries and are much more valuable than their constituent elements. The quality of the recovered materials must be assured.

In parallel with the technological advancement, the regulatory environment for the battery industry is changing and tightening. The European battery directive, which states that batteries must be recycled, is presently being reviewed. China recently introduced regulations that put the responsibility of auto battery recycling on the car producer. At present there are no harmonised regulations regarding battery recycling in the US and existing regulations are on a state basis. More regulations can be expected globally.

Due to challenges in the collection systems, it is estimated that only some 10% of spent Li-ion batteries currently reach the collection systems and end up being recycled. Most of these batteries are from various portable electronic products.

Other batteries presently collected and recycled are NiMH batteries, including batteries from HEVs containing 23% nickel, 4% cobalt, 7% rare earth metals, 36% steel, 18% plastics, 9% electrolytes, 2% other metals and 1% polytetrafluoroethylene (PTFE). Toyota Prius is by far the world's top-selling HEV and the car manufacturer is committed to the NiMH battery, seen as a mature and reliable battery technology. With global annual HEV sales at 1.5-1.8 million for the last five years and a ten year battery life, growing numbers of NiMH car batteries will require recycling.

China

Worldwide sales of PHEVs reached 250,000 units with China as the leading market (29%) because of high incentives in place. Incentives have also made China the leading market for EVs. In 2016 some 500,000 EVs were sold, 55% in China. The industry anticipates sales numbers to shift upwards in the next five years, suggesting that battery recycling companies will start processing larger and larger volumes of Li-ion batteries in the next decades. Ni

A LEADING RECYCLER

UMICORE BATTERY RECYCLING

△ *Umicore's precious metals facility in Hoboken, Belgium. Umicore is one of the world's largest recyclers of precious metals.*

Through its award winning zero waste and closed loop battery recycling process, Belgium-based Umicore Battery Recycling (UBR) is a leading recycler of NiMH and lithium ion batteries. By combining a unique pyrometallurgical treatment and a state-of-the-art hydrometallurgical process UBR is able to recycle all types and all sizes of Li-ion and NiMH batteries in the most sustainable way.

The Umicore pyrometallurgical phase converts the batteries into three fractions:

- An alloy, containing the valuable metals cobalt, nickel and copper;
- A slag fraction which is used in the construction industry. The slag from Li-ion batteries has the potential of lithium recovery. The slag from NiMH batteries can be processed to a Rare Earth Elements concentrate that is then further refined through a cooperation with Solvay; and
- Clean air, released from the stack after it has been treated by the unique Ultra High Temperature (UHT) gas cleaning process.

The pyrometallurgical step utilises Umicore's UHT technology. The UHT technology is pushing the boundaries for recycling and sets a new standard in Best Available Technology for metallurgical recycling processes. It is designed to safely treat large volumes of different types of complex metal based waste streams. It differentiates itself from other recycling technologies, by:

- A higher metal recovery compared to existing processes and the output of directly marketable products;
- Direct feeding of the batteries, which avoids the need for any potentially hazardous pre-treatment;
- The gas cleaning system, which guarantees that all organic compounds are fully decomposed and that no harmful dioxins or volatile organic compounds (VOCs) are produced. Fluorine is safely captured in the flue dust;
- Reducing the consumption of energy and CO_2 emissions to a minimum by using the energy present inside the battery components (electrolyte, plastics and metals); and
- Generating close to zero waste.

In the subsequent hydrometallurgical process, the alloy is further refined so the metals can be converted into active cathode materials for the production of new rechargeable batteries.

Umicore has long been a leading supplier of key materials for rechargeable batteries used in portable electronics as well as hybrid and electric cars. Ni

With an installed capacity of 7,000 metric tons per year, the UHT furnace in Hoboken is one of the largest dedicated recycling installations for Li-ion and NiMH batteries in the world. 7,000 mt =

± 250,000,000
Mobile phone batteries

± 2,000,000
E-bike batteries

± 35,000
EV batteries

WORLD BATTERY SALES

The world battery industry reached sales of US$ 65 billion in 2016 and has seen 5% average annual growth in 1990-2016. Cathode active materials usage having grown from 6,900 tons in 2000 to 178,000 tons in 2016 is another reflection of the significant growth in this industry. Strong demand for a variety of products using batteries, such as portable electronics, cellular phones, E-bikes, power tools, E-buses and others drive this development. Lithium ion battery sales grew in volume by 22% per year between 2006 and 2016. For the time period 2016-2025, Avicenne Energy forecasts compound annual growth of 13% per year for sales of lithium ion batteries.

Batteries improve air quality in underground mines

Next-generation nickel-based battery technologies and the potential they hold in underground mining

Ventilation currently represents around 50% of underground metal mines' overall energy costs. Producers are looking to go deeper and still remain economic, while also eliminating fine diesel particulate matter from the underground work environment. Couple these aims with the need to achieve clean-energy targets and it's clear that there are a myriad of drivers for the introduction of battery-powered vehicles that are engineered for life underground.

"Interest is coming from two sources," says Jani Vilenius, director of research and technology development, PA Rock Drills and Technologies, at Sandvik Mining and Rock Technology, one of the first OEMs to introduce a battery-propelled drill rig. "Battery technology is being applied more widely in other industries and, for that reason, its applicability in mining is also being questioned, creating a technology push.

"On the other hand, future mining conditions are going to be even tougher than today, creating the need for greener and more efficient technologies. Battery cell production has ramped up in recent years to be ready for the automotive and green-energy industries. The mining industry has acknowledged that an improved work environment with better air quality, plus the application of new battery technologies, may enable an increase in the productivity of underground units, giving the ingredients for a new way of mining."

What's available?

Batteries of some sort or design have been around in mining for decades. However, with advances in chemistry and associated technologies such as DC motors and charging technologies, what exists now are batteries that are much more suitable for the underground mining environment.

ISTOCKPHOTO.COM © GKUNA

There are three types currently in use:

- Lead acid;
- Sodium-nickel chloride; and
- Lithium ion: a subcategory that includes lithium iron phosphate (LFP), lithium titanate (LTO) and lithium nickel-manganese-cobalt (NMC).

Each has its strengths and weaknesses based on the specific application.

Traditional lead-acid batteries have been used in mining for a long time, mainly in soft-rock applications such as coal, salt and potash. However, their widespread use has been stunted by their large size and heavy weight, limited energy and power capacity, limited cyclic life of the batteries and questionable safety credentials.

Many modern battery technologies are now still being pilot tested, but others have been accepted by the industry and market interest is increasing. These include different lithium ion (Li-ion) formulations and sodium-nickel chloride technology. Li-ion technologies include several chemistry alternatives; the most attractive for mining applications include LTO, LFP and NMC.

"Fast rechargeable LTO batteries seem favourable for loading and hauling products as they give the possibility for rapid charging, cyclic longevity and superior intrinsic safety features," explains Vilenius. "Sodium-nickel chloride batteries also seem favourable for mining due to their high safety level and excellent volumetric energy density, providing sufficient operation time and range."

US-based OEM MacLean Engineering launched its Fleet Electrification programme in 2015, based on NMC battery technology. The effort resulted in three completed builds in 2016—two battery-powered underground Bolters and one battery-powered Boom Truck.

▽ *MacLean Engineering's EV BT3 Boom Truck utilises NMC battery technology*

STUART LISTER

SANDVIK

△ *Sandvik's DD422iE drill rig*

Anthony Griffiths, MacLean's product manager, explains: "The [NMC] chemistry that we have chosen for powering our fleet has easily doubled and, in some cases, tripled the total life cycle and number of charging cycles that a traditional lead-acid battery can provide."

Sandvik has two battery technologies in use at the moment. "No single technology can today fulfil the needs of different applications, so application needs to drive technology selection," says Vilenius.

"However, our number one selection criterion is safety. For applications needing lower power and higher energy-capacity-per-volume, sodium-nickel chemistry is used. For high power, LTO chemistry is used."

Vilenius acknowledges that there is a continuous need for higher-energy capacity batteries, but no promising solutions are available in the near future. "Battery technology selection is a multivariable question with technical and financial aspects," he says. "If some of the current high-energy alternatives were chosen, good properties such as safety would be compromised."

JAMES HODGINS, MINING INDUSTRIAL PHOTOGRAPHER

▽ *MacLean Engineering's EV 975 Omnia Bolter*

Looking forward

Currently, the vast majority of underground mining equipment is powered by diesel. However, every major miner in the world is evaluating the use of battery-powered machines. Several have projects underway to deploy battery-based equipment for large-scale production operations and these will help drive broader market acceptance.

"Mining executives are telling us that they know the industry is moving away from diesel and toward zero-emission equipment for underground use," says Mike Kasaba of Artisan Vehicle Systems. "The tipping point for the entire industry will be driven by success stories from soon-to-be-announced large-scale deployments.

"We believe that by 2020 all RFPs [request for proposals] for underground operations will request only zero-emission equipment and any remaining diesel equipment will be phased out soon thereafter." Ni

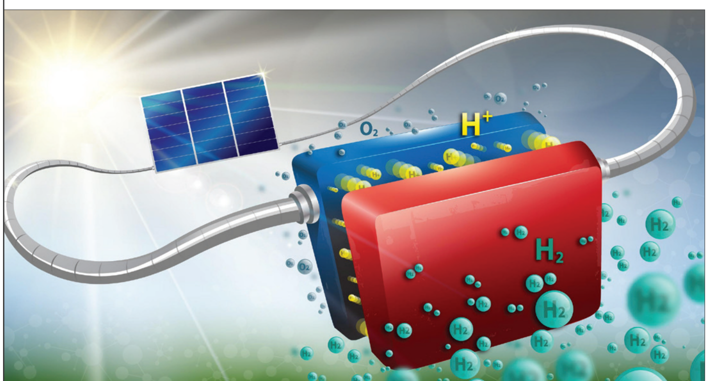
This article is abridged from "Propelling UG mining into tomorrow" by Carly Leonida, published in Mining Magazine, Jan-Feb 2017 issue.

WHEN THE SUN DOESN'T SHINE

Nickel catalyzes low-cost solution for storing solar energy

How do we store solar energy for periods when the sun doesn't shine? We do know that solar energy can be stored by converting it into hydrogen. The problem? Current hydrogen-production technologies have given promising results in the lab, but they are still too unstable or expensive and need to be further developed to use on a commercial and large scale.

The good news is that researchers at École Polytechnique Fédérale de Lausanne and Swiss Center for Electronics and Microtechnology have now designed a device that outperforms in stability, efficiency and cost, using commercially available solar cells and none of the usual rare metals.



The approach taken by the researchers is to combine components that have already proven effective in industry in order to develop a robust system.

Their prototype is made up of three interconnected, new-generation, crystalline silicon solar cells attached to an electrolysis system that does not rely on rare metals.

The electrochemical part of the process requires a catalyst made from nickel, which is much less expensive and widely available.

Hydrogen that goes the distance

The device converts solar energy into hydrogen and has already run for more than 100 hours straight under test conditions. The method, which surpasses previous efforts for stability, performance, lifespan and cost efficiency, is published in the *Journal of The Electrochemical Society.*

"A 12-14m^2 system installed in Switzerland would allow the generation and storage of enough hydrogen to power a fuel cell car over 10,000km every year", says Christophe Ballif, who co-authored the paper. "In terms of performance, this is a world record for silicon solar cells and for hydrogen production without using rare metals." Ni

EARTHQUAKE-RESILIENT BRIDGE

made possible with nickel-titanium smart technology

△ Two super earthquake-resilient columns are part of a new exit bridge ramp on a busy downtown Seattle highway. They are built to shake and flex in a large earthquake and remain standing and usable.

Rods of a super-elastic nickel-titanium alloy, commonly called Nitinol, containing about 55% nickel and bendable concrete composites have been used for the first time, in downtown Seattle, USA. A bridge that bends in a strong earthquake and not only stays standing, but remains usable, is making its debut in its first real-world application as part of a new exit bridge ramp on a busy downtown Seattle highway.

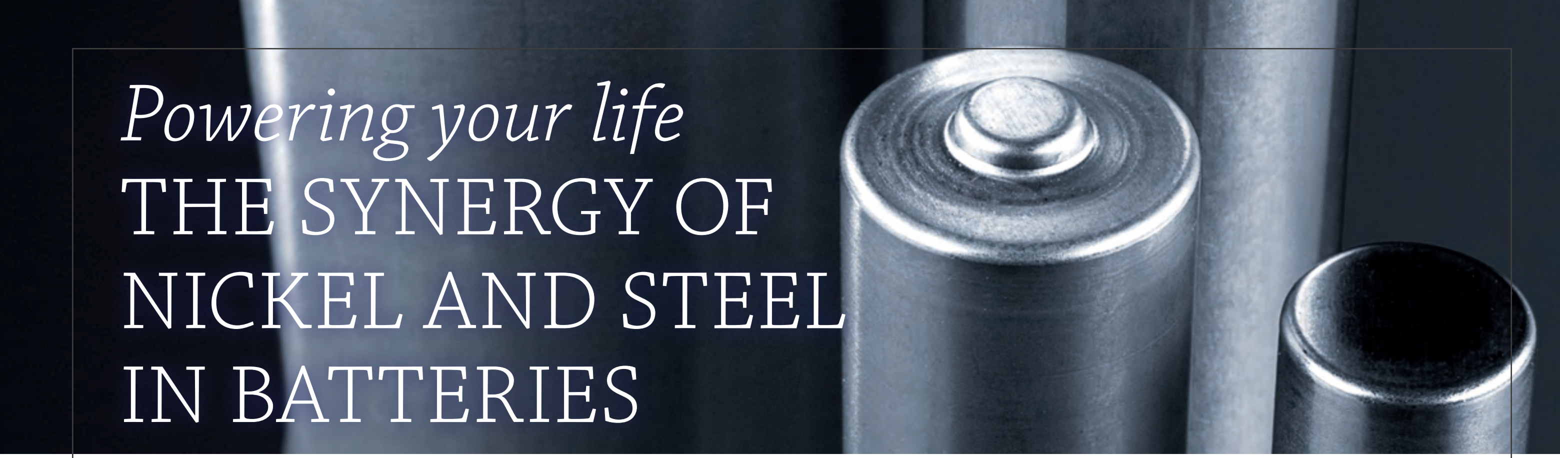
Modern bridges are designed not to collapse during an earthquake, and this new technology takes that design a step further. In the earthquake lab tests, bridge columns built using shape memory nickel-titanium rods and a flexible concrete composite returned to their original shape after an earthquake as strong as a magnitude 7.5.

"We've tested new materials, memory-retaining metal rods and flexible concrete composites, in a number of bridge model studies in our large-scale shake table lab. It's gratifying to see the new technology applied for the first time in an important setting in a seismically active area with heavy traffic loads," explained Saiid Saiidi, civil engineering professor and researcher at the University of Nevada, Reno. "Using these materials substantially reduces damage and allows the bridge to remain open even after a strong earthquake."

Saiidi, who pioneered this technology, has built and destroyed, in the lab, several large-scale 200-ton bridges, single bridge columns and concrete abutments using various combinations of design and innovative materials including the A-titanium rods in his quest for a safer, more resilient infrastructure.

"We have solved the problem of survivability, we can keep a bridge usable after a strong earthquake," Saiidi said. "With these techniques and materials, we will usher in a new era of super earthquake-resilient structures."

"This is potentially a giant leap forward," Tom Baker, bridge and structures engineer for the Washington State Department of Transportation, said. "We design for no-collapse, but in the future, we could be designing for no-damage and be able to keep bridges open to emergency vehicles, commerce and the public after a strong quake." Ni



TATA STEEL

Powering your life
THE SYNERGY OF NICKEL AND STEEL IN BATTERIES

Nickel plays a major role in many of the battery systems available on the market today that simplify life and provide freedom from electrical outlets.

But whatever the chemistry, nickel has another lesser known—yet important role in battery production when used in combination with steel on the cylindrical cans and covers that protect the battery interior. This nickel-plated-steel configuration ensures the power in the batteries is transferred to the device efficiently, whenever it is needed.

A cylindrical can provides a robust design to guarantee the cell integrity. Volume expansion and contraction during (dis)charge can be accommodated by the strength of the steel and these cylindrical nickel-plated steel cans have found widespread application in single use and rechargeable systems.

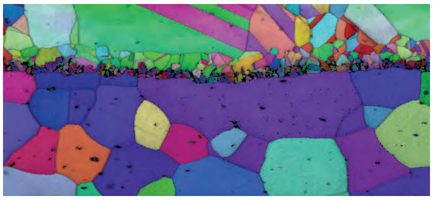
Low contact resistance is achieved by depositing a few microns of nickel on the top and bottom surface of the steel strip. Tata Steel Plating has perfected this technique with their state-of-the-art plating lines. After electroplating, the coils are heat treated. This treatment reduces the contact resistance and enhances the adhesion for the high speed can-making that follows. Besides electrical properties, the nickel also provides an excellent corrosion protection against the caustic inside of the cell. This limits the potential for gassing that puts the construction under significant pressure over its lifespan.

> ...the role that nickel and nickel-plated steel play in the performance and reliability of all types of battery systems cannot be overstated.

The cans are produced by transforming the strip in a number of drawing steps using high speed precision stamping presses. Cans are then shipped to battery producers around the globe.

Besides good properties during deep drawing and in the cell performance, nickel is also important during cell assembly as it provides good welding behavior.

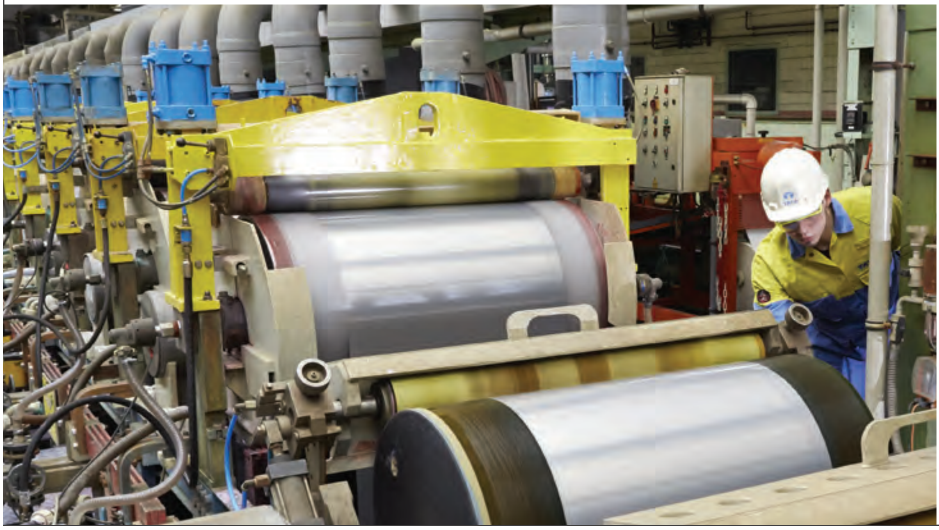
"Even though batteries are oftentimes taken for granted, the role that nickel and nickel-plated steel play in the performance and reliability of all types of battery systems cannot be overstated" says Dr. Marcel Onink, Commercial Innovation Director at Tata Steel Plating. "Today, the biggest volume is in alkaline batteries. However, in the future this successful combination can be expected to further be present with the strong growth of electric vehicles. Whatever the final chemistry of the cell, most likely it will be packaged in the proven concept of steel with a nickel deposit". Ni



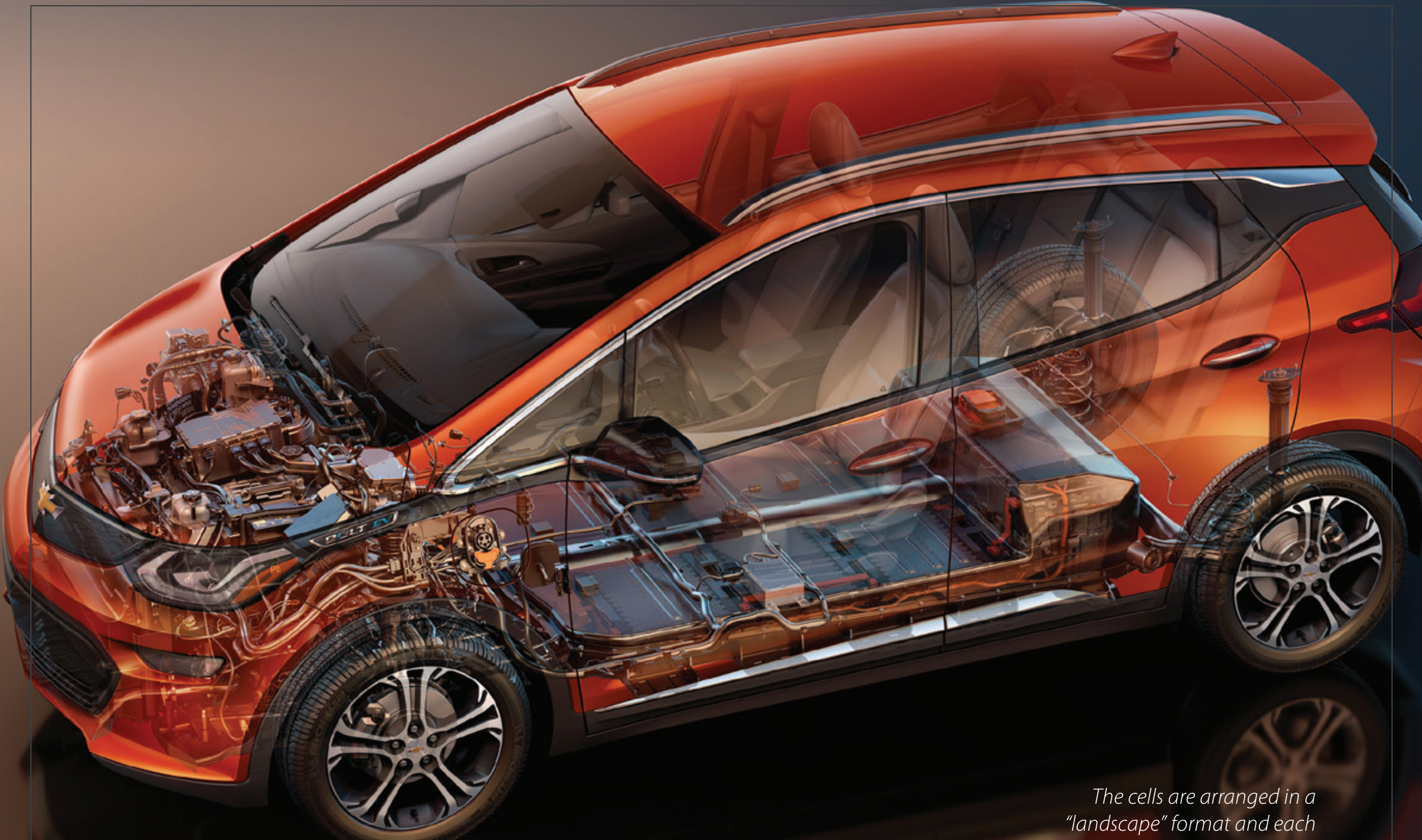
TATA STEEL

◁ *Heat treated Nickel deposit (top) on the steel strip (bottom) with a fine grain diffusion zone (middle)*

▽ *State-of-the-art nickel plating line*



TATA STEEL



UNIQUE CHEMISTRY A BIG BOOST TO EV BATTERIES

The cells are arranged in a "landscape" format and each measures in 100mm high and 338mm wide. ▽

HTTP://A.CHEVROLET.COM

How do you get a 320km range from an electric vehicle, propulsion of 0-100km/h in less than seven seconds, and the ability to charge it in 30 minutes for a range up to 145km? You use a nickel-rich lithium ion battery!

Powering the Bolt EV is a newly designed 60kWh lithium battery which resides in the floor of the car from the front foot well to back of the rear seat.

The nickel-rich lithium ion chemistry provides improved thermal operating performance over other chemistries, which requires a smaller active cooling system for more efficient packaging. The chemistry allows the Bolt EV to maintain peak performance in varying climates and driver demands.

Improved power and energy

"You usually have a battery cell that delivers either the desired levels of energy or power, but not traditionally both. With this cell design and chemistry we were able to deliver a battery system with 160 kilowatts of peak power and 60 kilowatts hours of energy," said Gregory Smith, Bolt EV battery pack engineering group manager.

The cells are arranged in a "landscape" format and each measures in at only 100mm high and 338mm wide providing improved packaging underfloor. The lower profile cell design enabled the vehicle structure team to maximize interior space.

> With this cell design and chemistry we were able to deliver a battery system with 160kW of peak power and 60kW hours of energy

"Being the leader in range and affordability means nothing if the car isn't going to excite you each time you get behind the wheel," said Josh Tavel, Chevrolet Bolt EV chief engineer.

"That's why the team was tasked with delivering a propulsion system that would also make the Bolt EV an electric vehicle that owners would love to drive."