

NICKEL

THE MAGAZINE DEVOTED TO NICKEL AND ITS APPLICATIONS

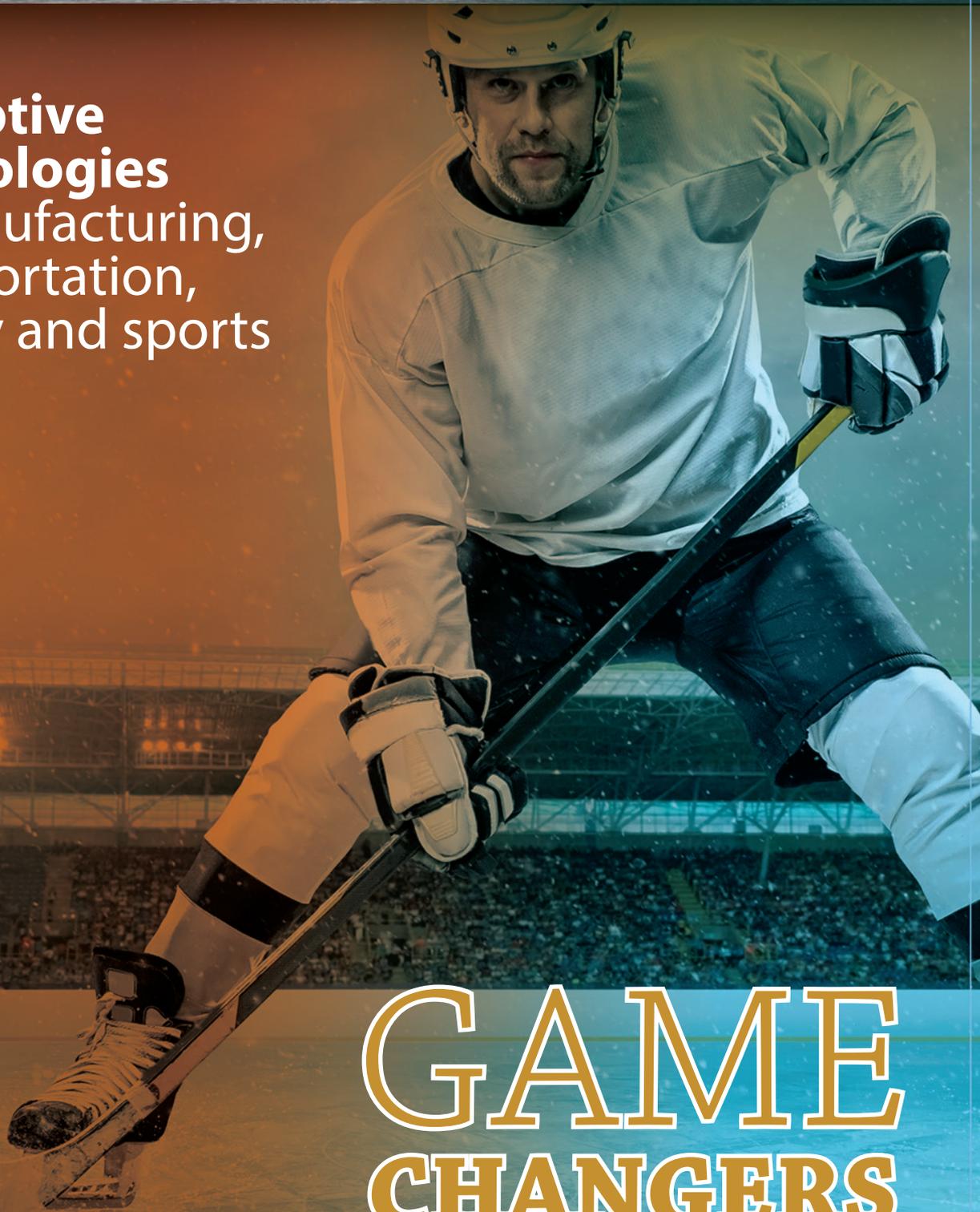
Small batteries, big
advances for Tesla

Additive manufacturing –
bringing space flight down
to earth

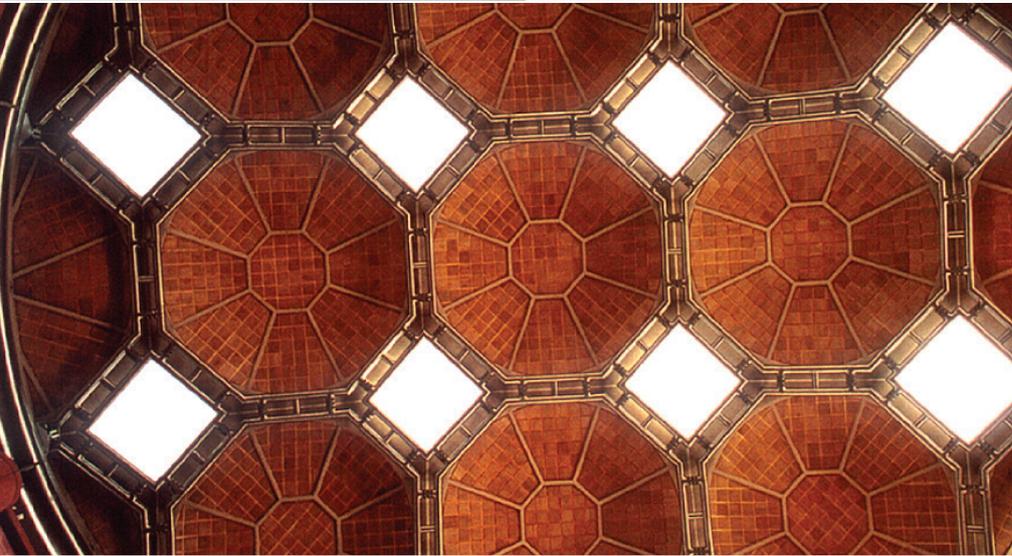
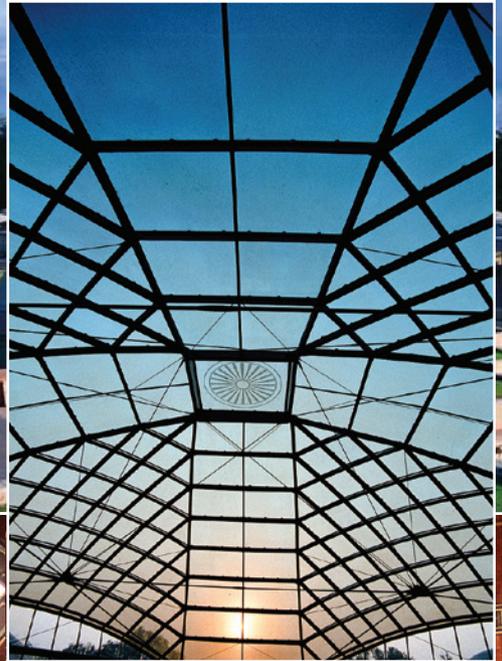
Greener ethanol

July 2014, Vol. 29, N° 2

**Disruptive
technologies**
in manufacturing,
transportation,
energy and sports



**GAME
CHANGERS**



△ New Delhi Parliament Library Domes △ Internal view of the VIP dome
▷ Central focal dome made of stainless steel and glass

CASE STUDY 02 PARLIAMENT LIBRARY BUILDING DOMES

The Parliament Library building in New Delhi, India, was completed in 2002. The twelve individual domes which make up the roof are the prominent features, each of different dimensions, designs and materials. Two are made from glass and nickel-containing stainless steel, chosen for its durability and low maintenance as well as its excellent corrosion resistance and aesthetics.

The library was intended to be contemporary yet harmonious with the adjacent 1920s Indian Parliament building. The result is a four-storey construction, two floors of which are above ground.

After consultations with Nickel Institute and the Indian Stainless Steel Development Association, austenitic grade Type 304L (S30403) stainless steel was selected. Around 350 tonnes have been used for many diverse applications such as the domes' structural members, cramps for fixing the cladding, handrails, library stacks and fittings and furnishings. 

This article has been adapted from a series of Structural Stainless Steel case studies produced on behalf of Team Stainless by SCI and available for download from www.nickelinstitute.org

DOMES OF DISTINCTION

The central focal dome spans 25m with a rise of 4.2m and comprises a lattice of stainless steel tubular members and cables converging at key tension cast nodes. There are four curved triangular 'petals' inter-supported through four ladder purlins which are joined at the top by a rectangular compression element. Each petal is a grid of stainless steel tubes with an outer diameter of 101.6mm and 10mm in thickness. The overall stability is ensured through a network of tension rods. All joints in the framework, which appear simple and elegant, were cast in foundries and connected to the tubes by a combination of high strength preloaded (slip resistant) bolts and welding. The entire structure is clad with insulated glass elements which allow natural light into the central part of the building.

The second dome containing stainless steel, known as the VIP dome, has a diameter of 16m and a height of 2.5m. It contains stainless steel tubes shaped into a combination of nine octagons and 12 squares. To fit these shapes onto a truly spherical surface, the octagons were slightly distorted and covered with a fibre reinforced concrete shell clad with sandstone and granite, held by stainless steel cramps. The squares are clad with glass panels. The entire structure is supported on a ring beam through articulated pin joints at 16 locations. The ring beam is further supported on eight circular columns.

The novel design and construction of the domes is the first of its kind in India.

NICKEL

The Magazine Devoted to Nickel and its Applications

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THE GAME CHANGERS

Whether it was the assembly line of Henry Ford or the ‘green revolution’ in cereal production initiated by Nobel Laureate Norman Borlaug, ‘game changers’ are real events initiated by real people.

Another name and event that is earning game changer status is Elon Musk with his re-invention of the electric automobile. In *Driving to Lower Carbon Living* on page 12, read how the electric car and everything that goes into it is seriously threatening the carbon-based status quo.

And in May of this year, ground was broken for a Tesla-Panasonic ‘gigafactory’ that, by 2020, will be producing annually – just to meet Tesla’s needs – more than three billion nickel-cobalt-aluminum lithium ion cells similar to those pictured above.

After many decades of relative calm and incremental changes, the game is changing too in electricity.

The energy mix is becoming more complex even as climatic challenges become more intense. The integration of non-carbon energy sources, most notably wind and solar, increases the complexity of managing electrical grids. Starting on page 10, you will see that no matter how the energy game changes, nickel will have roles – sometimes leading, sometimes supporting – to play.

The whole business of 3D printing or additive manufacturing as it is known in the industrial world has moved from laboratory experimentation to marketable products.

This has truly disruptive potential, especially when nickel superalloys can be used to make complex parts that would otherwise be much more expensive or even impossible to make to the same tolerances, either as one-off prototypes or in commercial production. One example is the combustion chamber of the SuperDraco engines of SpaceX Incorporated where Elon Musk – again – is threatening to drastically change how we go into space.

Turn to our article on page 8 to catch up with some of the latest developments in biofuels, another area where a game changing revolution is taking place, enabled by nickel-containing materials.

And yes, we confess, the use of nickel in ice hockey and other sports gear was irresistible when we were looking for game changing products and technologies.

On our back cover look for the Kelpies. As works of public art and as cultural images made real, the Kelpies are extraordinary. Not, perhaps, a game changer but like all the stories in this issue, a vision made possible through the use of nickel-containing materials.

Clare Richardson
Editor, *Nickel* magazine



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3D PRINTING

bringing opportunities across the board

Three dimensional (3D) printing received the ultimate accolade last year when, in his State of the Union address, President Obama said it had the potential to revolutionise the way in which we make almost everything; what he might have said was, it's a potential game changer.

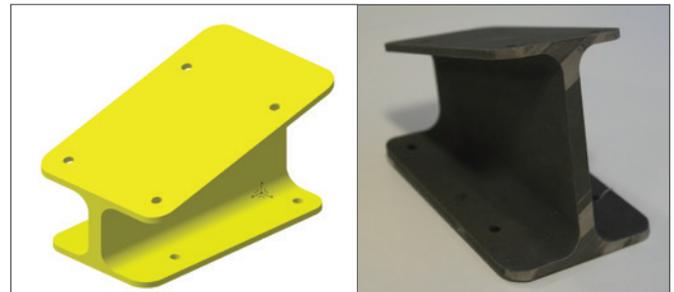
In the industrial world, the preferred term for 3D printing is Additive Manufacturing (AM). Although it's been around since the early 80s, it's only in the last few years that it has hit the headlines. One reason is the drop in prices of desktop-size printers and the media has hailed 3D printing as the future manufacturing option of choice for everything from machine parts to medical implants and from buildings to bikinis.

The initial focus for 3D printing was on rapid prototyping of plastics and polymers but more recently, there has been more emphasis on the 3D printing of metals.

This brings a change from current manufacturing methods whereby raw materials are cut, drilled or filed (i.e. reduced) to produce the desired shape, to 'additive' processes where layer upon layer of a raw material is sequentially added to produce an object.

Although there are several processes that fall under the banner of 3D printing, typically they start with a design team that prepares sketches of the desired final product. This computer-aided design (CAD) file acts as the blueprint for the process. The 'printer' takes the information from the CAD file and creates thinly-sliced, horizontal cross-sections of the eventual object that are then printed layer upon successive layer.

While there are many types of 3D printing, there are three predominant techniques applicable to metallic additive manufacturing. The first and most common method for stainless steels and nickel alloys is powder



△ Isometric rendering of a metal camera bracket

△ Final 3D printed version of the metal camera bracket

bed fusion, where thermal energy selectively melts or fuses (sinters) regions of a powder bed. The part will then often undergo further processing. The second and less common type is directed energy deposition, where thermal energy, usually a laser beam, fuses the powder by melting it as it is being deposited. A third type of metal printing commonly performed is known as binder jetting. In this process stainless steel powder is laid down loosely followed by a binder solution which when dried by a heating lamp holds the powder together. The binder is then cured in an oven. The porous and still fragile part is then put into a box containing bronze powder, which when baked at high temperature, will melt and infuse into the part so that it will become 99.9% dense. However, the part is composed of stainless steel powder held together by bronze, so that its properties are quite different from stainless steel alone.

One version of powder bed fusion is GE Aviation's Direct Metal Laser Melting (DMLM). Steve Rengers, Metal Additive Manufacturing Principle Engineer for GE Aviation, says there's been a lot going on behind the scenes since around 2005, but it's only recently that the plans have become public. Already, GE Aviation is committed to provide 'printed' fuel nozzles within the combustion system of the LEAP (Leading Edge Aviation Propulsion) jet engine. By 2020, it expects to have made over 100,000 parts by DMLM for their engines.

GE uses a range of metal alloys for AM, including nickel alloys such as 625 (UNS N06625) and 718 (N07718), as well as stainless steels such as 17-4PH (S17400) and 316L (S31603). Nickel superalloys have exceptional high temperature strength and a high resistance to corrosion, which makes them useful in aircraft or land-based turbine engines.

Rengers adds that GE has developed many proprietary materials over the years, alloys that will be now made as powder so they can be used in the additive manufacturing process. "This will allow the manufacture of shapes that couldn't be made previously."

BAE Systems' Matt Stevens, Additive Manufacturing Capability Development Team Leader, says that his company has been involved in additive manufacturing for 15 years, especially in the non-metallic

ASTM definition of additive manufacturing

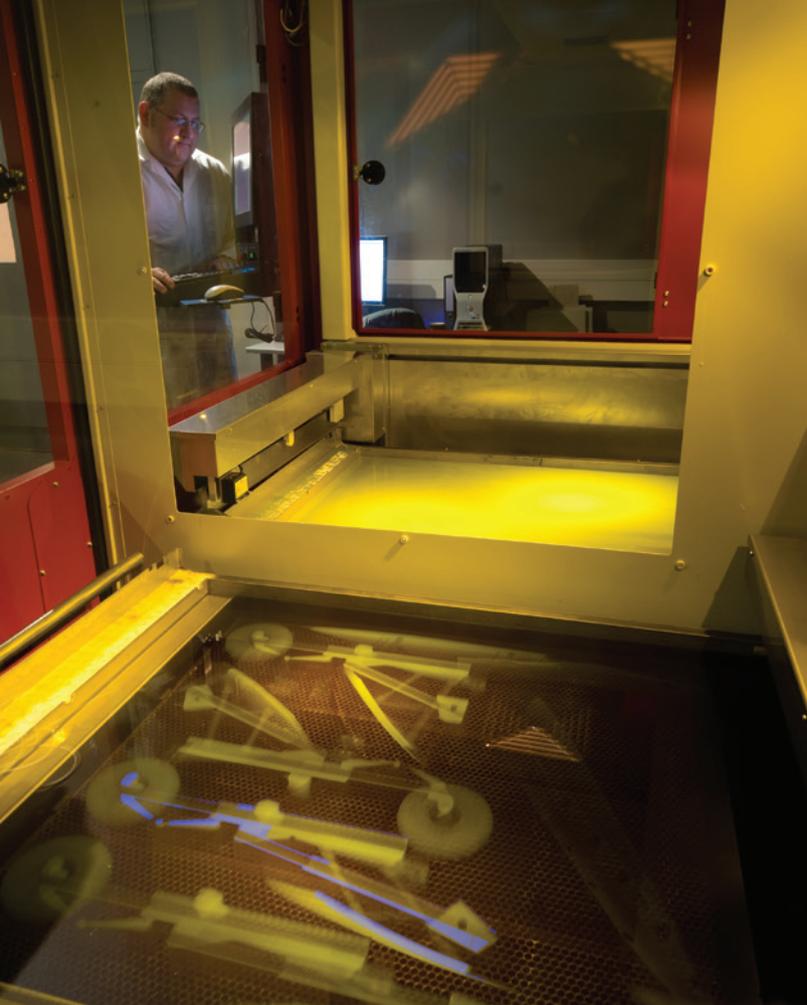
The process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining.

Benefits of additive manufacturing

- Less waste
- Faster production
- More complex designs
- Very small production runs, even one-offs
- Useful for prototypes
- Lighter parts suitable for aerospace applications

The 3D printing marketplace

- The market grew by more than a third in 2013
- The global products and services market for 3D printing was estimated to be around \$3 billion in 2013



△ Machine and operator at BAE Systems, Warton, UK

arena. More recently, BAE has been working in the powder bed fusion area – for the manufacture of ground support equipment and wind tunnel modelling.

Stevens emphasises that 3D printing is good for complicated shapes – due to the flexibility in design, especially for scale models of parts. For larger scale parts, BAE Systems is collaborating with Cranfield University in the U.K. RAF Tornado fighter jets have recently flown with a BAE metal 3D printed part – a bracket for holding a camera. Stainless steel 316L is one of the main materials used by BAE in this area.

Robert Scudamore, member of the Additive Manufacturing Sub-Platform Committee of the MANUFUTURE European Technology Platform, feels that additive manufacturing will be a game-changer in niche areas, especially where there is a need for complex design.

Scudamore sees the main areas for growth as aerospace and medical
cont'd on page 6

Nickel use in 3D Printing

Alloys 718 (53% Ni) and 625 (60% Ni) as well as a number of proprietary nickel-based superalloys are now also being used in Additive Manufacturing (AM) for high temperature applications. After printing, they undergo additional processing such as HIP (Hot Isostatic Processing). Stainless steels such as 316L (12% Ni) are used in AM for parts in less severe service. Theoretically any stainless steel alloy could be printed.



△ A view of the second generation Dragon II spaceship

△ There will be four pairs of these nickel superalloy engines powering each Dragon II capsule

Rocket science

SpaceX designs was founded in 2002 to revolutionize space transportation, with the ultimate goal of enabling people to live on other planets. Today, SpaceX is advancing the boundaries of space technology through its Falcon launch vehicles and Dragon spacecraft. And nickel is playing an important role.

The company has developed the SuperDraco thruster, an engine that will power the Dragon spacecraft's launch escape system and enable the vehicle to land propulsively on Earth or another planet with pinpoint accuracy.

The SuperDraco engine chamber is manufactured using direct metal laser sintering (DMLS), a version of the powder bed fusion 3D printing technique. The regeneratively cooled chamber is printed in a high-performance nickel superalloy that offers both high strength and toughness for increased reliability. Unlike previous launch escape systems that were jettisoned after the first few minutes of launch, SpaceX's launch system is integrated into the Dragon spacecraft. Eight SuperDraco engines built into the side walls of the Dragon spacecraft will produce up to 54,400kg (120,000lb) of axial thrust to carry astronauts to safety should an emergency occur during launch.

"Through 3D printing, robust and high-performing engine parts can be created at a fraction of the cost and time of traditional manufacturing methods," said Elon Musk, SpaceX's Chief Designer and CEO. "SpaceX is pushing the boundaries of what additive manufacturing can do in the 21st century, ultimately making our vehicles more efficient, reliable and robust than ever before." **Ni**

3D Printing

cont'd from page 5



GE AVIATION

implants. However, he reasons that although these areas have the most potential, they are also those with the most risk and the most barriers to certification. Each 3D-printed part has to go through a rigorous testing and certification programme which can be a barrier to entry.

Scott McGowan, VP of Marketing at California-based Solid Concepts says another barrier for the industrial usage of AM is the cost of entry, which he puts at "something like a million dollars" for an industrial-level machine and supporting technologies. Additive manufacturing is seen as complementary to traditional manufacturing technologies as post-machine work is often necessary. However, GE Aviation's Rengers forecasts that in the next five years there will be dramatic changes in the economics of the additive manufacturing process.

In that sense, these are early days for 3D printing. But companies like GE Aviation and BAE Systems are integrating it into their advanced manufacturing processes to bring new products and solutions to the global marketplace.

Rengers says that additive manufacturing is a 'disruptive technology' as GE Aviation will be able to 'grow' a part that was previously only able to be manufactured by a more complicated technique or process. For his part, Stevens says BAE Systems will be able to make parts not just quickly, but at the location where they will be required. For Rengers, that's a new way of working and he says it's a great challenge in a safety-conscious industry.

So, whichever way you add it up, 3D printing is changing the game. Ni

ELECTROPLATING

LESS MATERIAL,

Nothing upsets an ice hockey player more than having a stick break at a critical scoring moment. But now, nanotechnology and nickel offer players a lightweight stick with the performance associated with modern composites and with significantly increased strength.

Integran Technologies of Mississauga, Ontario, Canada, has been able to advance traditional electroplating processes. Under the name Nanovate™, they offer advanced metallic materials technology based on nickel (nickel-cobalt, nickel-iron), cobalt-phosphorous and copper alloys for a wide variety of applications – including ice hockey sticks.

Integran's various complementary technologies focus upon the engineering of the internal structure of materials on a near-atomic scale to yield 'super materials' which meet the demanding performance requirements of new products. Standard Watts or

sulphamate nickel electroplating systems result in as-deposited tensile strengths up to 435MPa (63ksi) and 610MPa (88ksi) respectively. The Nanovate nickel offers a tensile strength of 1300MPa (189ksi) and nanocrystalline nickel-cobalt and nickel-iron products have tensile strengths of 1600MPa (230ksi).

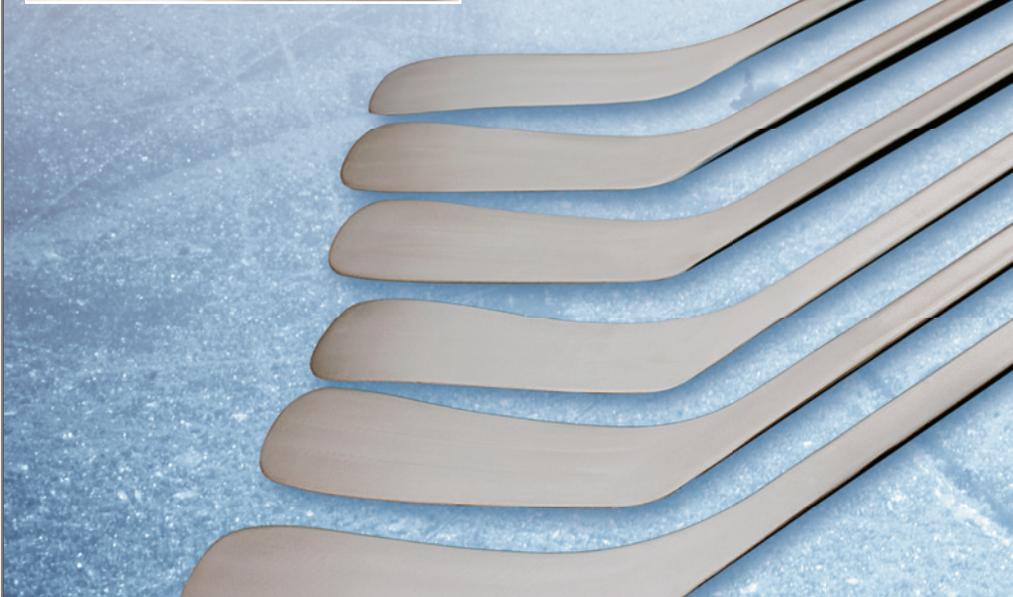
Changing the games

It's perhaps not surprising that a Canadian company, PowerMetal Technologies Inc., has applied the Nanovate coating to ice hockey sticks. After impact, a standard carbon composite hockey stick has a bend strength of about 120kg. The residual strength of a Colt hockey stick plated with nanocrystalline nickel is increased by 50% to 180kg, resulting in a longer life expectancy.

In cycling, for the Tour de France, Cervélo Cycles of Toronto, Canada, uses a Nanovate metal reinforced composite product in one



◁ Thousands of hours of testing and use show that the flex of the nanocrystalline nickel plated ice hockey sticks remain unimpaired. In addition the strength, compared to standard composite sticks, is increased by 50% without compromising weight or balance. ▽



AND NANOTECHNOLOGY

MORE STRENGTH

of its steering tube/fork assemblies to give longer life and maximize the toughness of its lightweight frame structures.

And in golf, two winners of United States Masters tournaments and a US Open have been assisted with nickel-iron nanocrystalline-coated club shafts.

Industrial applications

Nickel has long been associated with electromagnetic (EM) shielding but there can be issues with complex shapes, or environments where shock and vibration can be expected. Again, nickel-iron nanocrystalline finishes are providing robust and effective EM shielding for critical electronic components.

In addition to high strength, hardness and durability, nano-grain nickel, nickel-iron and nickel-cobalt present a product with superior chemical and laser etching. As embrittlement is not an issue, cleaner

edges and sharper subsequent final products for solder stencils and electronic devices are achieved.

Many special engineering plastics can be activated so that they are ready to receive high strength nano-coatings that conform to the original shape faithfully. This results in a lightweight composite product which is a low cost alternative to machined aluminum. For example, 100µm (0.004in.) thick nanonickel plated on glass filled nylon results in a 30% weight saving compared to aluminum.

Nanovate NV™ (Nanovar), a 36% nickel-balance iron nanocrystalline fully dense deposit, with very high hardness, finds application in carbon composite layup tooling. Here a 200µm (0.008in.) skin gives engineers a lightweight and strong product with associated weight savings and zero coefficient of thermal expansion.

Size matters

- Polycrystalline metal has a grain size generally in the range of 10µm (micrometers) or 390 microinches
- Nanocrystalline metal grain size ranges from 10-100 nanometers (0.39-3.9 microinches)
- Nano, symbol n, means billionth and denotes a factor of 10⁻⁹
- The huge reduction in grain size results in many unique structural and functional properties

Industrial nano-technologies using nickel are doing more with less: more safety, more performance, longer life and less material. And in sport, nickel-based nano surfaces are giving both amateurs and professionals better tools for their game. It is still up to them, of course, to put the puck in the net. **Ni**

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INTEGRAN TECHNOLOGIES



△ Tennis racket
△ Bicycle

◁ For every piece of sporting equipment there are key performance considerations. Depending on the needs, nano-plating can add strength without adding weight, add durability without diminishing flexibility. Amateurs and professionals alike can have the best tools for the job and within the rules that govern their equipment.



Golf putter ▷
Baseball bat ▷

REALLY GREEN ETHANOL

enabled by nickel-containing alloys

The use of food crops for the production of fuel is somewhat controversial. 2014 will see, however, the commissioning of the first commercial-scale cellulosic ethanol production facilities that will increase the utilization of plant waste, reduce competition for food crops and provide a substitution for fossil fuels. And nickel-containing alloys are central to this game-changing revolution.

Evolution of an industry

The current dominant ethanol production process involves the fermentation of sugars and starches in food crops such as sugar cane, corn, potato and cassava. These raw materials have short molecules which are quite easily digested by enzymes and are the feedstock for the first generation ethanol industry.

Major research has taken place over the last decade to find a way to be able to use agricultural waste products, such as the corn stover (stalks, leaves and other residue) and sugar cane bagasse (plant mass after the removal of sugar). The unutilized sugars contained in these types of biomass are made up of long molecules of polysaccharides which cannot easily be converted into ethanol by simple fermentation. In addition, cellulose and hemicellulose are entrapped in a matrix of lignin, preventing the enzymes' access to the sugars and thus their transformation into ethanol.

The key is a pre-treatment phase to be integrated into the production process. Numerous pre-treatment process designs were developed using either acid or enzymatic hydrolysis or a combination of both; or thermo-mechanical technologies. The challenge was to move such technologies from small scale pilot and demonstration plant production to cost-efficient commercial scale production.

Commercial viability

The first company to reach commercial scale production of cellulosic ethanol was Beta Renewables in Crescentino, Italy. Its patented Proesa™ process technology subjects the biomass to high temperature and pressure, enabling the necessary separation of the cellulose and hemicellulose from the lignin, followed by subsequent enzymatic treatment releasing simple sugars which are fermented by yeast into ethanol. The lignin and biogas derived from the processes are recovered and used as fuel in the boiler, generating heat and power.

Construction of the Crescentino plant started in 2010 and became operational in 2012. Its success has given confidence to others and as a result cellulosic ethanol plants are presently under construction in the US (Alpha Project and CanEnergy) and in Brazil (Granbio), using energy grasses, wheat straw and corn stover as feedstocks. In early 2014 the technology was also licensed in China (Fuyang Bioproject).

Many other industry participants have also progressed to commercial scale production with their cellulosic ethanol process technologies: Inbicon in Denmark, Enerkem in Canada and Raizen in Brazil.

In the United States, commercial scale cellulosic plants will begin production in 2014: Abengoa Bioenergy in Hugoton, Kansas, Poet-DSM in Emmetsburg, Iowa and Dupont in Nevada, Iowa. The cellulosic ethanol will both be used as fuel and feedstock for the production of bio-based chemicals, a fast emerging industry. NI



The bio-based chemicals industry

A cost-competitive bio-based chemical industry is emerging globally using bio-renewable feedstocks instead of fossil-based ones. The demand for bio-chemicals is driven by both consumers and manufacturers concerned about long term sustainability of fossil fuels, as well as the environment.

Research activity is intense and some bio-based chemical process technologies have reached commercial scale production.

The bio-based chemicals industry is expected to grow at a compound annual growth rate of 12.4% between 2012-2021, bringing its value from US \$4.3 to \$12.3 billion.¹

There is increasing demand for standard bio-based chemicals such as lactic acid, glycerin-based chemicals and bio-plastics and additionally for new ones such as bio-methanol, bio-epichlorohydrin (ECH), bio-monoethylene glycol (MEG), bio-succinic acid and n-butanol/isobutanol.

With highly corrosive operating media, this industry will be relying on standard and specialty nickel-containing stainless steels for most production equipment. As an emerging industry with new process-related developments, appropriate material selection choices are crucial for economically viable commercial scale production and long term sustainability.

¹ World Market for Bio-Based Chemicals/2nd edition, SBI Energy



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Cellulosic Ethanol Production: **NICKEL'S ROLE**

A large share of the production equipment in any commercial scale ethanol plant is made from nickel-containing stainless steels such as Type 304(L) (UNS S30400 and S30403) and 316(L) (S31600 and S31603). They are the materials of choice for numerous applications as they offer corrosion resistance coupled with good strength, ductility, toughness and ease of fabrication. The ethanol industry appreciates the long maintenance-free performance of production equipment made from stainless steels.

For cellulosic ethanol production, the pre-treatment environments are harsh. This is especially the case in plants using acid hydrolysis, where the biomass is treated with diluted sulphuric acid at high temperature and high pressure. This operating environment is highly corrosive and often nickel alloys such as Alloy C276 (UNS N10276) and other G-type nickel alloys must be used.

Many pre-treatment process technologies are based on enzymatic hydrolysis. Depending on the biomass feedstock, physical or chemical methods will be used. Some of the most cost-effective technologies may involve a combination of both acid and enzymatic hydrolysis. Various stainless steel grades and nickel alloys are used in such operating environments: Types 316(L) and 316Ti (S31635), specialty stainless grades 904L (N08904), duplex 2205 (S32205), super duplex grades, such as 2507 (S32750), and super-austenitic 6% molybdenum alloys such as N08367 and S31254.

△ Sugar cane field

△ Advanced steam system in lignocellulosic ethanol pre-treatment system

△ Discharge device made from a nickel alloy

▷ Inside Iogen Corporation's ethanol plant

Greening power

how nickel is enabling the shift to low-carbon energy

Where and how the world finds its energy is changing. Yet how nickel-containing materials are enabling and supporting this dynamic process may not seem obvious until one looks closely.

By far the most important to date and with a long engineering and economic history is hydro power. It is there that the role of nickel-containing alloys in turbines, rotors, pumps and all the supporting engineering plant is understandably best known. The role of nickel and the role of hydro in providing enormous contributions of base load power is not going to change even as its percentage contribution to low-carbon renewable energy grids declines: there are only so many rivers, and hydro developments are not without their own environmental concerns.

Solar, wind and...

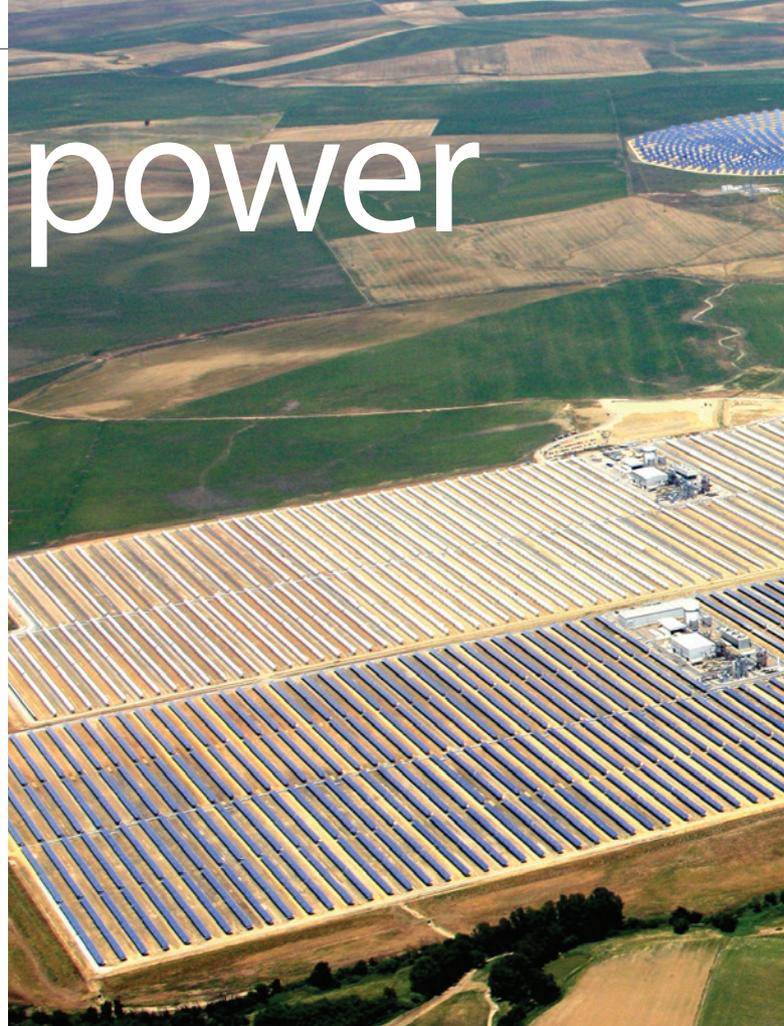
There are two classes of solar power technologies. The dominant and familiar technologies are the photovoltaic ones and while nickel has roles in the manufacture of panels and control equipment they are not essential to their functioning. Concentrated solar power (CSP) thermal technologies, however, are a different matter. The two main CSPs are parabolic troughs and power towers (see sidebar). They are industrial in scale and, depending on the technology, involve high temperatures, boilers and challenging fluids: molten salts or sea water. The enabling role of nickel is obvious because of its resistance to corrosion and high temperature strength. And while the photovoltaic technologies currently play the largest solar roles, the innovation and industrial potential of CSPs seems highest.

Wind turbines come in many shapes and sizes and while nickel-containing stainless steels are found in small turbines and in the fasteners that attach them to roofs or buildings, there are other nickel-containing alloys in the drive shafts, gear-boxes and generators in the familiar large wind turbines. The amount of nickel used in support of wind power generation increases when the turbines are mounted (or, in a few cases, floating) off-shore. Service platforms for the towers require the corrosion resistance of nickel-containing stainless steels or the anti-fouling properties of copper-nickel alloy 90-10 (UNS C70600).

▽ Solar tower part of the Solnova power complex



© ISTOCK.COM/TYPHOONSKI



Other challenging corrosion environments include the small but growing use and interest in tidal and wave power (with their salt water environments) and geothermal power where the hot water or steam (depending on the nature of the geothermal source) can be saline or sulphurous. Here again nickel-containing materials appropriate to the operating environments are needed and include stainless steels, high-nickel alloys, and copper-nickel alloys.

Future material needs

The energy picture is in flux and there are strong political, economic, and innovation forces at work that make it difficult to forecast the material needs of the energy industry as the technological mix changes.

Questions of materials supply and demand have led researchers to consider the implications of supply constraints to different economic and technical choices for energy production.¹ Of current scenarios in use by different institutions, two were modeled for the period 2010-2050: *Market First* (where economics have primacy) and *Policy First* (where governments take strong measures to achieve social and environmental goals).

The mix of energy sources shows dramatic differences. Note, however, that it doesn't matter which scenario or variation dominates by 2050. Nickel and nickel-containing materials and chemicals will be there to enable technologies and sustain the electrical grids upon which societies depend. Ni

¹A. Elshkaki and T.E. Graedel, *Dynamic analysis of the global metal flows and stocks in electricity generation technologies*, Journal of Cleaner Production, 2013



Concentrated solar power (CSP)

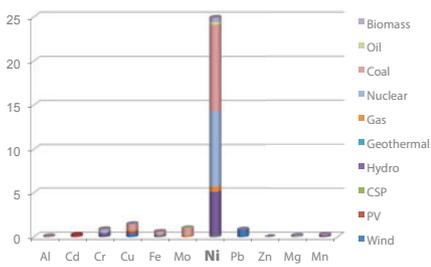
Some of the emerging technologies are not very familiar but are being intensely investigated even if they are not – yet – significant contributors to electrical grids.

A parabolic trough consists of a linear parabolic reflector that concentrates light onto a receiver. The receiver is a tube filled with a molten inorganic salt (with working temperatures between 150-350°C) which flows to produce steam for a conventional power generation system.

A solar power tower receives reflected sunlight from dual-axis tracking reflectors. The receiver, like a parabolic trough, has a working fluid such as a molten salt which can be heated to temperatures in excess of 1000°C and used to produce steam immediately or stored for use during periods of peak demand.

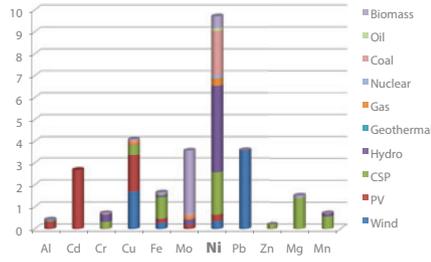
PHOTO © ABEŃGOA SOLAR

Market First



GRAPHS: A. ELSHKAKI

Policy First



△ *Nickel's Continuing Roles 2010-2050*
Average annual percentage of world nickel production going to energy in the **Market First** (25% of global production) and the **Policy First** (9.6%) scenarios (see page 10). Actual experience will fall between these two extremes but nickel's importance to the sector will remain.

△ *Not greenhouses in the foreground but a parabolic trough facility that produces steam for a conventional turbine. In the background two solar towers that heat a medium such as molten salt to very high temperatures. These facilities form the Solnova Solar Power Station, west of Seville in southern Spain.*

	Where's the nickel?	Why is it there?	Materials
Hydro	Turbines/rotors Pumps Pipes	Toughness, strength Toughness, strength Strength	Nickel steels Stainless steels
Wind	Turbines/rotors Towers Platforms (marine)	Toughness, strength Toughness, strength Strength, corrosion resistance	Nickel steels Ductile iron Stainless steels
Solar	Boilers, pipes, pumps (solar furnace)	Corrosion resistance, thermal strength	Nickel alloys Stainless steels
Biomass	Boilers, pipes, pumps	Corrosion resistance	Nickel alloys Stainless steels
Tidal	Turbines Structures	Corrosion resistance, strength, toughness Corrosion resistance, strength	Nickel alloys Stainless steels Copper-nickel alloys
Wave	Turbines Structures	Corrosion resistance, strength, toughness Corrosion resistance, strength	Nickel alloys Stainless steels Copper-nickel alloys
Geothermal	Boilers Turbines, pipes, pumps	Corrosion resistance, toughness, strength Corrosion resistance, toughness, strength	Nickel alloys Stainless steels



△ Model S is the main Tesla product in 2014. Depending on the choice of model it has a range of up to 500 km at 90 kph

Gigafactory Projected Figures	
2020 Tesla Vehicle Volume	≈500,000/yr
2020 Gigafactory Cell Output	35 GWh/yr
2020 Gigafactory Pack Output	50 GWh/yr
Space Requirement	Up to 10M ft ² w/ 1-2 levels
Total Land Area (acres)	500-1000
Employees	≈6,500

△ The gigafactory will produce in excess of 3 billion cells a year

Driving to lower carbon living

Elon Musk and his electric car

Tesla Motors and the driving force behind it, Elon Musk, have captured the attention of the world. Tesla is taking a 20th century idea and shows every sign of turning it into a disruptive force in the automotive world in the 21st century. The man and the machine collectively constitute a game changer, for which nickel is essential.

Battery Evolution

The battery industry is in a prolonged period of research, development and end-use specialization. At the same time, 'nickel' is disappearing from the name of the dominant battery chemistries in favour of 'lithium'. That, however, disguises the reality that nickel continues to contribute its unique qualities to most lithium-ion chemistries. Sometimes it will be a supporting role (the electrode tabs, for instance) but sometimes it is an essential component of the chemistry itself.

nickel continues to contribute its unique qualities to most lithium-ion chemistries

No battery chemistry is perfect, but for each application there will be one that is optimal. For a motive power battery pack the recent chemistries have been nickel-metal hydride (by far the most common), nickel-cadmium, LiFePO₄ and lithium polymer. Since 2012, however, the type 18650 (nickel/cobalt/aluminum – LiNiCoAlO₂ – commonly referred to as an NCA battery) has been the sole choice of the most electrifying all-electric car: Tesla's Model S and, late next year, Tesla's Model X SUV.

Battery Performance

The current Tesla S model is a luxury sedan but powered by an unimpressive looking cell that would seem entirely familiar to all of us: the double AA battery. The chemistry inside the double AA case is, however, not standard. Also, many are put to work in the current Tesla automobile. The 85kWh battery pack contains 7,104 cells in 16 modules wired in series. Each module contains six groups of 74 cells wired in parallel with the six groups wired in series within the module.

Putting all of these cells to work in this configuration results in impressive statistics. The driving range is rated at 500km at a sustained speed of 90kph. It takes just 5.6 seconds to achieve a speed of 100kph. And the top speed is 200kph. While the grid from which Tesla owners recharge their cars will not be zero



△ TESLA 85kWh battery pack contains 7,104 cells in 16 modules

carbon, the operational life of those cars – and the competing cars that will emerge – will be an enormous advance over the internal combustion engine.

Meeting Demand

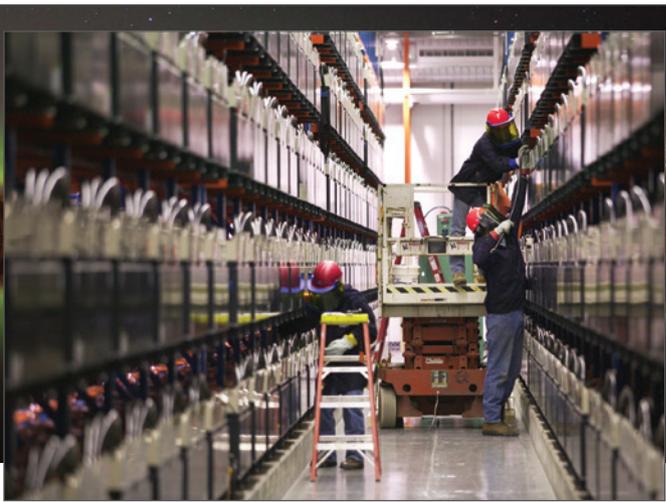
The company is currently on track to sell 35,000 of this model in 2014 and predicts that by 2020 there will be an annual production of 500,000 units of various Tesla models. This suggests that, in round numbers, more than three billion nickel-containing NCA cells will be needed to power just Tesla cars alone. And given that Tesla, in June 2014, opened all its patents to all potential competitors, there could be a far larger number of full-electric cars being produced than currently envisaged.

Clearly some large scale changes in production will be required and, consistent with the large vision of Mr Musk, Tesla has proposed, in partnership with Panasonic/Sanyo, a 'gigafactory' (so-called because of all the giga-watt capacity it will manufacture) that will, by 2020, produce in excess of three billion NCA (nickel, cobalt, aluminum) cells. Site preparation began in May of this year (see illustration opposite). The company claims that the scale and efficiencies achieved will reduce the cost of producing the cells by 30%.

The future

Battery chemistry is evolving and diversifying rapidly. While today's main batteries for hybrid (NiMH) and electric cars (NCA) depend on nickel there is no guarantee that this will continue. What will continue, however, are the unique, varied and still being explored attributes of nickel alone and when combined with other elements. The relationship between energy and nickel – from hydro to nuclear to chemical – will evolve but seems assured.

Ni



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PATRICK JENDRIES

Coping with extremes: Alaska Nickel-cadmium batteries bring security

Living in Alaska is living on the edge. Both geography and climate conspire to challenge service providers. One such provider is the Golden Valley Electrical Association (GVEA), a cooperative headquartered in Fairbanks, Alaska's second largest city. It supplies electricity to some 90,000 customers spread over 5,700km² in the interior of the state.

Here, because of the harsh climate, failures, if prolonged, can cause more than just inconvenience.

This concern led to the planning and building in 2003 of BESS: the Battery Energy Storage System. BESS was, at the time, the largest battery facility in the world when, during a December 2003 test of its capacity, it maintained a discharge of 46MW for five minutes. In more normal circumstances BESS can provide 27MW for 15 minutes. This is made possible by 13,760 71kg flooded NiCd cells.

In 2013, BESS responded so seamlessly to 60 interruptions of supply that many of the 34,202 members of the cooperative were probably unaware that there had been a problem. Because of

△ Nickel-cadmium batteries produced by Saft Group SA of France being serviced. Ten years into their service life, they are exceeding expectations and are expected to last for up to another two decades.

BESS, an average of 6.9 outages per electricity meter in the GVEA system was avoided as the system operated at 99.86% reliability in 2013.

Dan Bishop, engineer at GVEA, reports that BESS was designed to enhance reliability without burning petroleum-based fuel. "The BESS is not cheap, but reduces purchases of expensive fuel. It also has eliminated the need for another Static VAR [volt ampere reactive] Compensation system because in addition to energy storage it provides reactive compensation (voltage regulation) for GVEA's 138kV transmission system. BESS has eliminated about 90% of all power supply outages, higher than the design goals. Our current expectation is that BESS will exceed its 20 year life before battery replacement needs to be considered. We are delighted to have BESS backing us up." **Ni**

UNS details Chemical compositions (in percent by weight) of the alloys and stainless steels mentioned in this issue of Nickel.

UNS No.	Al	B	C	Co	Cr	Cu	Fe	Mn	Mo	N	Nb	Ni	P	Pb	S	Si	Ti	V	W	Zn
C70600 p. 10	-	-	-	-	-	rem.	1.0-1.8	1.0 max.	-	-	-	9.0-11.0	-	0.01 max.	-	-	-	-	-	1.0 max.
N06625 p. 6,7	0.40 max.	-	0.10 max.	-	20.0-23.0	-	5.0 max.	0.50 max.	8.0-10.0	-	3.15-4.15	rem.	0.015 max.	-	0.015 max.	0.5 max.	0.40 max.	-	-	-
N07718 p. 6,7	0.20-0.80	0.006 max.	0.08 max.	1.00 max.	17.0-21.0	0.30 max.	rem.	0.35 max.	2.80-3.30	-	4.75-5.50	50.0-55.0	0.015 max.	-	0.015 max.	0.35 max.	0.65-1.15	-	-	-
N08367 p. 9	-	-	0.030 max.	-	20.0-22.0	-	rem.	2.00 max.	6.00-7.00	0.18-0.25	-	23.5-25.5	0.040 max.	-	0.030 max.	1.00 max.	-	-	-	-
N08904 p. 9	-	-	0.020 max.	-	19.0-23.0	1.00-2.00	rem.	2.00 max.	4.00-5.00	-	-	23.0-28.0	0.045 max.	-	0.035 max.	1.00 max.	-	-	-	-
N10276 p. 9	-	-	0.02 max.	2.5 max.	14.5-16.5	-	4.0-7.0	1.00 max.	15.0-17.0	-	-	rem.	0.030 max.	-	0.030 max.	0.08 max.	-	0.35 max.	3.0-4.5	-
S17400 p. 6	-	-	0.07 max.	-	15.0-17.5	3.00-5.00	bal.	1.00 max.	-	-	0.15-0.45	3.00-5.00	0.040 max.	-	0.030 max.	1.00 max.	-	-	-	-
S30400 p. 9	-	-	0.08 max.	-	18.00-20.00	-	bal.	2.00 max.	-	-	-	8.00-10.50	0.045 max.	-	0.030 max.	1.00 max.	-	-	-	-
S30403 p. 2,9	-	-	0.03 max.	-	18.00-20.00	-	bal.	2.00 max.	-	-	-	8.00-12.00	0.045 max.	-	0.030 max.	1.00 max.	-	-	-	-
S31254 p. 9	-	-	0.020 max.	-	19.5-20.5	-	bal.	1.00 max.	6.00-6.50	0.180-0.220	-	17.5-18.5	0.030 max.	-	0.010 max.	0.80 max.	-	-	-	-
S31600 p. 9	-	-	0.08 max.	-	16.0-18.0	-	bal.	2.00 max.	2.00-3.00	-	-	10.00-14.00	0.045 max.	-	0.030 max.	1.00 max.	-	-	-	-
S31603 pg 6,7,9,16	-	-	0.030 max.	-	16.0-18.0	-	bal.	2.00 max.	2.00-3.00	-	-	10.00-14.00	0.045 max.	-	0.030 max.	1.00 max.	-	-	-	-
S31635 p. 9	-	-	0.08 max.	-	16.0-18.0	-	bal.	2.00 max.	2.00-3.00	0.10 max.	-	10.00-14.00	0.045 max.	-	0.030 max.	1.00 max.	-	-	-	-
S32205 p. 9	-	-	0.030 max.	-	22.0-23.0	-	bal.	2.00 max.	3.00-3.50	0.14-0.20	-	4.50-6.50	0.030 max.	-	0.020 max.	1.00 max.	-	-	-	-
S32750 p. 9	-	-	0.030 max.	-	24.0-26.0	-	bal.	1.20 max.	3.0-5.0	0.24-0.32	-	6.0-8.0	0.035 max.	-	0.020 max.	0.8 max.	-	-	-	-

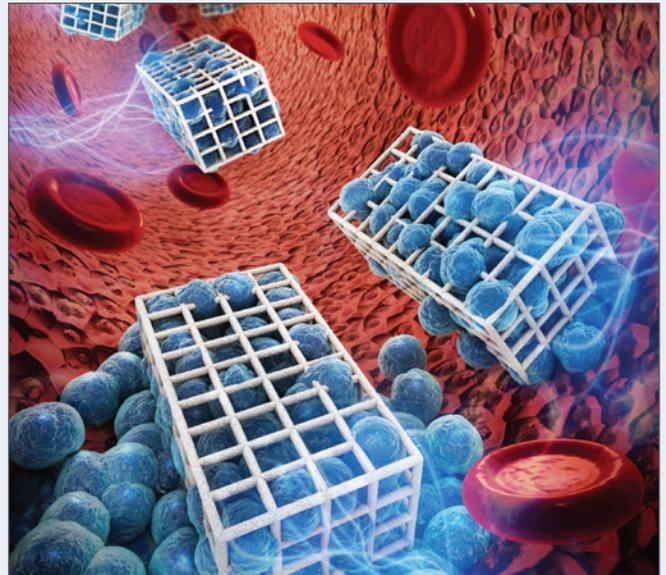
Tiny nickel-coated robots may deliver drugs more effectively

Drug delivery by means of micro robots, also called microbots, which are no bigger than a human cell may one day allow drugs to be delivered exactly where needed in the body. The nickel-coated cage-like device, 100 microns long and 40 wide, is small enough to be injected into the body and guided wirelessly with an electromagnetic field. To enable wireless control, parts of the microbot are coated with a thin layer of nickel which is ferro-magnetic.

Prof. Zhang Li of the Department of Mechanical and Automation Engineering of the Chinese University of Hong Kong led the team in co-operation with Daegu Gyeongbuk Institute of Science and Technology in South Korea and ETH in Zurich, Switzerland. They proved in laboratory tests that the microbot could be directed with minute accuracy by an external magnetic field. Additional laboratory testing where human kidney cells were cultivated with the microbots showed that the cells grew and even interacted with the microbots – a sign that the microbots were compatible with the cells.

Precise delivery of drugs to a specific part of the human body offers alternatives to invasive treatment especially for brain and eye diseases like stroke and retinal degeneration.

Prof. Zhang Li said that “If we can inject thousands of these microbots carrying drugs into the human body in-between vertebral columns and direct them to the affected area in the brain, we may be able to cure strokes without an operation.” There are still challenges ahead. Nuclear and magnetic resonance devices are



△ The nickel-coated cage-like device is small enough to be injected into the body and guided wirelessly with an electromagnetic field

commonly used to track microbots, but the resolution of the available devices was not high enough to track the new model, Zhang added.

The university is testing the microbot on rabbits and mice, but Zhang said it might take decades until the technology is developed enough to be tested on humans. Being able to guide the microbot to the exact location knowing exactly where it is at any moment is essential, and the nickel coating would enable that to happen.

Ni

IMAGE: SANGWON KIM, FAMIN QIU, SAMHWAN KIM, ALI GHANBARI, CHEIL MOON, LI ZHANG, BRADLEY J. NELSON, HONGSOO CHOI: MAGNETIC MICROBOTS: FABRICATION AND CHARACTERIZATION OF MAGNETIC MICROBOTS FOR THREE-DIMENSIONAL CELL CULTURE AND TARGETED TRANSPORTATION. ADVANCED MATERIALS 2013, 41, PAGE 5829. COPYRIGHT WILEY-VCH-VERLAG GMBH & CO. KGAA. REPRODUCED WITH PERMISSION.

New publication: Nickel Plating Handbook

The Nickel Institute has published the *Nickel Plating Handbook*, a free 78-page comprehensive guide to electroplating written by plating industry specialists, Ian Rose and Clive Whittington.

The *Nickel Plating Handbook* reviews modern industrial nickel plating practice against a background of fundamental electrochemistry. It covers electrolyte composition, specifications for decorative coatings, engineering coatings, testing procedures, troubleshooting, practical tips, waste minimisation and advice on occupational and environmental health aspects of nickel plating.

“Supporting the use of nickel in appropriate applications including electroplating is one of our goals as an association. The new *Nickel Plating Handbook* provides practical information for the operation and control of nickel plating processes,” said Tim Aiken, President Nickel Institute.

“Electroplated nickel is used extensively to enhance the utility, value and sales appeal of consumer goods and manufactured products. We hope the *Nickel Plating Handbook* will be a useful contribution to the industry.”

The Handbook can be downloaded from the Nickel Institute website. Printed copies may be requested from communications@nickelinstitute.org.



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Kelpies are mythical creatures said to come from Scottish sea-lochs. Andy Scott's finished design is a paradox of the ethereal kelpies and powerful traditional working horses



THE ENGINEERING OF

ART

Towering thirty meters above the Forth and Clyde canal in central Scotland, the Kelpies can claim to be among the world's most exciting pieces of public art. Scottish sculptor Andy Scott's massive pair of equine heads is inspired by the powerful heavy horses that worked the canal towpaths in times gone by.

Eight years on from Scott's initial sketches, the story is one of collaboration between the artist and some of the UK's finest engineers. They overcame with ingenuity the technical challenges of scaling up the original design tenfold, into two massive structures which combine painted carbon steel and hundreds of stainless steel cladding plates.

"I chose stainless steel both for its longevity and its visual effect," says Scott. The setting is 'big sky' country, with mountains in the distance and a special natural light. Stainless steel gave the effect I was looking for – a light, almost delicate quality against the natural backdrop."

Whilst remaining artwork, the sheer scale of this project meant it had to be approached in the same way as the building of a bridge. "Andy's maquettes were digitally scanned to produce a 3D surface model. So whilst we built the Kelpies, the form is a perfect copy of Andy's original work," explains Tim Burton of SH Structures, the project's principal contractor.

To create an efficient and stiff primary structure, two triangular trusses interconnected by frames braced in-plane were constructed. A secondary frame followed the profile of the internal surface of the skin with brackets to take the stainless steel cladding that forms the outer layer of



△ *The art of engineering: The interior structure of the two heads. The heads were covered with 150 tonnes of 6mm thick mill finish Type 316L (S31603) stainless steel plate, supplied and laser cut by Outokumpu. The finishing touch has been the installation of specially designed lighting, which dramatically transforms the Kelpies at night.*

The Kelpies, which started out as an artist's vision has, through a collaborative process, the use of traditional fabrication skills and the application of excellent structural engineering, been transformed into a stunning piece of public art. **Ni**