NICKEL

THE MAGAZINE DEVOTED TO NICKEL AND ITS APPLICATIONS

Space—it actually is rocket science

Stainless steel boat safer, lighter, greener

Stainless steel for high speed trains

NICKEL, VOL. 32, NO. 2, 2017

From bicycles to rockets

Nickel on the move

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△ *MOCAPE: Nickel-containing stainless steel panels cover 40,000m² of surface area*
THE CLOUD: 387 tonnes of stainless steel panels create the exterior cladding ▷

CASE STUDY 10
THE MUSEUM OF CONTEMPORARY ART & PLANNING EXHIBITION

The Museum of Contemporary Art & Planning Exhibition (MOCAPE) is standing out as the next global architectural landmark in the revived Futian Cultural District of Shenzhen, China.

Covering 233,447m² and offering 861,112m² of floor space, the seven-storey building is turning heads with its world-class, environmentally-friendly design that makes extensive use of nickel-containing stainless steel.

Designed by Vienna-based architecture firm Coop Himmelb(l)au, MOCAPE combines the synergies of two independent institutions—the Museum of Contemporary Art (MOCA) and the Planning Exhibition (PE)—as a cultural meeting point and venue for architectural exhibitions. While both museums are designed as separate entities to highlight their individual functions, the institutions are unified in a monolithic body enveloped by a multifunctional façade.

The museum's stunning façade is structurally independent of the main building, and its transparent design offers visitors an unhindered view of the cityscape from inside the open and column-free exhibition area. This design feature was achieved using a combination of glass with a skin of 51% perforated, Type 316L (UNS S31603) stainless steel panels.

Standing 40m tall, the roof of the museum was also designed to filter natural light for the exhibition rooms, delivering energy efficiencies and reducing the need for artificial lighting. Solid panels of 3mm, glass-bead blasted Type 316L stainless steel was used to construct the roof and is also exhibited on the grand entrance canopy and exits.

The nickel-containing stainless steel panels cover a total surface area of 40,000m² and were specified for its corrosion resistance, surface finish quality and light-reflecting properties.

Inside MOCAPE, Type 304L (UNS S30403) stainless steel was used at large on the metal claddings of all stairs, ramps and bridge walkways, as well as the façade of what is known as the 'Cloud', which connects the exhibition rooms of both museums. Ni

THE CLOUD

Featured in the central atrium of MOCAPE, the Cloud is a remarkable piece of architecture.

Inspired by Constantin Brancusi's Sleeping Muse and the moons of Mars, the Cloud's complex shape, and design is constructed of approximately 387 tonnes of welded Type 304L stainless steel panels which make up the exterior cladding. The panels were polished to achieve a homogenous surface and mirror-like effect which quite literally reflects back the spirit of the museum through the movement of its visitors, lights and colours.

The Cloud used robotic technology to manufacture, mount, weld and finish the exterior skin. According to the architect, the combination of robotic construction with 3D printing allowed more freedom and flexibility in its structural and aesthetic design. It allowed high precision as well as economical benefits by significantly reducing construction downtime.

Opened in September 2016, MOCAPE's extensive use of nickel-containing stainless steel is certain to provide the aesthetic appeal, durability, structural and material performance required to stand the test of time.

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NICKEL

The Magazine Devoted to Nickel and its Applications

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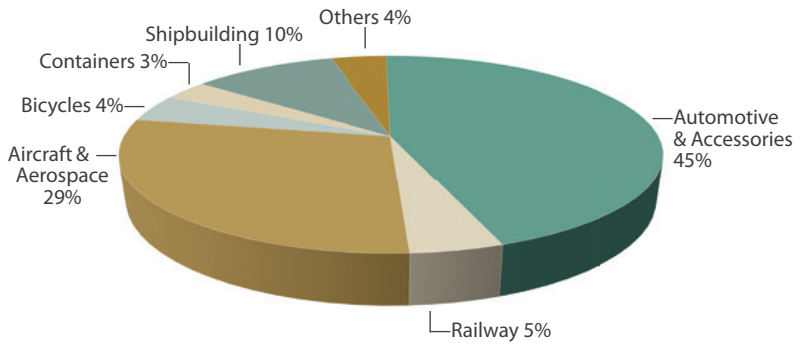
NICKEL ON THE MOVE

Good and efficient transport is vital in today's world, whether for moving goods, raw materials or people. As the population grows, demand for transportation is set to increase from around 50 billion passenger kilometres in 2015 to around 120 billion by 2050.

NICKEL USE IN TRANSPORT SECTOR 2015



SOURCE: ROSKILL PARISER

It is hard to think of a method of transport that does not use nickel or nickel alloys. Automobiles and trucks, rail cars, ships or aeroplanes and even bicycles, are all exploiting the many virtues of nickel and nickel-containing alloys. For example, Type 304 stainless steel and nickel-iron (36% Ni) are used for the transportation of liquefied natural gas by sea because they retain their ductility at the extremely low temperatures of the gas (-163°C). For railway carriages, Type 304 stainless steel provides corrosion resistance, excellent strength-to-weight and energy-absorbing properties in case of impact. And in aerospace high-nickel alloys provide essential strength and durability to engine components, while in the automotive sector a growing application for nickel is batteries in electric vehicles (EVs).

A new entry to the EV market is Tesla's highly anticipated mass market sedan, the Model 3, revealed in June 2017. The Model 3 is a smaller, simpler alternative to its high-end Model S and Model X stablemates. With a range of 345km the Model 3 is fitted with Tesla's new design battery module. While the exact chemistry of the nickel-containing high performance '2170 cell' has not yet been disclosed, we do know it is being produced at Tesla's Gigafactory 1, in Nevada, USA. To support Tesla's planned production rate of 500,000 cars per year by 2018, the Gigafactory is anticipated to produce more nickel-containing lithium ion batteries annually than were produced worldwide in 2013.

EVs are just one example of how nickel is helping the transportation sector to innovate. In this issue, we look beyond cars to nickel 'on the move' in applications from bicycles to space rockets.

Clare Richardson
Editor, *Nickel* magazine

Nickel INSTITUTE
knowledge for a brighter future

Maintenance free, safer, greener boats ready to make waves

An extremely corrosion-resistant, lightweight stainless steel design makes waves in the boating industry.

On May 12, 2017, the P16 prototype, an offshore patrol vessel made entirely out of stainless steel, set sail out of Gävle, 200km north of Stockholm. The goal was to construct a boat out of stainless steel that was light, more efficient, safer and greener.

By using an innovative design concept inspired by the features of a traditional Viking boat, together with the use of super duplex nickel-containing stainless steel, it was possible to build an extremely lightweight ship. The high strength of the duplex stainless steel allows a reduction of thickness in the material used resulting in a lighter boat.

"The lightness of the P16 clearly reduces fuel consumption. The ship is maintenance-free, which saves precious time and money. It is extremely resistant to salt water, and can even be used when the sea is partly frozen—a useful feature in the Scandinavian waters", explained Petra Rosén, Head of Marketing at SSY Stainless Steel Yachts, one of the companies behind the development of the P16 prototype.

"We chose Outokumpu's Forta SDX 2507 (UNS S32750) for the entire boat. It met all of the requirements. It's high-strength, durable, 100% corrosion-resistant, and maintenance-free with very good tensile strength—all properties conducive to a marine environment." says Rosén.

All metal under the waterline is mirror-polished which ensures that any marine organisms attached to the hull can be removed either with a low-pressure hose or even by travel at very low speeds. As a result, there is no need for environmentally hazardous and expensive anti-fouling paints. This project can potentially open a whole new market for high-performance and sustainable vessels of this type. Ni

△ *All metal under the waterline is mirror-polished to ensure easy removal of marine organisms.*

▽ *P16 Prototype*

OUTOKUMPU FOKUS MEDIA / JANNE RIIKONEN

NICKEL-CONTAINING MARINE SCRUBBERS ON BOARD

helping to protect our oceans

As our largest ecosystem, oceans provide more than half the oxygen we breathe and most of the fish we eat. They are also waterways for transportation. Healthy oceans are essential to our survival. As we become more mindful of the need to reduce our environmental imprint, the marine industry has increased its focus on ways to regulate its impact, including minimising the release of harmful emissions.

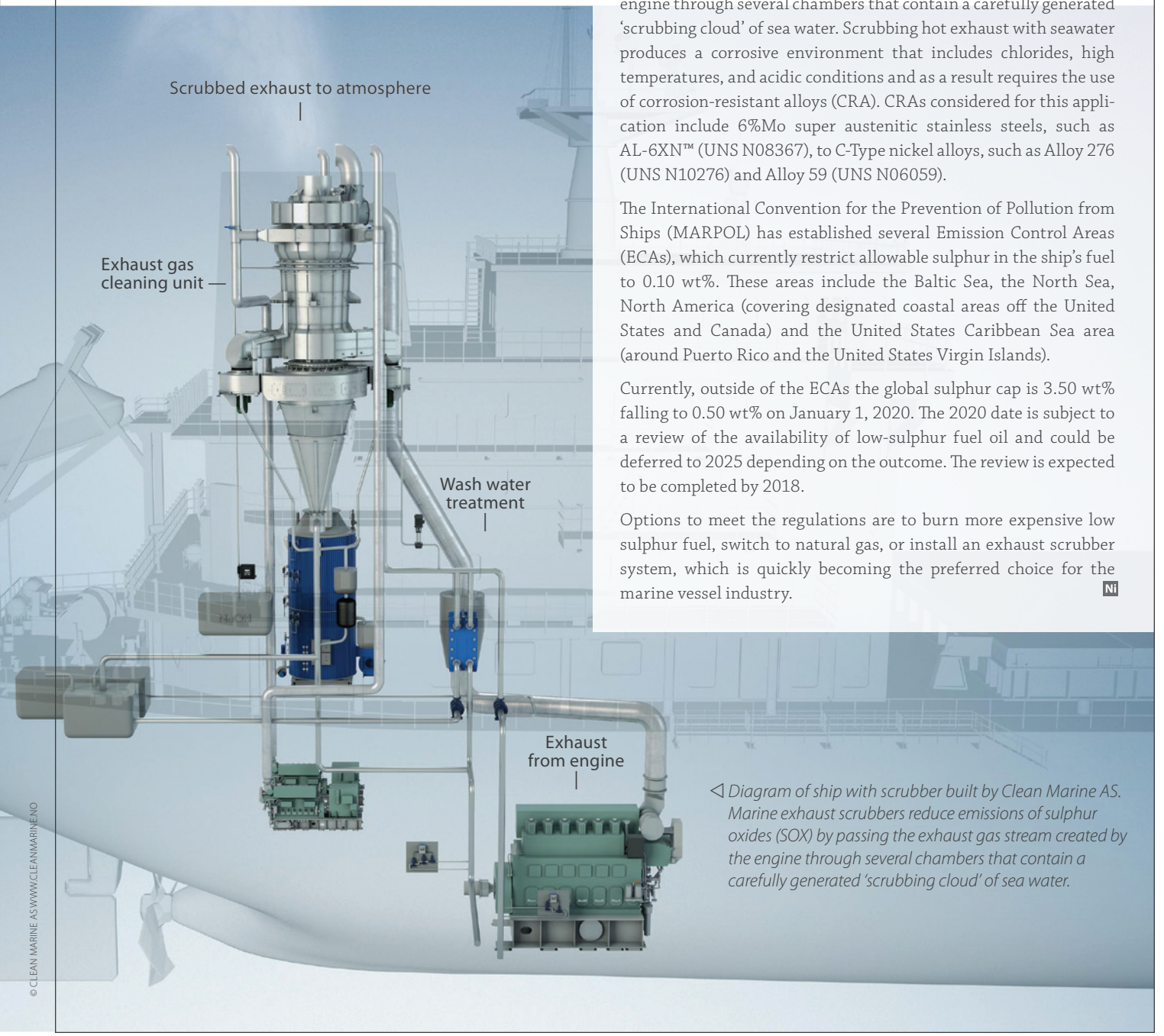
The release of sulphur in the atmosphere from marine vessels has caused considerable concern. The International Maritime Organisation (IMO) is introducing new environmental requirements to reduce the level of atmospheric sulphur from marine vessels. With the new regulation, substantial growth is anticipated for nickel-containing marine diesel exhaust scrubbers.

One design of scrubber, shown below, reduces emissions of sulphur oxides (SOX) by passing the exhaust gas stream produced by the engine through several chambers that contain a carefully generated 'scrubbing cloud' of sea water. Scrubbing hot exhaust with seawater produces a corrosive environment that includes chlorides, high temperatures, and acidic conditions and as a result requires the use of corrosion-resistant alloys (CRA). CRAs considered for this application include 6%Mo super austenitic stainless steels, such as AL-6XN™ (UNS N08367), to C-Type nickel alloys, such as Alloy 276 (UNS N10276) and Alloy 59 (UNS N06059).

The International Convention for the Prevention of Pollution from Ships (MARPOL) has established several Emission Control Areas (ECAs), which currently restrict allowable sulphur in the ship's fuel to 0.10 wt%. These areas include the Baltic Sea, the North Sea, North America (covering designated coastal areas off the United States and Canada) and the United States Caribbean Sea area (around Puerto Rico and the United States Virgin Islands).

Currently, outside of the ECAs the global sulphur cap is 3.50 wt% falling to 0.50 wt% on January 1, 2020. The 2020 date is subject to a review of the availability of low-sulphur fuel oil and could be deferred to 2025 depending on the outcome. The review is expected to be completed by 2018.

Options to meet the regulations are to burn more expensive low sulphur fuel, switch to natural gas, or install an exhaust scrubber system, which is quickly becoming the preferred choice for the marine vessel industry.



◁ Diagram of ship with scrubber built by Clean Marine AS. Marine exhaust scrubbers reduce emissions of sulphur oxides (SOX) by passing the exhaust gas stream created by the engine through several chambers that contain a carefully generated 'scrubbing cloud' of sea water.

STEFAN NILSSON

Nickel-containing stainless steel

As the demand for mass transportation burgeons around the world, railway companies are looking for new solutions to address the increasing challenges of moving more people quicker than ever before.

Replacement of old infrastructure combined with new high-speed links is a solution to meet these growing needs. In addition, reduced running costs and energy consumption, improved passenger safety, more attractive outer appearance and better comfort to redress the poor image of crowded mass transport are now standard requirements. Railway companies are looking to nickel-containing stainless steel in railcar construction to help meet these challenges.

△ *X2000 on the Öresund bridge at Pepparholmen, on the way to Copenhagen.*

X2000 trains in Sweden

When Swedish state railway company SJ ordered a fleet of high-speed trains in the late 1980s, they needed a solution that would be both safe, comfortable and cost-effective in the long term. Combined with lower maintenance costs and long service life, nickel-containing stainless steel—an austenitic alloy, Type 304 (UNS S30400) in cold-worked condition for enhanced strength—was the optimal choice for the fast and firm X2000 train frames.

The X2000 trains were manufactured by ABB and introduced into service between 1990 and 1998. The material of choice for the train frames was stainless steel supplied by Outokumpu.

The X2000 trains have a special design including a tilting system and radial bogies, which allow for a high speed of 200 kilometer per hour on curved tracks, without compromising passenger comfort and safety. The frame has a high level of bending stiffness which reduces vibrations and increases travel comfort.

> ...in the long-term stainless steel was a lighter, safer and cheaper option than aluminum or carbon steel.

In addition, Type 304 stainless steel has excellent impact resistance in a collision, enhancing passenger safety.

The trains operate mainly between big cities like Stockholm, Copenhagen, and Gothenburg. ABB's decision to use stainless steel as the frame material was based on thorough lifecycle analysis, which calculated that in the long-term stainless steel was a lighter, safer and less expensive option than aluminum or carbon steel. For instance, the savings in maintenance costs per railcar over a period of 30 years were estimated at 100,000 Swedish kronor (ca. USD 17,500 today), and the weight reduction per car was about 20% compared to carbon steel. The lighter build also means that less energy is needed to propel the train, which translates into considerable energy savings: an estimated 800,000 kWh per car over a period of 30 years.

Now, two decades later, the trains are undergoing a full technical and interior upgrade. However, the original stainless steel frames remain intact and are expected to stay in service for another two decades. The X2000 upgrade project promises to return the entire train fleet back to service with improved reliability and comfort by 2018. This application highlights how crucial it is to use a lifecycle approach when choosing materials. Looking at both costs and environmental impacts as well as selecting the right grade of stainless steel pays off.

in high speed trains

ISTOCKPHOTO.COM © ROLAND MAGNUSSON

ALSTOM

△ *India: The LHB design uses austenitic stainless steel for the roof and trough-floor where the chances of corrosion are high.*

LHB coaches for high speed trains in India

Indian Railways is the largest railway network under single ownership in the world. The system is the lifeblood of the nation, carrying over one billion tonnes of freight per year and more than 23 million passengers every day. It operates about 250,000 wagons and nearly 70,000 passenger coaches.

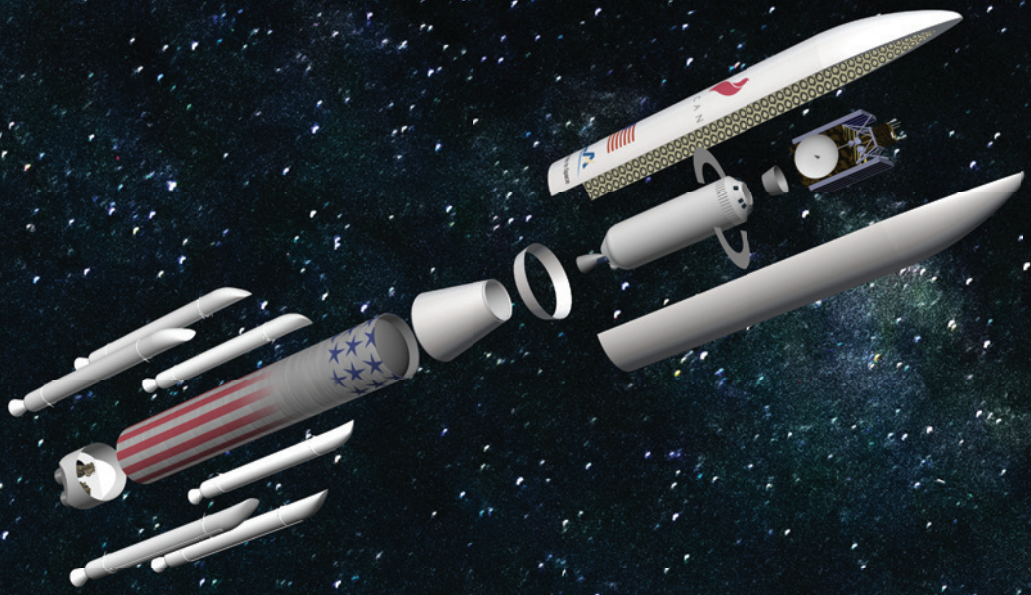
As India's economy grows, Indian Railways has a challenging task ahead transporting the increasing traffic demands with line and terminal capacity constraints. While initiatives are afoot to decongest the existing network by introducing high speed trains, passenger safety has assumed critical importance in the design and materials selected for construction for coach bodies.

With such a large network, there have been a number of fatal accidents over the last few decades, which has led to calls for better structural design for 'crashworthy' coaches made of superior material, with discussions intensifying after every major accident.

Ideally, in a vehicle crash, the passenger should be enclosed in a rigid, safe structure with seat belts so that they do not suffer serious injuries. Modern automobiles have adopted this design. The passenger compartment is a safe, rigid cell, and the front and rear of the car are crumple zones that collapse to absorb impact energy.

Indian Railways has understood the importance of nickel-containing stainless steel for the construction of coaches to improve passenger safety and in 2001 they introduced the LHB (Linke Hofmann Busch) coaches from Germany. According to a senior Rail Ministry official, "LHB coaches made of stainless steel have more built-in safety features as they can absorb shock and impact of derailment more effectively and do not topple easily when a train derails, reducing the loss of lives in case of an accident." Type 304 (UNS S30400) is used for roofing and the trough-floor where the chances of corrosion are high. For water tanks and bio digester toilet containers, Type 316L (UNS S31603) was the material of choice. Each coach roughly uses 10-11 tonnes of stainless steel, of which 40% is austenitic.

In 2016, Indian Railways planned to roll out 4,000 LHB coaches in India, and later announced an aggressive plan at the Rail India Conference 2016 to "make a complete switchover to LHB coaches by 2018." Indian Railways' decision to fast-track a complete replacement of steel coaches with nickel-containing stainless steel coaches to ensure the safety of its passengers will no doubt greatly increase the use of nickel-containing stainless steel in India. Ni



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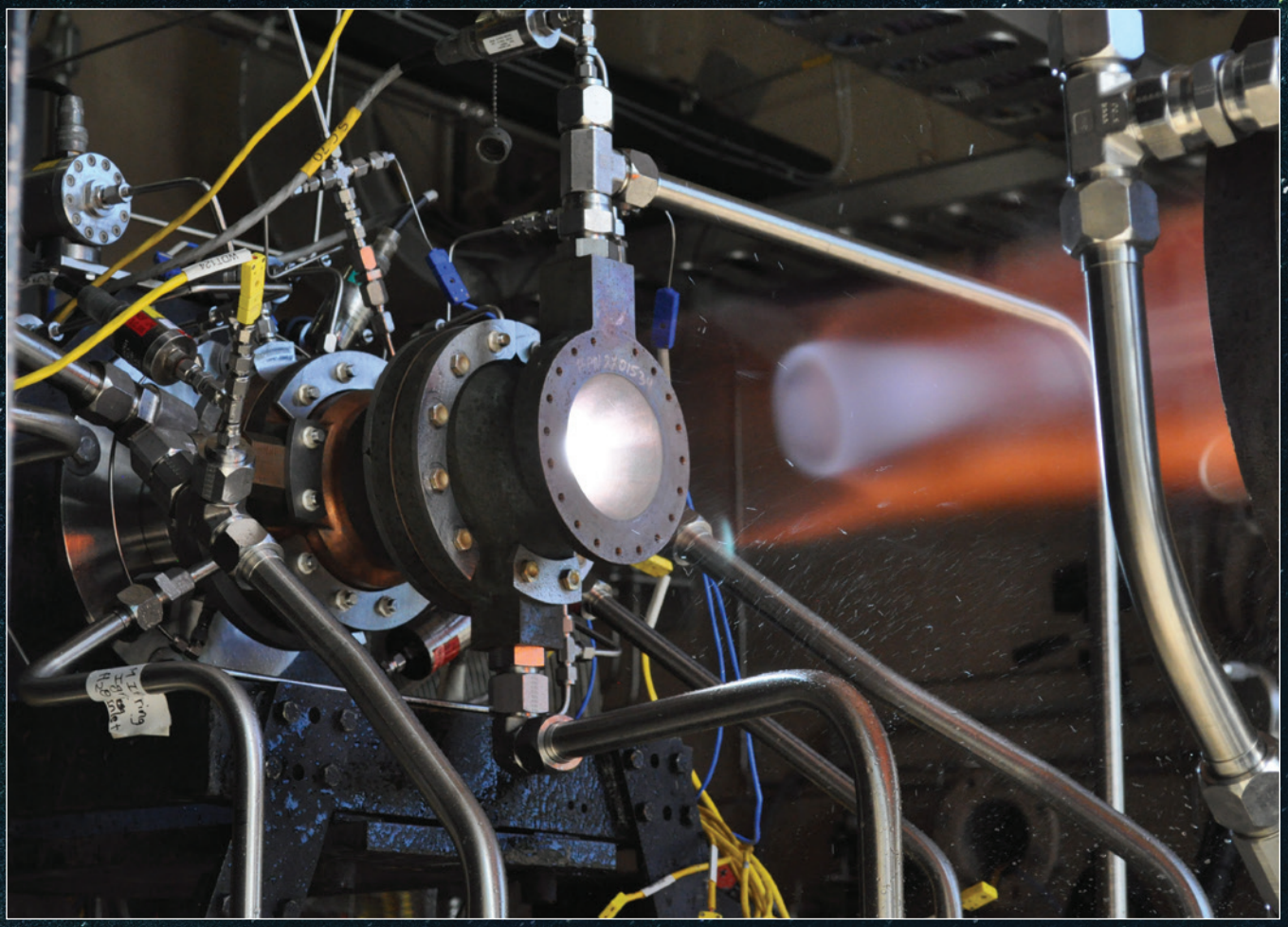
△ *ULA Vulcan 5-metre-diameter payload fairing configuration*



AEROJET ROCKETDYNE

△ *Aerojet Rocketdyne 3D printed engine parts withstand hot fire tests*

ISTOCKPHOTO.COM © WISSANU01

It actually *is* rocket science: 3D printing and nickel move us closer to space

In recent years, the vision of creating a worthy successor to the Space Shuttle—an affordable vehicle for space travel—has begun inching ever closer to reality.

The United States has been taking the lead in creating low-cost and reusable launch vehicles, an effort which has been accelerated by a critical fact: with the termination of the Shuttle program in 2011, the U.S. has become dependent upon Russian-built RD-180 rocket engines to move payloads (including national security satellites) into space. In 2014, the U.S. Congress mandated a 2019 deadline to eliminate this dependence and create domestic launch capabilities.

To that end, NASA has been partnering with numerous companies since 2006 to develop the capacity to transport cargoes and crews into low-earth orbit. Several U.S. companies are involved in this effort, and are now close to the promise of bringing payloads and passengers into space, deploying cost-effective (and in some cases, reusable) launch platforms, utilising nickel-containing alloys.

3D printing and nickel alloys are used in the manufacturing process

Space-X (founded by Tesla's Elon Musk), Blue Origin (founded by Amazon billionaire Jeff Bezos) and publicly traded Aerojet Rocketdyne are three companies using additive manufacturing (3D printing) to build critical elements of their next rockets. 3D printing has some distinct advantages over the traditional manufacturing approach in rocket design and manufacture. One important advantage is it makes the manufacture of complex elements less costly. According to NASA, a critical element in cost reduction is the ability to minimise the number of components. In the case of one Aerojet engine, the printing assembly requires the manufacture of only three separate parts, compared with over 100 in the original version. And nickel-containing alloys provide the ability to withstand the intense heat and stress required by space flight.

Space-X (as previously noted in Nickel, Vol. 29, No. 2, July 2014) utilises 3D printing to manufacture its engine chamber.

Similarly, Blue Origin is building its next generation liquid natural gas-fueled rocket engine (the BE-4) with the nickel-containing alloy Monel® alloy K-500 (UNS K05500).

Nickel-containing alloys provide the ability to withstand the intense heat and stress required by space flight.

Blue Origin's additive printing approach employs this alloy in the manufacture of all stages of its innovative hydraulic turbine, including some very complex engine flow passages. Monel® alloy K-500 consists principally of nickel (approximately two-thirds) and copper (slightly less than one-third), with smaller amounts of aluminum and titanium, which increases strength by a precipitation hardening mechanism.

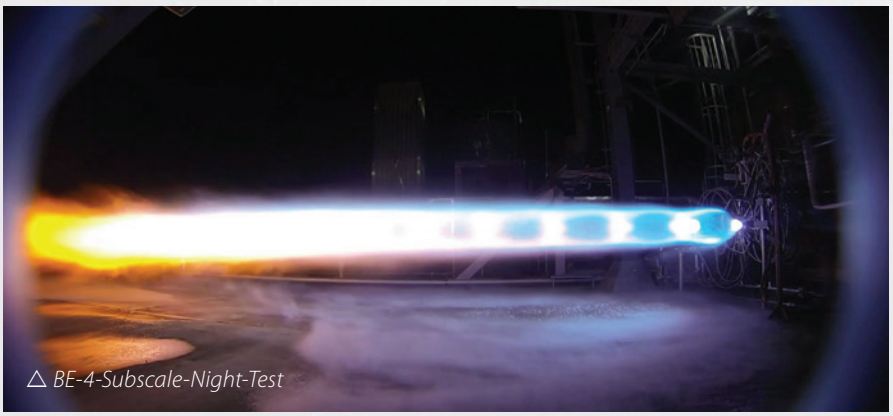
The first of the Blue Origin BE-4 engines is now fully assembled, with more engines to follow shortly. Ultimately, eight of these engines will be combined on the company's 270+ foot New Glenn Rocket, which will boost heavy payloads and passengers into orbit.

Competitor Aerojet Rocketdyne is also aiming at a 2019 launch date. Aerojet is using 3D printing of nickel-containing alloy Mondaloy™ to manufacture its critical pre-burner engine component. Aerojet recently successfully completed hot fire tests to validate the design of the pre-burner, a critical part of the engine's turbomachinery. Full engine testing is scheduled to occur at a future date.

Mondaloy™, which was jointly developed by Aerojet Rocketdyne in tandem with the Air Force Research Laboratory, is similar to Monel, and provides the critical strength and resistance required.

Both Blue Origin and Aerojet are vying to build the engines that will power the Vulcan. This vehicle, developed by the United Launch Alliance (ULA), a joint venture between Boeing and Lockheed Martin, will ship critical U.S. intelligence payloads into orbit in the future. ULA's current Atlas V rocket, currently powered by Russian engines has successfully performed over 60 launches.

Given successful test experiences to date, it is abundantly clear that 3D printing and nickel-containing alloys will be critical to the future of U.S. space travel for decades to come. Ni



△ *BE-4-Subscale-Night-Test*

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SUSTAINABLE GREEN CHEMICALS THROUGH INNOVATIVE BIOTECHNOLOGY

nickel keeps it together

Succinic acid is a dicarboxylic acid with the chemical formula $(CH_2)_2(CO_2H)_2$. The name derives from Latin *succinum*, meaning amber. Nickel-containing stainless steel is playing an essential role in the production of innovative 'green' succinic acid which is highly corrosive to low alloy and carbon steel.

Succinic acid can be used to make a broad range of products found in everyday life, including polyurethanes, paints and coatings, adhesives, sealants, artificial leathers, food and flavor additives, cosmetics and personal care products, biodegradable plastics, nylons, industrial lubricants, phthalate-free plasticisers, dyes & pigments and pharmaceutical compounds. Many of us don't know that when you cook your favorite dishes, the flavorings you use to enrich the taste often contain biosuccinic acid. In wine and soft drinks, succinic acid helps reduce acidity. As an ingredient in cosmetics and creams, it is a skin softener.

Historically, succinic acid has been made from fossil fuels. However, innovative green solutions have been developed by companies such as Myriant Corporation in the U.S., Reverdia V.O.F in the Netherlands (joint venture between Roquette and DSM), Succinity GmbH in Germany (joint venture of BASF and Corbion N.V), and BioAmber, with its head office in Montreal, Canada. These sustainable and proprietary industrial biotechnology processes, using fermentation to convert sugars into a succinic acid, are changing the industry worldwide.

BioAmber's disruptive technology

BioAmber's plant in Sarnia, Ontario, Canada, opened in late 2015, is the world's largest bio-succinic acid production facility. The succinic acid is produced with sugars in renewable feedstocks, such as corn. It is indistinguishable from the petroleum-derived chemical.

This disruptive technology not only produces succinic acid as a sustainable chemical, but also eliminates greenhouse gas (GHG) emissions and consumes much less energy than petroleum-based production. An independent life cycle analysis, which evaluated the entire production chain from the planting and harvesting of corn through to the purification of succinic acid, revealed that net GHG emissions for the entire process is zero. This compares to the 7.1 tonnes of GHG that are emitted per ton of succinic acid produced using the petroleum process. At full capacity, BioAmber's Sarnia facility will reduce GHG emissions by 210,000 tonnes per year, relative to the petroleum process. This is the equivalent of taking 45,000 cars off the road each year. The life cycle analysis also showed that the process uses 64% less electricity than conventional oil-based processes.

Disruptive technologies create new value, new markets and new operating parameters. Bayer Material Science has launched an innovative line of bio-based materials

Table 2: Major Stainless Steel Grades Used in Bio-Based Chemicals Plants

Common name	UNS	EN	Attributes
304	**S30400**	1.4301	Good general corrosion resistance to slightly acidic as well as caustic media. Minimum strength level slightly higher than for the 'L' grades.
304L	**S30403**	1.4307	As above but 'L' grades are preferred for welded constructions. Materials can be usually purchased 'Dual Certified' meeting the requirements of both 304 and 304L.
316	**S31600**	1.4401/1.4436	Better corrosion resistance than 304, especially in acidic conditions.
316L	**S31603**	1.4404/1.4432	As above but 'L' grades are preferred for welded constructions. Materials can be usually purchased 'Dual Certified' meeting the requirements of both 316 and 316L.

Table 3: Specialty Stainless Steels and Nickel Alloys used in Bio-based Chemicals Plants

Common name	UNS	EN	Attributes
316Ti	**S31635**	1.4571	Similar to 316 in corrosion resistance, higher strength at elevated temperatures, mostly used in Europe
317L	**S31703**	1.4438	Slightly more corrosion resistant than 316L
904L	**NO8904**	1.4539	Excellent corrosion resistance in sulphuric acid
6% Mo alloys	**Various**	Various	Greater corrosion resistance than 300 series alloys, especially at higher temperatures and/or with chlorides present.
2101	**S32101**	1.4162	One of several lean duplex alloys with high strength, suitable for large tanks
2205	**S32205**	1.4462	Duplex alloy, higher strength and better corrosion-erosion resistance than 300 series alloys
2507	**S32750**	1.4410	One of several superduplex alloys, higher corrosion resistance than 2205
Alloy C276	**C10276**	2.4819	Nickel-base alloy used in extremely corrosive conditions
Alloy C22	**N06022**	2.4602	Nickel-base alloy used in extremely corrosive conditions
Alloy 20	**N08020**	2.4460	Excellent corrosion resistance in sulfuric acid

▷ *BioAmber plant in Sarnia, Ontario*

for textiles used in the footwear, sportswear, automotive and apparel industries. Replacing petrochemicals with BioAmber's succinic acid means these eco-friendly products offer excellent performance and up to 65% renewable content.

Sustainability and alternate sources

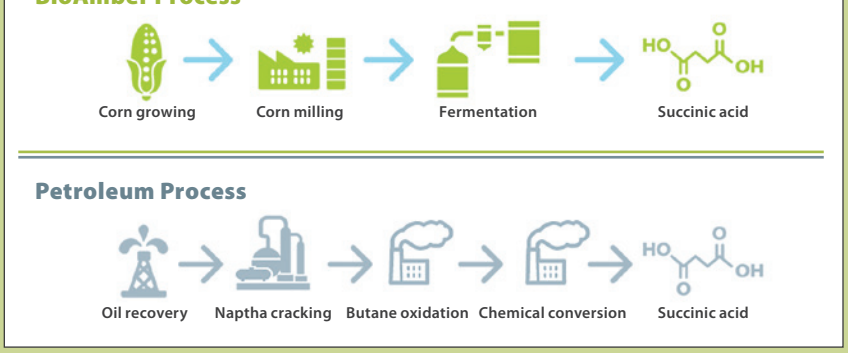
While BioAmber is focused on using the most abundant low cost sugar available as feedstock, the company is very conscious of the need to be as sustainable as possible. Presently, this sugar comes from corn, however, sugar from cane, beets, sorghum, wheat and tapioca can also be used. BioAmber's longer term goal is to move to agricultural waste, forestry and industrial waste as alternatives to traditional sugars.

BioAmber's plant in Canada is presently the world's largest bio-succinic acid plant, with a production capacity of 35,000MT of succinic acid and 23,000MT of 1,4 butanediol (BDO). To meet rapidly rising global demand for succinic acid and its derivatives, BioAmber intends to build additional plants in North America with a total cumulative capacity of 165,000 tonnes of succinic acid and 123,000 tonnes of BDO. Ni

Carbohydrates instead of hydrocarbons

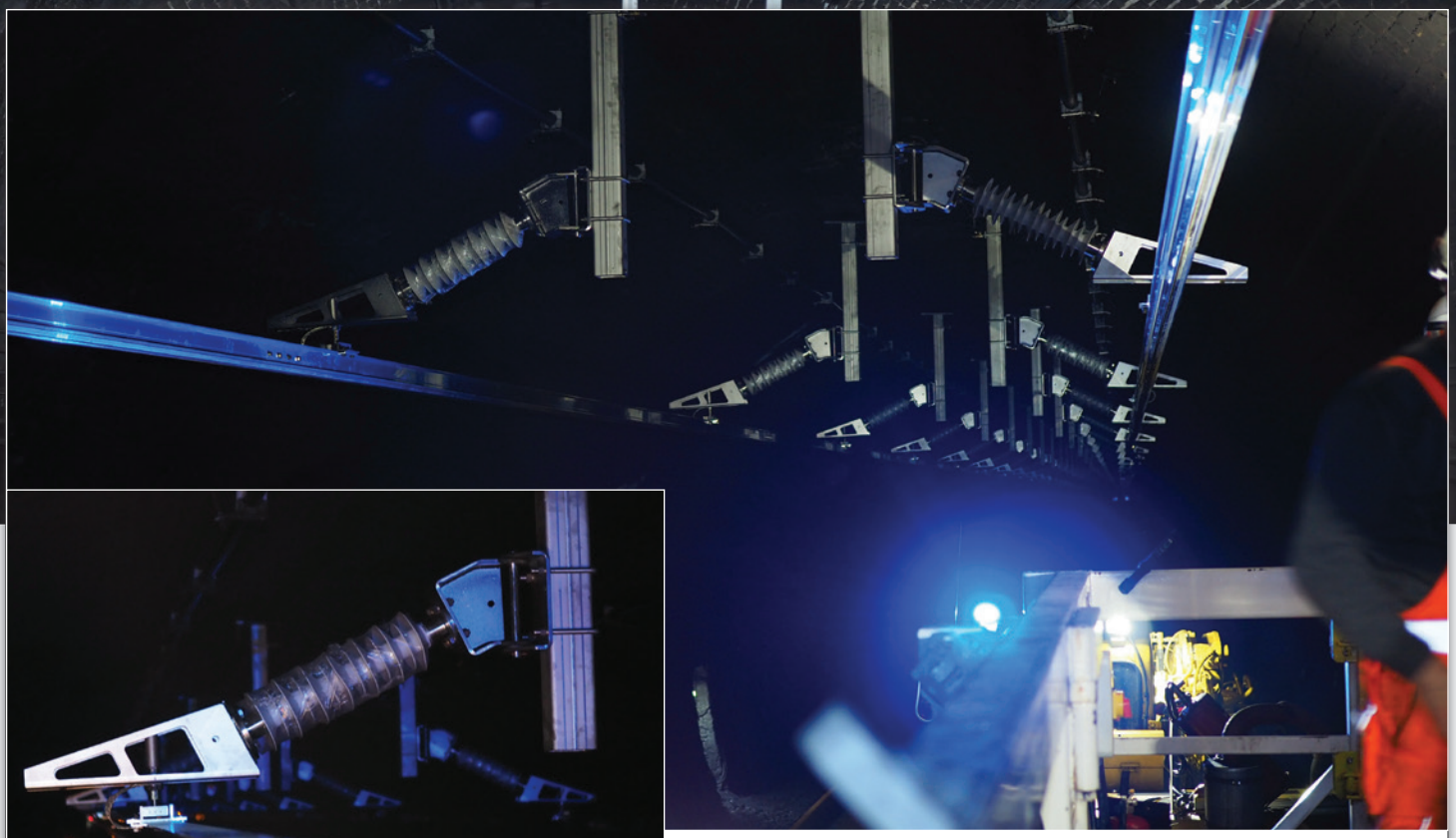
When you compare fossil-fuel based organic chemicals to organic chemicals made from biomass, in other words, hydrocarbon-based chemicals to carbohydrate chemicals, the major difference is the oxygen content in carbohydrates.

Fossil-fuel based organic chemicals are quite inert, non-reactive and their processing is not particularly corrosive. Therefore low alloy and carbon steel can often be suitable as materials for essential processing equipment. Bio-based chemicals on the other hand, which are water based, can be reactive, easily degrade and form compounds, such as acetic, formic and lactic acids, which are highly corrosive to low alloy and carbon steel. In biomass processing, the feedstocks, impurities, intermediates and by-products are all different compared to hydrocarbon processing. The majority of production equipment for bio-based organic chemicals must therefore be made from corrosion resistant materials. Nickel-containing austenitic (principally Types 304, 304L, 316 and 316L) and a range of nickel-containing specialty stainless steels, and at times also nickel-base alloys will be needed to ensure protection against corrosion. These nickel-containing materials are cost-effective and long lasting materials solutions for the growing bio-based chemicals industry. Ni



▽ *Nickel-containing stainless steel piping joins the various process stages.*

▷ *Nickel-containing stainless steel vessels ensure product purity and long life.*



FURRER+FREY

△ *High alloyed stainless steel was selected for all of the structural steelwork supporting the ROCS in order to provide an 80 year design life.*

Stainless steel supports new electrification system in Severn Tunnel

Over six weeks in September and October 2016, Network Rail—the company that manages most of the UK's rail infrastructure—installed an innovative system for electrification of the railway track through the Severn Tunnel. This seven kilometre long, 130-year-old tunnel links the west of England to South Wales. Instead of traditional overhead wires, the system in the tunnel consists of an aluminium rail (which carries the electrified contact wire), supported from the tunnel roof by drop tubes and registration arms. Made by Swiss company Furrer+Frey, the Rigid Overhead Conductor Rail System (ROCS) is more robust and efficient than overhead wires, with reduced maintenance requirements. It is also more compact than the traditional wired system and can be used in tunnels where headroom is constrained.

The environment inside the Severn Tunnel is aggressive due to the ingress of chlorides from the saline water in the Severn Estuary and dust deposition from freight trains carrying coal which pass through the tunnel. For this reason highly alloyed stainless steel was selected for all of the structural steelwork supporting the ROCS in order to provide an 80 year design life with minimal maintenance. Tunnels by their nature are difficult environments in which to undertake construction and maintenance activities and consequently the additional material costs of stainless steel are acceptable when the system is viewed from a whole life cost perspective; a large part of the capital cost is obviously also due to the labour and plant costs.

M16 anchor rod fixings made from super austenitic stainless steel (UNS N08926/N08367) support the auto transformer feeder cables (at 2m centres) and the baseplate/stovepipe for the ROCS (at 8.5m centres). The rod fixings were resin anchored into the tunnel brickwork to a depth of 315mm. Super duplex stainless steel 2507 (UNS S32750) was used for the baseplate and stovepipe which holds the registration arm and for the cantilever structural components of the registration arm for the ROCS.

Austenitic stainless steel grade Type 316L (UNS S31603) has been used for the supporting steelwork for the ROCS in five other tunnels with less aggressive environments, as part of the Great Western Electrification Project, which electrifies the main line railway from London to South Wales. Ni

On the move with soft magnetic Ni-Fe-alloys

Improving sustainable transport with shielding and sensor applications

With the growing importance of Electro Mobility (eMobility) and the use of electric powertrain technologies (in combination with an increase of electrical/digital equipment), the demand for effective shielding materials as well as sensors is on the increase. Nickel-containing materials are playing a crucial role in this growing field of application.

Nickel-based alloys are well known for their corrosion-resistance and their high temperature strength. However, some of them have even more to offer.

Nickel-iron alloys form the group called soft-magnetic alloys. Soft-magnetic nickel-iron alloys can easily be magnetised and demagnetised. Their magnetic properties, coercive force, permeability and hysteresis losses are clearly superior to those of the iron materials.

Higher nickel content, higher shielding

One of the most important fields of application is magnetic shielding.

Electrical equipment generates electromagnetic and magnetic fields. These fields can disturb interference-sensitive devices. In order to reduce the unwanted fields, the generating and/or the sensitive devices have to be 'shielded'. The shielding effect is the result of the undesired 'magnetic flux' being redirected via the shielding material, reducing or eliminating the field inside the shielded volume. The shielding property of a material is described by the shielding factor and correlates with the so called 'permeability'.

Generally speaking, the higher the nickel content (up to 85% Ni), the higher the shielding factor. The appropriate shielding material can be selected according to the strength of the undesired magnetic and electromagnetic field. Alloys with about 80% Ni provide the highest magnetic permeability. Soft magnetic nickel-based alloys, such as VDM® Magnifer 7904 (UNS N14080) with more than 75% Ni is a shielding material with the highest permeability.

Typical applications for shielding in nickel-iron alloys include sound recording heads, microphones, sensors and electron beam tubes. In some cases, these nickel materials are also used for cladding complete examination rooms in hospitals where highly sensitive measuring equipment is used.

The challenge is to transfer the know-how and experiences from other industries to the transportation sector.

Increased demand on sensors

With eMobility, the demand on sensors is increasing. For example, current measurement sensors for battery management systems are made from soft-magnetic nickel-based alloys due to their properties of saturation flux density, high permeability and low coercive force.

For both medical and transport applications alloys such as VDM® Magnifer 7904, VDM® Magnifer 36 (UNS K93600), and VDM® Magnifer 50 (UNS K94840) can be used.

Manufacturing for the desired properties

For good soft magnetic properties, very pure material has to be produced, starting with melting in air followed by vacuum treatment or vacuum melting. Soft-magnetic nickel-iron alloys are available as solid parts—forgings, bars, sheet, plate, strip and sheet metal—and as thin films or wires. The Ni-Fe alloys must be subjected to a final annealing. Only after the final annealing do the extraordinary soft-magnetic properties become apparent for the first time in the manufacturing process.

The desired magnetic properties of the nickel-iron alloys can be adapted to specific applications by alloy modifications as well as by adjusting the annealing procedures.

Thus, the future of soft-magnetic nickel-iron-alloys is poised to play a key role in the implementation of a sustainable and climate-friendly transport systems. Ni

VDM

▽ *VDM melting plant, Unna, Germany*

▽ *Strip made of nickel-iron alloys*

NICKEL PLATED STEEL

Preventing clogged lines

Innovation is often sparked by a frustrating experience. In this case, the car belonging to a senior executive of a major Original Equipment Manufacturer (OEM) broke down on a road trip, due to the complete failure of his fuel delivery system. The good news? A new fuel line application using nickel-plated steel was born.

Better internal protection

Photomicrographs from the fuel lines of the vehicle showed severe corrosion had clogged the lines, restricting flow of fuel to the engine. Fuel lines for gasoline powered vehicles have traditionally been manufactured from standard low carbon steel. OEMs concentrated on external tube coatings to protect against the corrosive attack of salt and mechanical damage from gravel. 'Internal' surfaces did not garner the same attention until the increased use of alcohol blended fuels (ethanol blends) in automotive fuels. These hydroscopic fuels can be very corrosive to the internal diameter of a fuel line, leading to total system failure.

Growing demand from OEMs

With increased use of Ethanol blended fuel, more nickel-plated steel is being requested by tube makers. The beauty rests in its physical properties. Nickel melts at roughly the same temperature as steel and when a nickel-plated steel sheet is formed into a tube and welded, the melted nickel flows over the weld bead encapsulating it creating a coated internal surface and a protective barrier against corrosion.

As fuel blends continue to evolve, nickel-plated steel has proven to be an effective material for automotive innovation. Ni

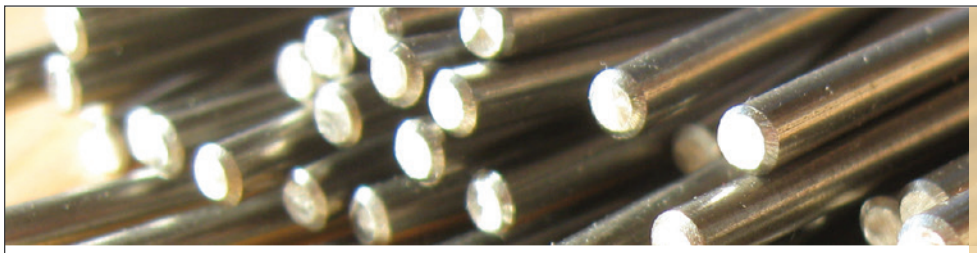
△ *Fuel line components made using nickel-plated steel.*

TATA STEEL

UNS details

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

UNS	C	Co	Cr	Cu	Fe	Mn	Mo	N	Ni	P	S	Si	Ti	W	Al
S30400 p. 6, 7, 10, 11	0.08 max	-	18.0-20.0	-	bal	2.00 max	-	0.10 max	8.0-10.0	0.045 max	0.030 max	0.75 max	-	-	-
S30403 p. 2, 10, 11	0.03 max	-	18.0-20.0	-	bal	2.00 max	-	0.10 max	8.0-12.0	0.045 max	0.030 max	0.75 max	-	-	-
S31600 p. 10, 11	0.08 mas	-	16.0-18.0	-	bal	2.00 max.	-	0.10 max	10.0-14.0	0.045 max	0.030 max	0.75 max	-	-	-
S31603 p. 2, 7, 10, 11, 12	0.03 max	-	16.0-18.0	-	bal	2.00 max	2.00-3.00	0.10 max	10.0-14.0	0.045 max	0.030 max	0.75 max	-	-	-
S31635 p. 10	0.08 max	-	16.0-18.0	-	bal	2.00 max	2.00-3.00	-	10.0-14.0	0.045 max	0.030 max	0.75 max	5x(C+N) min 0.70 max	-	-
S31703 p. 10	0.03 max	-	18.0 20.0	-	bal	2.00 max	3.00-4.00	-	11.0-15.0	0.045 max	0.030 max	0.75 max	-	-	-
S32101 p. 10	0.04 max	-	21.0-22.0	0.10-0.80	bal	4.00-.00	0.10-0.80	0.20-0.25	1.35-.70	0.040 max	0.030 max	1.00 max	-	-	-
S32205 p. 10	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. 4, 10, 12	0.030 max	-	24.0-26.0	0.50 max	bal	1.20 max	3.3-5.0	0.24-0.32	6.0-8.0	0.35 max	0.020 max	0.80 max	-	-	-
N08904 p. 10	0.020 max	-	19.0-23.0	1.00-2.00	bal	2.00 max	4.00-.00	-	23.0-8.0	0.045 max	0.035 max	1.00 max	-	-	-
N08926 p. 12	0.020 max	-	19.0-21.0	0.50-1.50	bal	2.00 max	6.00-7.00	0.15-0.25	24.0-26.0	0.030 max	0.010 max	0.50 max	-	-	-
N08020 p. 10	0.07 max	-	19.0-21.0	3.00-4.00	bal	2.00 max	2.00-3.00	-	32.0-38.0	0.045 max	0.035 max	1.00 max	-	-	-
N08367 p. 5, 12	0.030 max	-	20.0-22.0	0.75 max	bal	2.00 max	6.0-7.0	0.18-0.25	23.5-25.5	0.040 max	0.030 max	1.00 max	-	-	-
N10276 p. 5, 10	0.01 max	2.5 max	14.5-16.5	-	4.0-7.0	1.0 max	15.0-17.0	-	bal	0.025 max	0.010 max	0.08 max	-	3.0-4.5	-
N06022 p. 10	0.01 max	2.5 max	20.0-22.5	-	2.0-6.0	0.50 max	12.5-14.5	-	bal	0.02 max	0.02 max	0.08 max	-	2.5-3.5	-
N06059 p. 5	0.01 max	0.3 max	22.0-24.0	-	1.5 max	0.5 max	15.0-16.5	-	bal	0.015 max	0.005 max	0.10 max	-	-	0.1-0.4
N05500 p. 9	0.25 max	-	-	27.0-33.0	2.0 max	1.5 max	-	-	bal	-	0.01 max	0.5 max	0.35-0.85	-	2.30-3.15
N01555 p. 15	0.005 max	0.005 max	0.005 max	0.005 max	0.005 max	-	-	0.025 max	54-57	-	-	-	bal	-	-
K93600 p. 13	0.10 max	1 max	0.50 max	-	bal	0.60 max	0.50 max	-	35-38	0.025 max	0.025 max	0.35 max	-	-	-
K94840 p. 13	0.05 max	0.50 max	0.30 max	0.30 max	bal	0.80 max	0.30 max	-	47-49	0.03 max	0.01 max	0.50 max	-	-	-
N14080 p. 13	0.05 max	0.50 max	0.30 max	0.30 max	bal	0.80 max	3.5-6.0	-	79.0-82.0	0.02 max	0.01 max	0.50 max	-	-	-



WIKIMEDICOMMONS

How Nitinol's unique properties help shape the new waste heat technology

As a metal alloy of nickel and titanium, Nitinol exhibits the unique properties of shape memory and superelasticity. Its key properties are that although it can be bent out of shape, it reverts to its original structure when heated to a certain temperature. Nitinol also expands when cooled, making it an ideal component of the new technology.

A bundle of metre-long Nitinol wires is attached to a piston, with cold and hot water being alternately flushed over the wires every ten seconds. This rapid expansion and contraction of about four centimetres drives the piston. A linked hydraulic system then drives a generator.

Most existing applications for Nitinol only require small quantities of the material, e.g. medical devices. The new technology could be the first industrial-scale application of Nitinol. Each unit would contain several kilograms of this shape memory alloy. Ni

NITINOL HELPS ENERGY-EFFICIENT ENGINE TURN WASTE HEAT INTO ELECTRICITY

A new energy-efficient engine that generates electricity from waste hot water could reduce both carbon emissions and energy consumption within the shipping industry and many other sectors.

The application uses the special 'shape memory' properties of Nitinol (UNS N01555)—a nickel-titanium alloy—and is being developed by Dublin-based firm Exergyn.

According to Exergyn's Head of Product Management Mike Langan, "the technology will make recovery of 'low-grade waste heat'[1] cost effective for the first time."

Langan says the technology can help ship owners to improve efficiency and reduce emissions, helping them to comply with the increasingly stringent regulations.

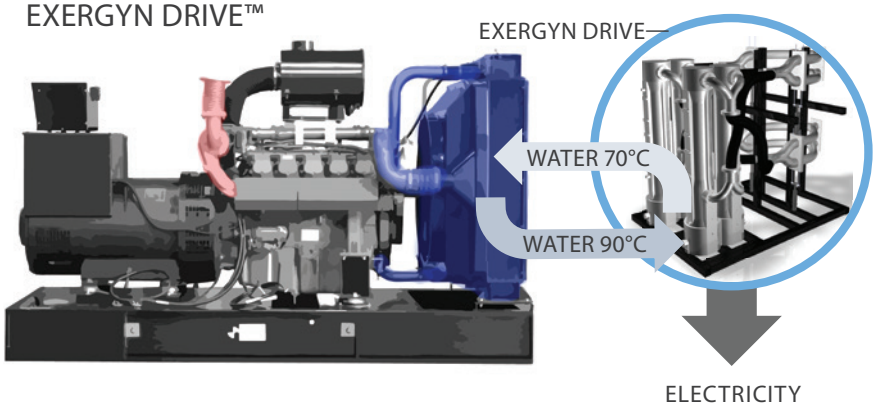
Indeed, the International Maritime Organisation (IMO) has forecast a 250% increase in shipping emissions if actions are not taken to improve engine efficiency.

Furthermore, the technology is safe for shipping as there are no hazardous fluids prone to leakage and it has a low operating pressure.

Exergyn aims to deliver a product that is one of the lowest cost forms of power generation, with a LCOE[2] (levelised cost of electricity) of 0.045 €/kWh or less.

Exergyn were awarded 2.5 million euros from the European Commission's Horizon 2020 fund to help bring the product to market. Industrial tests are due to start later this year.

Tests for the shipping sector are scheduled for 2019, with a further 6,000 hours of testing the full system in the pipeline. Ni



EXERGYN

1. *Low-grade waste heat ('LGWH') is defined as water of <120ºC, usually 80º-95ºC. Most power producers are making no use of their LGWH.*
2. *The levelised cost of electricity (LCOE), also known as Levelised Energy Cost (LEC), is the net present value of the unit-cost of electricity over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime.*

The Nickel Edition
BROMPTON BIKE

A shining example of form follows function

When Andrew Ritchie started designing a folding bike in his South Kensington flat in 1975, he knew he wanted to make a better and more beautiful folding bike than the clunky, awkward fold-in-half one he had just tried out.

His first Brompton bike faced challenges, but after 25 years of refining and constant improvements, Brompton Bicycle Ltd. is now the largest bicycle manufacturer in the UK.

With its striking finish and smart design, the bicycle folds into an effective compact unit that can be carried, towed or stowed easily.

The Nickel Edition is Brompton's finest bike. The polished 50-micron high-phosphorus electroless nickel plating creates a rich, reflective finish and is Brompton's most advanced finish to date with exceptional anti-corrosion resistance usually reserved for mining and deep-sea drilling equipment.

With over 45,000 bikes in production each year, the Brompton is an easy bicycle to pedal these days. Ni

BROMPTON BICYCLE LTD.

△ *The Nickel Edition Brompton*

▽ *Folded bike: The chain and gears are in the centre of the folded package keeping them away from clothing and luggage.*

Bottom left: Each bike is hand brazed (joined together) by a skilled craftsman who has a 'signature' which they proudly stamp on the parts of the bike that they work on.

BROMPTON BICYCLE LTD.