NICKEL MAGAZINE

THE MAGAZINE DEVOTED TO NICKEL AND ITS APPLICATIONS

NICKEL, VOL. 38, Nº 3, 2023

Nickel leading the charge

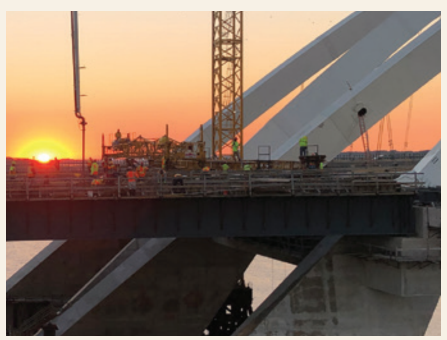
Nickel in rechargeable aviation batteries

Battery chat with Dr. Stanley Whittingham

Commercially pure nickel: outstanding corrosion resistance

MODJESKI AND MASTERS

CASE STUDY 29
IOWA-ILLINOIS MEMORIAL BRIDGE



ISSOA

The arches are made from a combination of nickel-containing ASTM A709 HPS70W and ASTM A709 HPS50W steel coated with a fluoropolymer coating system. The anchor and coupling nuts are made of Type 2507 (UNS S32750) duplex stainless steel with 116-ksi yield strength to reduce maintenance needs and extend the service life of the arches. Uncoated weathering steel was used in the floor system. Stainless steel was also used for the rebar in the bridge deck.

It is one of the largest investments ever made by the two states Iowa and Illinois. Key priorities for the $1 billion USD project? Building a bridge designed for a 100-year lifespan as well as creating an iconic landmark that would transform and beautify the riverfront in the Quad Cities.

The original twinned bridges were no longer capable of efficiently handling ever-increasing traffic loads in the bustling region. The first was built in the 1930s and then twinned in 1959. There were no shoulders and lane widths were substandard by modern day codes. Working together, the team of the Iowa and Illinois Departments of Transportation, engineering and infrastructure design firms Alfred Benesch and Company, and Modjeski and Masters developed a steel true arch "basket-handle" design with minimal bracing.

General contractor Lunda Construction Co. began construction in 2017 and the bridge opened in late 2021. The need to keep traffic flowing between both states required complex staging and unique building methods. To facilitate construction while sandwiched between two bridges, Lunda brought in two of the tallest free-standing tower cranes (400 ft tall) ever used to build a bridge in the Midwest.

Constructing a bridge with 245 ft tall basket-handle arches required high-quality materials and emerging technology. To assemble them, fabricator Industrial Steel Construction created 30 welded steel box sections for each of the two spans at its Gary, Indiana facility. The arch sections were loaded onto barges and trucks and delivered to the Quad Cities. The two spans incorporate more than 35,000 tons of structural steel in total.

This transformational project won top honors at the America's Transportation Awards. Ni

EDITORIAL:
NICKEL LEADING THE CHARGE

Victor Hugo once said, "There is nothing more powerful than an idea whose time has come". *And battery technology — particularly its role in the transition to an electric future — is such an idea. This is how Dr. Parvin Adeli, the Nickel Institute's battery expert opened the Nickel Institute Battery Day in July 2023. You can read more about that event on page five.*

Battery Day was a rich source for the latest information on nickel-containing batteries and inspiration for this edition of *Nickel*. Nickel-containing batteries are shaping the future of energy storage and transportation, and the charge towards a greener and more connected world is propelled by nickel batteries.

EVIATION ILLUSTRATION

Nickel-based chemistries account for almost two-thirds of the battery capacity for the electric vehicle sector, and new applications for transport are continually under development. The sky's the limit. Literally! At around 12% of transport-related emissions, aviation is in the spotlight. Could battery powered aircraft be common in the future? In this issue we weigh up the advances and challenges in the quest to electrify aviation.

Dr. Stanley Whittingham tells us about his own battery journey from the 1970s and the breakthroughs that led to his Nobel Prize for chemistry in 2019 for the development of lithium-ion batteries. His work and that of his co-laureates, Dr. John Goodenough and Dr. Akira Yoshino, is the basis for much of the battery technology in place today.

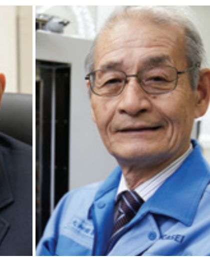
And in our explainer series, *Why Nickel?* the topic is of course, batteries!

While the focus of this issue of *Nickel* may be on batteries, we are not forgetting some of the other applications for nickel-containing materials. Turn to the back page to learn about the stunning Salmon Eye, a project commissioned to inspire and inform on how to provide the world with sustainable food from the sea.

Another idea whose time has come.

Clare Richardson
Editor, *Nickel*

JOHN B. GOODENOUGH



AKIRA YOSHINO

STANLEY WHITTINGHAM

Dr. John Goodenough, Dr. Akira Yoshino, and Dr. Stanley Whittingham were awarded the 2019 Nobel Prize for chemistry, for their work in developing lithium-ion batteries.

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Nickel magazine is published by Nickel Institute

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Design: Constructive Communications

ISSN 0829-8351

Printed in Canada on recycled paper by Hayes Print Group

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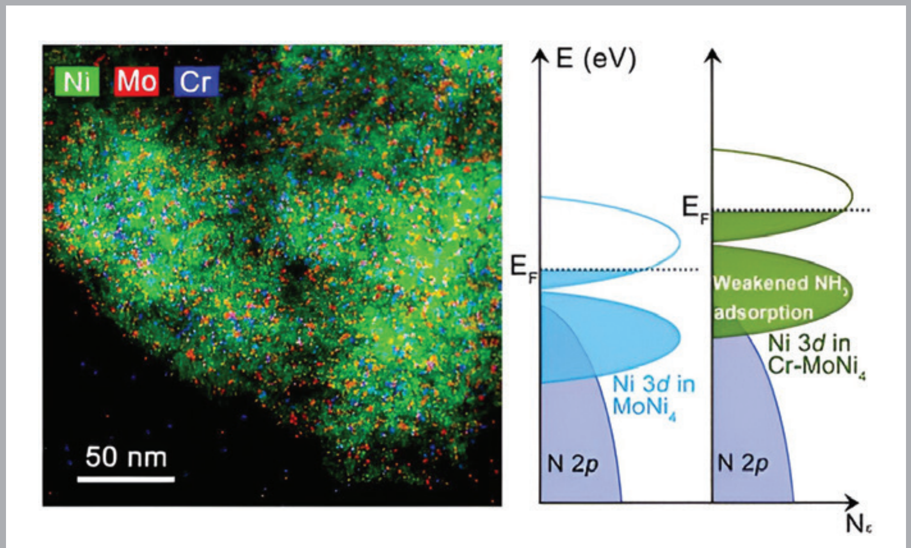
NICKEL NOTABLES

Hydrogen cell helper

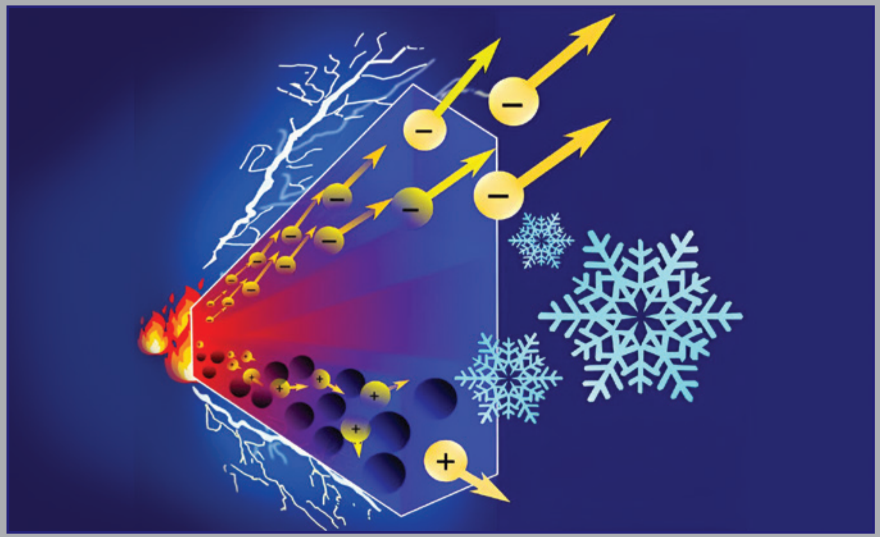
It's an important step towards making hydrogen fuel cells cleaner, more cost-effective, and more efficient. A research team from the University of Science and Technology of China (USTC) has developed a nickel-based anion-exchange membrane fuel cell (AEMFC) anode catalyst with high resistance to ammonia (NH_3) toxicity. Platinum on carbon (Pt/C) catalysts have demonstrated susceptibility to ammonia poisoning which causes performance degradation. The team was able to tackle this problem by enriching electrons around nickel sites and doping chromium into the efficient hydrogen oxidation catalyst molybdenum-nickel alloy ($MoNi_4$), greatly weakening the ammonia adsorption. Findings were published in the *Journal of the American Chemical Society*.



JOURNAL OF THE AMERICAN CHEMICAL SOCIETY (2023). DOI: 10.1021/JACS.3C06903

A golden discovery

Physicists from the Vienna University of Technology have discovered excellent thermoelectric properties of nickel-gold alloys that can be used to efficiently convert heat into electrical energy. Outperforming conventional semiconductors, the unique combination of these metals enables high electrical conductivity and a significant Seebeck coefficient. By mixing the magnetic metal nickel with the noble metal gold, they were able to radically change the electronic properties. As soon as the yellowish colour of gold disappears when about 10% nickel is added, the thermoelectric performance increases rapidly. Because of particular electronic properties of the nickel atoms, positive charges are scattered more strongly than negative charges, which resulted in the desired imbalance to create a high thermoelectric voltage. Explains Fabian Garmroudi, first author of the study, "With the same geometry and fixed temperature gradient, many times more electrical power could be generated than in any other known material." The high-power density may enable everyday applications in the large-scale sector in the future, opening doors for other promising, cost-effective metallic alloys for thermoelectric use.



THE DAILY SCIENCE

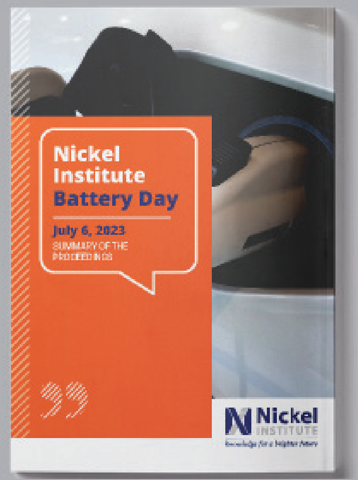
UNSPLASH+

A good dose of vitamin C

What's good for human health has proven to be an effective ingredient for EV battery recycling. Researchers at the University of Birmingham have developed a method to separate out higher value materials using ascorbic acid. To test the concept, Nissan Leaf battery cells with at least 40,000 miles were treated with organic acids, such as ascorbic acid (Vitamin C), as the leaching agents. The results, published in *ChemRxiv*, demonstrated that ascorbic acid selectively leaches low-value electrode material (lithium manganese oxide) and leaves the higher-value nickel and cobalt-based material in a solid state, from which it can be directly recycled. Their now patented process is less energy-intensive and uses less hazardous chemicals than current recycling methods.

Power presentation

In July 2023, the Nickel Institute brought together some of the brightest minds in the battery world to share their insights and expertise on advances in nickel-containing battery technologies. Eight expert speakers, including Nobel Prize winner for chemistry, Professor Stanley Whittingham and Dr. Jeff Dahn, Principal Investigator NSERC/Tesla Canada Alliance Grant at Dalhousie University, explored nickel-containing battery technologies, discussed emerging applications and examined the role of recycling. The Battery Day summary report is now available from the Nickel Institute website. The next NI Battery Day is scheduled for June 6, 2024. *www.nickelinstitute.org*



ELECTRIC AVIATION:
APPROACHING TAKE-OFF SPEED?

PIPISTREL

The Pipistrel Velis Electro, the first type certification worldwide of a fully electric aircraft and an important milestone in the quest for environmentally sustainable aviation.

— European Union Aviation Safety Agency

In the battle to reduce greenhouse gas emissions, virtually all modes of transport are exploring and deploying alternatives to fossil-fuel powered vehicles. Battery power is playing a major role in this, particularly in road-based applications. Until now, the aviation sector has been relatively resistant to such change. However, it is already responsible for some 12% of transport-related emissions. Demand for air transport, both passenger and freight, is growing rapidly again following the pandemic. Without mitigation measures, this level of emissions seems likely to increase. It is therefore understandable that aviation is under increasing pressure to reduce its environmental impact through alternative energy sources.

Radical redesigns required

So far, the sector has preferred to explore the potential of options such as hydrogen power and sustainable aviation fuels. To an extent, this reflects existing market inertia; the airline industry is well established; original equipment manufacturers produce airframes compatible with conventional jet fuel-powered aeroengines, while aeroengine manufacturers make power plants compatible with modern airframes. Switching to electrical power plants would require the radical redesign of commercial airframes, which would be both costly and time consuming.

The other element is that batteries have been perceived as lacking sufficient energy density to compensate for their weight. This aspect is seen as particularly challenging given that, unlike jet fuel, their weight doesn't decrease as the power is used. It is, however, worth noting that this is somewhat of a misrepresentation; electrical power can lead to weight savings in a number of other aspects of aviation.

Providing proof of concept

So, is there a role for battery power in aviation? Clearly, the answer is: yes. Indeed, in the area of light aircraft, electrical power is already a reality; the Pipistrel Velis Electro – a single-engine, two-seater light aircraft – has been certified for operation in Europe since 2020. Looking almost indistinguishable from a conventional light aircraft, its two high-performance batteries make it capable of flying for up to 50 minutes (and it can operate on one battery in the event of failure).

While the certification of the first true electric aircraft may not alone be a gamechanger, it represents an important proof of concept. It has made it inarguable that battery powered aircraft can, and do, work. This is acting as a stimulus to new developments.

The ideal next step would be to increase the energy density of batteries; enlarge this, and range and performance will be extended as a result. It is here that nickel is likely to play an increasing role. At the moment, nickel has a number of applications in conventional aircraft, particularly in jet turbines, with superalloys providing exceptional high-temperature strength, corrosion resistance, and thermal stability. In the aviation of the future, it will be nickel's capacity to boost battery energy density that will become its dominant role.

A significant boost

Nearly all batteries deployed in electric aircraft already in service and in development, make use of high nickel chemistries to achieve high-specific energy. In high-specific energy batteries, the nickel is usually used in combination with cobalt and either manganese, 'NCM', or with aluminium, 'NCA'. When these metals are distributed throughout the transition metal layer in a cathode, they act together to enhance performance. Manufacturers have realised that increasing the level of nickel enhances the storage capacity of a battery without significantly increasing weight, improving the overall energy density. Now that battery power for aircraft has been proven viable, this development will provide a further significant boost.

The question of safety of batteries in aviation is fundamental. The early days of Boeing's 787 'Dreamliner', albeit a conventionally powered aircraft, were marked by fires caused by thermal runaway issues in the lithium batteries they used for onboard power. This is

In the future, it will be nickel's capacity to boost battery energy density that will become its dominant role.

Joby JAS4-1 Specifications
Aircraft type: *Tiltrotor eVTOL*
Seats: *Pilot + 4 pax*
Max takeoff weight: *4,800 lb*
Length: *21 ft*
Wingspan: *39 ft*
Max cruising altitude: *15,000 ft*
Max cruise speed: *170 kt (200 mph)*
Range: *Up to 150 sm (130 nm)*
Propulsion: *Six electric motors, four on the wings and two on the V-tail. Motors include dual redundant inverters, variable prop control, nacelle tilting and cooling, and dual windings.*
Power/energy storage: *Four lithium-ion battery packs*

–jobyaviation.com

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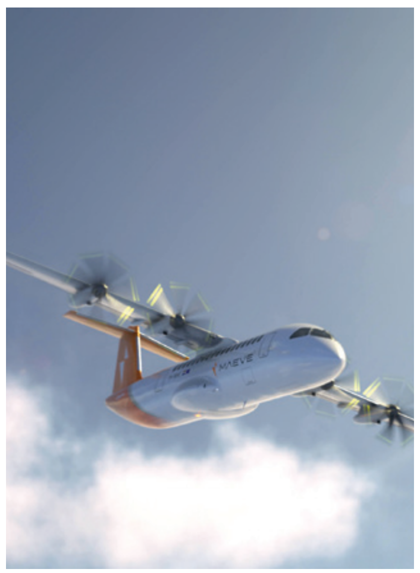


Maeve 01 is the world's first-ever electric aircraft with a capacity of 44+, setting a new standard for sustainable and eco-friendly air travel. With a recharge time of only 35 minutes, the Maeve electric aircraft enables rapid and streamlined flight operations.

– Maeve Aerospace B.V.

a serious problem on the ground, and a considerably greater one when in the air. The industry has recognised these concerns, and batteries certified for aircraft use must be shown to be resistant to thermal runaway. In the event that fire does happen, it is contained and does not spread across other batteries or even the aircraft. Furthermore, any potential risks need to be weighed against the risk posed by carrying large quantities of highly flammable aviation fuel.

Lighter, quieter, and more reliable

In terms of market potential for aircraft batteries and nickel use, it's important not to view this opportunity solely through the prism of existing aviation applications. Conventional airliners have immense design restrictions imposed on them by their reliance on (usually) two increasingly large, heavy, and noisy power plants, which goes a long way to determine their deployment, requiring significant infrastructure in terms of airports. Despite this, there is no likelihood of them being phased out in the foreseeable future; electric batteries cannot offer alternatives yet.

In other settings, however, they can. Electric engines are lighter, quieter, more reliable with fewer moving parts and offer a relatively constant power-to-weight ratio irrespective of their size. As a result, more, rather than larger, engines are an option, with far fewer limits on their location on the airframe. This means that electric vertical take-off and landing (eVTOL) aircraft are becoming a reality. The near-silent operation of their engines opens up a range of potential applications, including air taxis, delivery services and emergency services.

As well as interest from existing players such as Airbus and Boeing, many startup manufacturers are seeking to reach the market. These include Maeve (44–50 passengers) and Eviation (nine passengers), which are seeking to produce regional airliners with ranges of 250–330 nautical miles. These will use around 30 tons and 9 tons of nickel respectively throughout their lifetime. In addition, US-based Joby Aviation and Archer Aviation, as well German manufacturer Lilium, are developing air taxis as is Velis, maker of the Pipistrel.

Estimates for the full market potential for batteries depends on a range of variables, most significantly the numbers of aircraft and batteries. However, with the growing pressure on meeting emissions targets and the increasing demand for air-based transport, the opportunities for nickel are likely to be significant. Ni

THE RACE TOWARDS **SOLID-STATE BATTERIES** IN EVS

Solid-state batteries (SSB) that have nickel-rich cathodes have captured a tremendous amount of attention in recent years and this interest keeps growing. The most significant distinction between the conventional Li-ion batteries and all-SSBs is the move from a liquid electrolyte to a solid one. Safety is the key selling point of solid-state batteries which employ solid electrolytes in lieu of their flammable organic liquid counterparts. Additionally, a solid-state battery offers higher energy density by enabling a lithium metal anode, which has specific energy ten times higher than the graphite one used in lithium-ion batteries.

Several companies are racing to place a practical solid-state battery in electric vehicles and have made bold announcements. Several motor manufacturers including Toyota, NIO, General Motors (GM), Nissan, Ford, BMW, have solid-state aspirations, and are teaming up with battery manufacturers.

Electrode material selection has a direct impact on the energy density of automotive battery cells. In a conventional Li-ion battery (LIB), the common components are lithium metal oxide cathode, organic liquid electrolyte and the typical anode material is graphite. However, in terms of theoretical energy density, the most desired anode material is Li metal. Metallic lithium has the advantage of being lightweight and possessing the lowest potential among all elements, meaning more energy can be stored.

Li metal is very reactive and if it were incorporated with a liquid electrolyte, extreme safety issues would result. Contrary to lithium-ion batteries, all-solid-state batteries provide a platform for Li metal to be integrated because the liquid electrolyte (+ separator) is replaced with a solid layer. This rigid layer hinders leakage and reduces the formation of unwanted structures. Furthermore, solid electrolytes have a higher thermal stability compared to liquid electrolyte. This means SSBs can offer a wider range of applications and enhanced safety. Solid state batteries also have the advantage of eliminating expensive cell production steps such as electrolyte filling.

In both battery types, cathode consists of cathode active material plus a conductive agent (e.g., carbon additive) and possibly a binder (polymer-based). Therefore, in a SSB, incorporating a Li metal anode in combination with a Ni-rich cathode offers high practical capacities. High-capacity Ni-rich cathodes complement solid-state batteries. And higher safety means that ultra-Ni-rich cathodes can be implemented to provide a battery with very high energy density.

While there is excitement and advantages of solid-state batteries, technical challenges still need to be overcome. SSB-based EVs have a way to go before they can be adopted widely by the market, but there is everything to play for. Nickel-rich solid-state batteries have the potential to eliminate range anxiety and ease the transition to electric vehicles. Ni

A prototype of Toyota Motor Corp.'s forthcoming electric vehicle batteries, unveiled at a media event preceding the Japan Mobility Show in October 2023.

BATTERY CHAT — AN INTERVIEW WITH DR. STANLEY WHITTINGHAM

SEBASTIAN GOLLNOW, AP IMAGES

Dr. Stanley Whittingham is a Chemistry Nobel laureate with more than 200 publications in leading scholarly journals and 16 patents. He has earned a national and international reputation as a prolific scientist.

Dr. Stanley Whittingham is a SUNY distinguished professor of chemistry and the 2019 Chemistry Nobel Laureate for pioneering research leading to the development of the lithium-ion batteries. The Nickel Institute's battery specialist, Dr. Parvin Adeli caught up with him to talk about his long career in battery research and what's next.

Q: Tell us about your battery research journey. What made you embark on a career on batteries and carry on?

Back in the 1970s the interest was electric vehicles, electronic gadgets, backup storage for applications like telephones, but not for large grid storage. I was working for Exxon at the time, and their interest was that they wanted to be the energy company not the oil company. They wanted to explore EVs as well as continue with ICE.

Q: When did you realise the significance to the energy landscape of your discovery of the intercalation (housing) of lithium ions in a host material?

Early on. Because our first paper was published in *Science* and that is not easy to get into. The particular material that we worked on was titanium disulphide which, at a molecular level, has spaces that can house – intercalate – lithium ions. Exxon made small cells for some applications. The price went down, and Exxon lost interest and licensed to Sony. Sony then developed the lithium-ion rechargeable battery for all the electronic gadgets. Right now, most systems are 80% nickel, 10% manganese, 10% cobalt.

Q: Do you think a Nobel Prize was overdue?

People have commented on it. John Goodenough was the oldest person to receive a Nobel Prize. We were happy that he lived long enough to accept it.

Q: What were the key challenges you faced during the process of developing the lithium-ion battery?

The biggest challenge is that we made all the inventions. All the battery intellectual property is American or British but then everything got moved to Asia because Europeans and Americans did not want to invest the money in learning how to manufacture. The huge issue we face now is that we have no supply chain in the US for materials, trained people or manufacturing facilities.

We just received $113 million USD from the federal government of New York State to build a prototyping facility in an old IBM building and $12 million USD to train the workforce. That is what is missing in North America.

Q: You are currently working on the impact of Nb coating/substitution in Ni-rich cathode materials. How does the modification with Nb affect the overall battery performance?

We know that 60% nickel is stable in the air and works well. However, once the nickel content reaches 80%, stability in the air becomes compromised. This means we have to control the atmosphere more as the reactivity with the battery electrolyte increases so we lose capacity fairly fast. We started stabilising the 80% nickel by adding valence elements. We found niobium works best. We got several hundred cycles out of 90% Ni (NMC 9055) with about 1% Nb. You do not need more than that. It looks like Nb stops the cracking of those cathode particles, and there is no capacity loss over several hundred cycles. The results are published in our 2022 open access paper: *Electrochemical characterization and microstructure evolution of Ni-rich layered cathode materials by niobium coating/substitution.*

Q: What are the next steps for this research?

The next step is to study behaviour at different temperatures and see if we can get to 800-1000 cycles. This means building bigger cells for EVs. The theoretical energy density possible for high-nickel cathodes should be 1000 Wh/kg. In reality the cell is at 250 Wh/kg, so we are only getting 25%. The goal is to get up to 500 Wh/kg to double the energy density. We are also doing some research funded by the US army to see how well the Nb-coated NMC behaves at higher and lower temperatures.

Q: Do you have the infrastructure to achieve this at Binghamton?

We have one of the few dry rooms and pouch cells manufacturing facilities in the US within a University.

I work as part of Battery 500, a large consortium of national labs and academic institutions, so we work closely together with them. We are going to scale up.

Q: We discussed cathodes, but we know that electrolytes are also important. Can you tell us about your recent studies on the impact of different electrolytes on nickel-rich cathodes?

One of the things we are doing in Battery 500 is getting rid of the graphite anode, so we are using pure Li metal. Pure Li metal does not plate-out well from the carbonate electrolyte presently used in Li-ion. We developed a new electrolyte which is really based on the old Exxon electrolyte. The new electrolyte is organic ethers, with a new salt LiFSI included.

EVIATION

Eviation, a company based north of Seattle, is designing a standard take-off plane not a VTOL.


BINGHAMTON UNIVERSITY

The goal is to get higher Ni. The question is, how high is too high?

The ether plate-out Li is much better than the carbonate. We have been looking at how stable those systems are. Do they react with Li or high nickel? So, we embarked on a thermal stability study. Our major goals in Battery 500 right now are to study the stability of the entire system, understand any side reactions that we do not want and how to wipe them out.

The stability study started maybe a year ago and we published the first paper in 2023: *Enabling Long Cycling with Excellent Structure Stability for High-Nickel Layered Cathodes in Lithium Metal Batteries.*

Q: What is the commercialisation path for Nb doped NMC materials ?

My suspicion is that people are already looking at it and they have not told us yet. When they want to commercialise it, they will come and talk to us about licensing. All the details are in the publication mentioned earlier.

Q: Two recent US startups are working on scaling up high-nickel cathode materials (Ni>90%). What's your view?

Most of the commercial batteries for the last decade have been ⅓Ni, ⅓Co, ⅓Mn and then it went to 60% Ni. Then we have Tesla using high-nickel NCA in EVs. It was 85% Ni and now going to 90% Ni. These days we talk NMCA [nickel-manganese-cobalt-aluminium oxide]. The goal is to get higher Ni. The question is, how high is too high?

Q: What is your perspective on the various applications that nickel batteries contribute to a sustainable future beyond EVs?

Beyond EVs, batteries for drones. The next logical step is search and rescue, moving people in emergencies. Also, aerospace type applications.

Eviation, a company based north of Seattle, is designing a standard take-off plane, as opposed to a VTOL. Ni

Dr. Stanley Whittingham received his BA and DPhil degrees in chemistry from Oxford University, where he is an honorary Fellow of New College. He has been active in Li-batteries since 1971 when he won the Young Author Award of the Electrochemical Society for his work on beta-alumina. In 1972, he joined Exxon and discovered the role of intercalation in battery reactions, which resulted in the first commercial lithium rechargeable batteries that were built by Exxon Enterprises. After 16 years at Exxon, he returned to academia in 1988. At Binghamton University (SUNY) he has initiated a program in materials chemistry. A Chemistry Nobel laureate with more than 200 publications in leading scholarly journals and 16 patents, Whittingham has earned a national and international reputation as a prolific scientist.

COMMERCIALLY PURE **NICKEL**

While the element nickel is the basis of a wide variety of nickel-containing alloys, what about nickel on its own? What do we know about commercially pure (C.P.) nickel?

Commercially pure (C.P.) nickel (99.0% min) is available in two grades Nickel 200 (UNS N02200) and Nickel 201 (N02201). Nickel 201 has a lower carbon content which is specified when operating above 315°C (600°F) to prevent embrittlement by graphite formation.

C.P. nickel has corrosion resistance that is useful in several chemical processing applications. An outstanding characteristic is its resistance to caustic soda (sodium hydroxide) and other alkalis. In caustic soda, C.P. nickel has excellent resistance to all concentrations up to and including the molten state. Below 50% concentration, corrosion rates are negligible, even in boiling solutions. C.P. nickel is one of the best metals for resisting caustic corrosion while simultaneously avoiding unacceptable metal contamination. C.P. nickel is used in many applications in the production of caustic soda, in caustic evaporators and crystallisers, U-tubes in heat exchangers and salt separators.

This caustic soda is then used in many significant industries, such as, extraction of alumina from bauxite which is used to produce aluminium; in pulping wood for making paper; in the conversion of fats into soap and for making artificial textiles such as rayon.

Also, C.P. nickel has excellent resistance to dry chlorine gas at high temperature. The upper limit for Nickel 201 is about 540°C (1000°F). C.P. nickel is used for reactors, coils, agitators, and piping in the 250-500°C (480-930°F) range in the production of chlorine.

While the element nickel is the basis of a wide variety of nickel-containing alloys, C.P. nickel is also an important industrial material. Ni

Grade	UNS	%Ni	%C	Strength, min, MPa (ksi) (annealed)	
				Yield	Tensile
Nickel 200	N02200	99.0 min	0.15 max	100 (15)	380 (55)
Nickel 201	N02201	99.0 min	0.02 max	80 (12)	345 (50)

C.P. nickel is one of the best metals for resisting caustic corrosion while simultaneously avoiding unacceptable metal contamination.

ASK AN EXPERT FAQ FROM THE NICKEL INSTITUTE TECHNICAL ADVICE LINE

Geir Moe P.Eng. is the Technical Inquiry Service Coordinator at the Nickel Institute. Along with other material specialists situated around the world, Geir helps end-users and specifiers of nickel-containing materials seeking technical support. The team is on hand to provide technical advice free of charge on a wide range of applications such as stainless steel, nickel alloys and nickel plating to enable nickel to be used with confidence.
https://inquiries.nickelinstitute.org/

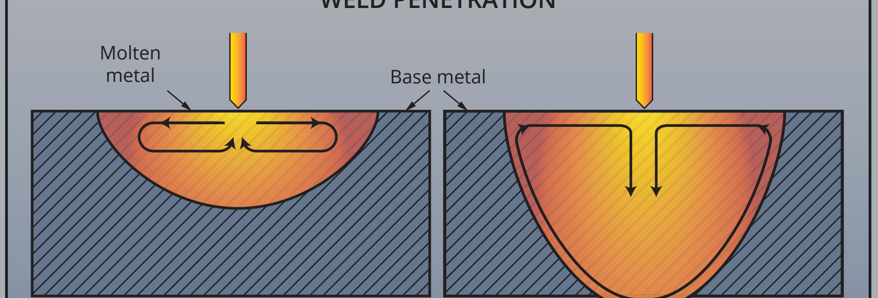
Q: A customer is requesting 316L tubing with higher sulfur (0.005–0.017%) for pharmaceutical application. After welding there is dross on the weld. My question is: Why is the higher sulfur content required? And what action can be taken to avoid the dross formation during welding?

A: Sulfur is a complicated element in nickel-containing stainless steel. In the majority of cases it's undesirable. Sulfur promotes centerline cracking in austenitic welds. Sulfide inclusions are potential sites for pitting corrosion by chloride and can produce unsightly surface imperfections which are aesthetically undesirable, particularly if stainless steel is going to be polished. Thus, stainless steel mills have worked hard to reduce sulfur levels as much as possible, down to 0.001% and lower. However, sulfur is a surface-active agent and has a large influence on weld pool flow.

The sulfur range of 0.005-0.017% is a requirement of the American Society of Mechanical Engineers' Bioprocessing Equipment Standard to ensure optimal weld penetration particularly for orbital gas tungsten arc welds which is the preferred weld method used by the pharmaceutical industry. Sulfur promotes convergent mass flow which in turn promotes heat flow to the centre of the weld at the surface which then diverts downward in the centre of the weld to promote deeper weld penetration.

The dross is primarily sulfides that float to the surface of the weld pool and thus accumulate on the surface of the advancing weld pool. The dross is due to the higher sulfur content and the amount of dross present at the end of the weld will increase as the tube diameter increases. The dross can't be avoided but can easily be brushed off. Ni

WELD PENETRATION



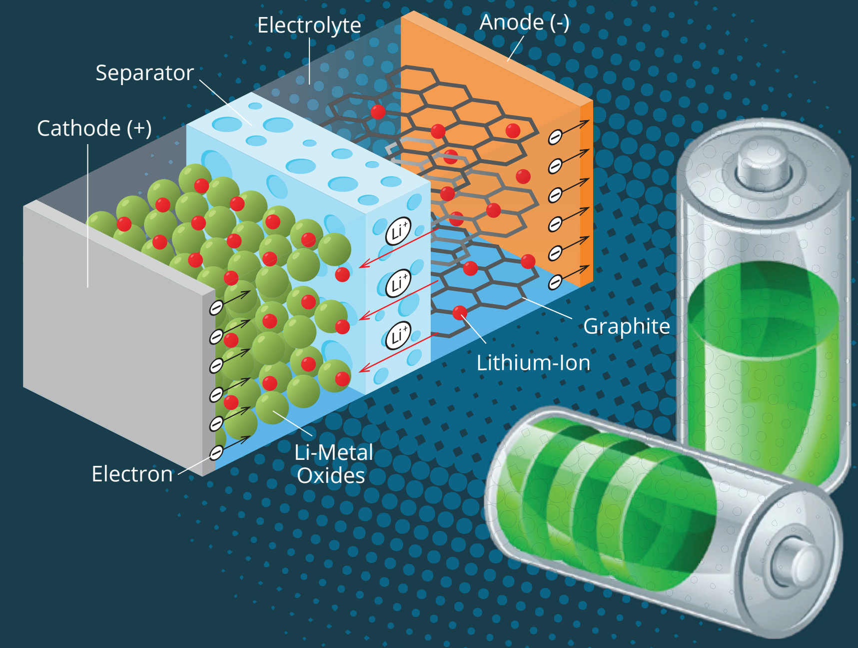
Nickel can be found in many forms from nanowires to stainless steel alloys. But what are the properties of nickel that make it an essential element in everyday objects?

Why nickel?

NICKEL IN YOUR BATTERIES

The battery

A battery converts chemical energy into electric energy. It powers devices, such as smartphones, portable power tools and cars. Batteries come in various chemistries, shapes and sizes depending on the size and power requirements of the device being powered. It consists of one or more electrochemical cells, which is comprised of two electrodes – an anode and a cathode – and an electrolyte. When the two electrodes are linked by an electrical pathway, electrons flow from the anode and deliver energy to an external device.



Why Nickel?

Lithium-ion is the most common battery type, however, there are many different formulations. NMC is the most popular cathode which stands for Lithium Nickel Manganese Cobalt Oxide.

During discharge, lithium ions (Li+) migrate from the anode to the cathode through the electrolyte. The NMC cathode serves as the host for these lithium ions. Also, at the cathode the nickel, manganese and cobalt ions are reduced by accepting the electrons that are passing through the electrical pathway. This reaction can be reversed, making the battery rechargeable.

The secret of NMC lies in combining nickel and manganese. Nickel is known for its high specific energy but poor stability; manganese has low specific energy but provides stability. Combining these metals enhances each others' strengths.

UNS DETAILS

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

UNS	C	Cr	Cu	Fe	Mn	Mo	N	Ni	P	S	Si
S31254 pg 16	0.020 max	19.5-20.5	0.50-1.00	bal	1.00 max	6.0-6.5	0.18-0.22	17.5-18.5	0.030 max	0.010 max	0.80 max
S32750 pg 2	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	0.80 max

SEBASTIAN L. TORJUSEN

SALMON EYE FOOD FOR THOUGHT

@SALMONEYE

Nickel-containing stainless steel used for the facade is 6% Mo (UNS S31254).

- *1 of a kind floating experience*
- *2 electric shuttle ferries transport visitors to the pavilion*
- *13 anchors*
- *26 m in diameter*
- *330° view from roof top*

It's a unique project, featuring 9,275 seawater-resistant stainless steel cladding elements produced to withstand long-term exposure to seawater. Called Salmon Eye, this four-storey, 23 m high floating aquaculture pavilion was unveiled in Norway's Hardangerfjord in September 2022. Salmon Eye is not only a spectacular art installation, but also world-class visitor and learning centre, and home to a fine-dining restaurant, Iris.

With one level underwater, the frame of the structure is made of bent H-beams and sheathed with steel sheets. Rectangular plates with cut corners are attached to the curved body of the building. Small stainless steel elements, designed to resemble silvery fish scales, reflect the surrounding nature on the outer surface of the pavilion.

This complex elliptical shape floats on the surface of the 100 metres deep bay, creating special requirements for the load bearing and envelope structures. Moored with large anchors to the bottom of the fjord, it weighs 1 000 tonnes and is built to withstand waves up to 5 m high. Ballast tanks are positioned on the ground floor to keep the floating structure stable.

This stunning example of sustainable architecture was designed by the Danish firm Kvorning Design for the Norwegian salmon and trout farm Eide Fjordbruk.

The project was commissioned to inspire and inform about how we can provide the world with sustainable food from the sea. Now that's food for thought. Ni