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# MOLY REVIEW



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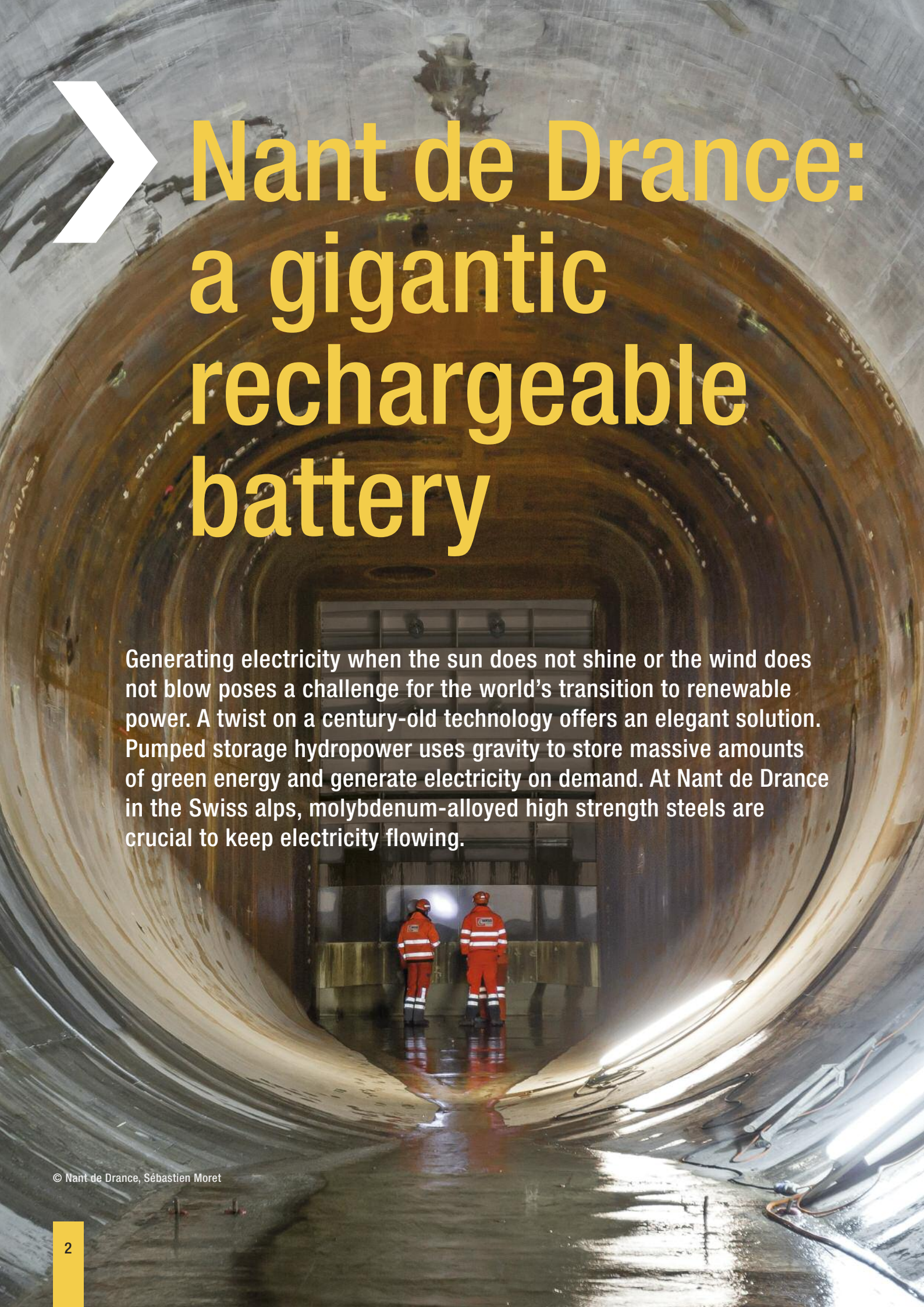
# Nant de Drance: a gigantic rechargeable battery

Generating electricity when the sun does not shine or the wind does not blow poses a challenge for the world's transition to renewable power. A twist on a century-old technology offers an elegant solution. Pumped storage hydropower uses gravity to store massive amounts of green energy and generate electricity on demand. At Nant de Drance in the Swiss alps, molybdenum-alloyed high strength steels are crucial to keep electricity flowing.



Among renewable energy sources, solar and wind are considered the most viable to reduce greenhouse gas emissions by 2050, according to the International Energy Agency. However, the availability of both depends on the course of nature, making electricity supply variable, unlike that from fuel burning power plants. For instance, if a very windy day produces more power than needed, that power is wasted without adequate storage. A mismatch in supply and demand puts communities at risk of black outs or power surges. Hydropower storage, also known as pumped storage, offers both a solution and an alternative to massive utility-scale battery banks. When there is excess electricity in the power grid, it is used to pump water from a lower reservoir into a second reservoir at a higher elevation, like recharging a giant battery. When demand necessitates, the water is released and uses gravity to drive a turbine, producing electricity. Currently, pumped storage is the largest battery technology by far, representing over 90% of all installed energy storage capacity globally, according to the International Hydropower Association. The amount of energy stored in the world's hydropower plants dwarfs all traditional batteries on earth combined, including all electric vehicles (EVs).

## Nant de Drance in numbers

**900 MW:** generating capacity

**6:** Francis turbines, each with a capacity of 150 MW

**20 Mio. kWh:** storage capacity ~ 400,000 EV batteries

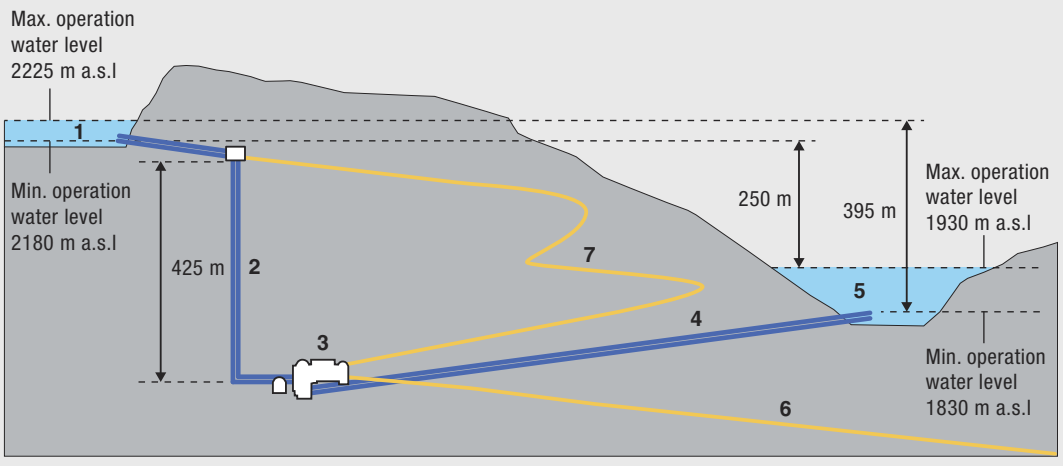
**194 m:** length of the underground turbine chamber

**25 million m³:** capacity of Vieux Emosson reservoir ~ 20 hours of electricity

## Building a plant in the Swiss alps

Pumped storage isn't appropriate for every environment: droughts, for example, can severely compromise the system's function. Hydropower technology can also affect sensitive ecosystems. And there must be a significant elevation difference for water to fall from: the greater the difference, the more energy efficient. But in areas with ample space, water, and mountains where a height difference can be exploited, pumped storage offers immense potential to compensate for fluctuations in power supply and demand. According to Australian National University, there are over 600,000 sites potentially suitable for pumped storage systems worldwide.

A good use case for pumped storage lies in Switzerland, which already generates nearly all of its electricity with carbon-free hydro and nuclear power. Around 60% comes from hydropower and an additional 35% comes from nuclear. Though the country has among the lowest carbon emissions in electricity generation worldwide, its ability to transition away from nuclear generation to renewables depends on large scale storage solutions. Bringing Nant de Drance online provides storage capacity, generates low carbon electricity, and adds system flexibility. The plant is crucial not only for stabilizing the Swiss grid but also for the European electric grid at large. For example, if a wind farm in Germany produces an excess supply, that energy can be transferred and stored at Nant de Drance.




1 Vieux Emosson reservoir
2 Vertical shafts/penstocks
3 Caverns (machines and transformers)
4 Lower pressure tunnel
5 Emosson reservoir
6 Main access gallery
7 Access and ventilation gallery

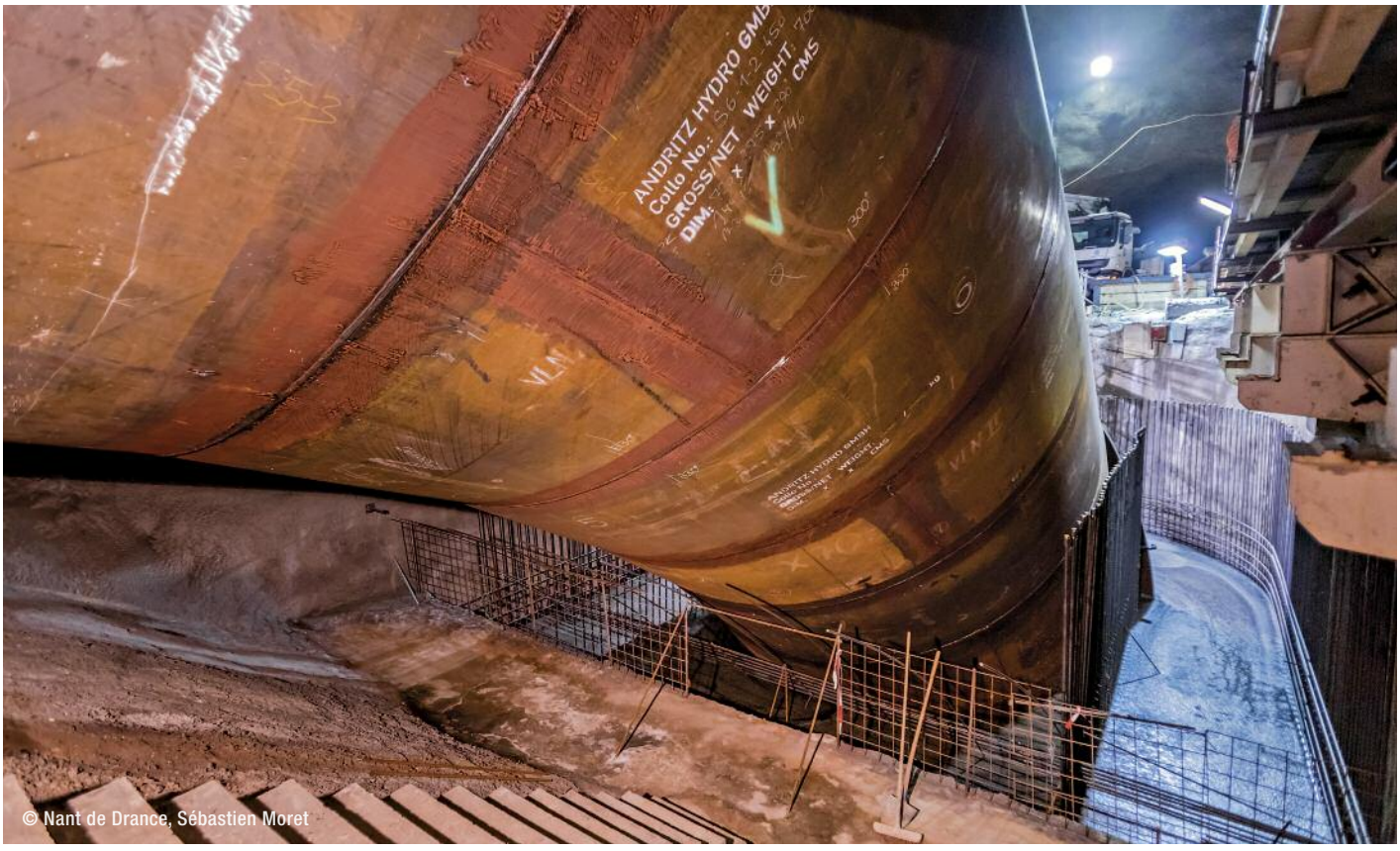
Two existing reservoirs with a significant height difference inspired this project in the Valais alps. The reservoirs are connected by a pair of gargantuan 2 km-long parallel conduits called “headraces”. These include the 425 m high vertical shafts, some 7 m in diameter. The two pipes transporting water through the headrace, known as “penstock,” are concrete-lined and reinforced with high strength steel in the areas of higher stress. Components exposed to the highest stresses use molybdenum-containing S690 QL1, a quenched and tempered steel. This includes the pipe elbows leading into and out of the vertical shaft, their flanges, and the reinforced distributors at the bottom of the shaft that supply the six turbines. Some of the areas of highest stress utilize S690 QL1 plate as thick as 130 mm, containing up to 0.7% molybdenum. Housings for the gates that help control inflow and outflow at either end of the headrace are also made with this steel. The force of the water crushing down is enormous – but heavy-duty plate steels can handle it. Especially if they’re alloyed with molybdenum.


**Inside a reinforced distributor. It divides each large diameter penstock into three branches, feeding one turbine each.**

## What makes the steel strong?

When the required yield strength of a plate steel surpasses 500 MPa, molybdenum becomes important, especially for thicker plates. When quenching a steel plate after heat treating at high temperature, the center of the plate cools more slowly than the surface, a phenomenon that becomes more pronounced as steel sections become thicker. This variation in cooling is problematic because it results in inconsistent steel strength across the thickness. Molybdenum is very valuable in thicker steel plates because it helps to homogenize the steel’s strength profile across the thickness of the plate.

**The massive penstock is reinforced with high strength steel in the areas of highest stress like the elbows.**



Molybdenum is therefore a key hardening element in high-strength penstock. The steels involved in pumped storage plants are thick plates that need to be exceptionally hard, strong, and tough, but also weldable. Molybdenum helps heavy duty steels develop an ideal balance between hardness and toughness. Strength usually comes at the expense of toughness, a measure for a material's ability to absorb impact. Imagine a piece of glass, something very hard, also needing the properties of something highly shock absorbent like rubber. Strong steel can be tempered – a form of heat treatment – to increase toughness, but then the material usually loses some of its desired strength. Molybdenum, however, largely prevents the loss of too much strength during tempering and maintains toughness. During tempering, molybdenum precipitates by itself or jointly with other elements such as chromium and micro alloys, to form what are known as "nanosized carbides", which are essentially very hard, microscopic particles in the microstructure. These microscopic particles dispersed in the microstructure are responsible for secondary hardening. When steel is heated and cooled according to carefully designed time-temperature schedules, its microstructure can be adjusted to a wide variety of phase constituents, grain sizes, and other structural features resulting in wildly different properties. Molybdenum plays a major role in controlling the phase formation and particularly promoting strong microstructures.


**Installation of a pump turbine. The turbine blades are made of martensitic stainless steel, containing 0.3–1.0% molybdenum.**

## Nant de Drance: excellent energy efficiency

With its 900 MW of installed generation capacity, around as much as a typical nuclear reactor, the Nant de Drance plant is one of the most powerful in Europe. It operates at over 80% efficiency – among the highest achieved in pumped storage power plants, and far above traditional thermal power plants. For example, coal-fired plants average just over 33% efficiency. They can also take hours to reach full operation. Nant de Drance, on the other hand, can start up in two minutes and go from pumping to generating in less than five minutes, so it can react to any spike in demand or drop in supply almost instantaneously.

Because Nant de Drance will so greatly improve the Swiss grid's ability to react to rapid changes in power supply and demand, the country's famous railway system, SBB, became a shareholder in the project. SBB's trains are fully electrified, requiring as much electricity as Switzerland's largest city, Zurich. However, power demand for the rail system varies dramatically throughout the day, peaking to several hundred MW in the early morning when locomotives all over the country power up nearly simultaneously. Demand also surges every half hour when trains leave the stations according to the synchronized train schedule.

But where exactly is all the massive equipment hidden within the pristine peaks of the Swiss Alps? Well, the entire plant is built inside a mountain. Hiding so much of the storage plant's structure within the mountain not only preserves stunning views of the Alps, but also reduces its impact on the local ecosystem. Over 17 km of tunnel were dug into the mountain using a huge tunnel boring machine. One 5 km tunnel leads to the gaping subterranean engine room, where the turbines are housed. Though it's 600 m below ground, the room is so large, the Leaning Tower of Pisa could comfortably fit inside! Most of the welding of the massive steel pipes and other components took place on site in caverns. The construction of the plant spanned 14 years and operation began in July 2022.

The world's transition to clean energy will be challenging. The inherent variability of supply requires massive energy storage systems. However, solutions are developing, and some are already available, like hydropower storage. Nant de Dance is an example of successful large-scale energy storage, made more reliable and longer lasting through the special properties of molybdenum-alloyed high-strength steels. Once again, molybdenum is instrumental in a technology poised to meet the world's energy demands more sustainably. (KW)

# Gardens of stainless steel

Located outside the Chinese city of Nanjing, the Jiangsu Garden Expo recreates famous classical gardens from across Jiangsu province. The 3.5 km$^2$ park is an outstanding example of regenerating a degraded environment into a living museum furnished with hotels, restaurants, and entertainment. Stainless steel features prominently throughout the Expo.

A hilly area in eastern Nanjing once hosted a cluster of stone and sand quarries and cement factories; they supplied building materials for a booming local construction industry that has since declined. The abandoned mines, equipment, and factory infrastructure left a legacy of severe environmental damage: kilometers of scarred mountain slopes, hills of debris, polluted water, and all but extinct plants and animals. A team of prominent personalities in urban planning, landscaping, and sustainable infrastructure headed by Chinese "starchitect", Cui Kai, has now developed the damaged site into a tourist destination that celebrates the region's rich history of garden design. Contrast and rebirth are key themes guiding the project. There are replicas of 13 existing classical gardens from across Jiangsu Province, including several UNESCO World Heritage sites, spanning over 1200 years of history.

Throughout the park, industrial remains are repurposed as massive planters for trees, living roofs, and other innovative green spaces. The timeless ancient gardens contrast with defunct factory equipment reclaimed by vegetation. These installations and others reflect the design team's mission: to create a space embracing harmonious coexistence between humans and Planet Earth; appealing beauty coupled with efficient pragmatism and to make all this sustainable in the long term. Or, in Cui Kai's own words, the Garden Expo "respects the environment, protects industrial heritage, and unearths the potential of space. (The Expo) juxtaposes old and new, heaviness and lightness, and with novel construction techniques, materials, and technologies, it creates a new space, a new landscape, a new experience". Stainless steel plays an important role in the realization of this vision. Its varied surface finishes throughout the Expo help visually express both contrast and integration between humanity and nature. Thanks to its 2% molybdenum content, Type 316 stainless steel has improved corrosion resistance, contributing to sustainability and durability. A few examples of stainless steel at the Expo are detailed below.

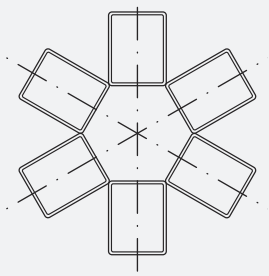
## The Future Garden

Nanjing's high humidity, abundant year-round rainfall, and vast seasonal temperature swings challenged the designers to find a solution different from the traditional greenhouse; something that would provide cover to both plants and visitors while maintaining natural airflow. The result is a forest of giant "umbrella trees", open on all sides allowing for good ventilation, shade, and protection. The Future Garden sprawls across 16,000 $m^2$ and boasts almost 1,000 species of plants. Over 1,000 tonnes of Type 316L stainless steel tubes with a mirror-polished surface are used in the installation due to the material's resistance to corrosion, and its ease of maintenance and cleaning.

42 umbrella-like stainless steel trees structurally support the whole installation. Each is covered by a 12-sided transparent acrylic sheet spanning 21 m across. This sheet allows the structures to function as any umbrella should: a thin layer of gently flowing water continuously washes over them. It produces ripples, reflections, and all sorts of visual effects that can be observed from above and below – that's why the area is also called the "Underwater Botanical Gardens". Because of the difference in the coefficient of thermal expansion between the acrylic and stainless steel, a special connection allows both rotation and displacement between the vertical stainless steel tubes that connect the branches to the acrylic sheet.

### Design and construction of the "trees"

The umbrella trees vary in height from 5 m to nearly 21 m. The "trunks" are each made up from six interconnected stainless steel cold-rolled tubes. The wall thicknesses of the rectangular hollow sections (RHS 250 x 200 mm) range from 8 to 12 mm, depending on height and load requirements. The tubes forming the two tallest trees are filled with concrete for added strength. The trunk divides into six main branches (RHS 300 x 200 x 8–12 mm), which then branch out into smaller, stainless steel elliptical hollow sections that connect to the acrylic canopy. The whole structure is welded and finished with a polished surface.



"Trunk" section

© Fabio Ries

## Commercial Complex

On its northern side, the Future Garden is bordered by the Expo's main Commercial Complex, characterized by its accordion-like façade made of perforated and polished stainless steel panels. These panels produce a spectacular distorted mirror effect that reflects the colors and lights of the garden, the water ponds, the cliffs, and the sunlight. The need for an easily installable solution with long service life, beautiful aesthetics, and minimal maintenance made Type 316L stainless steel an ideal choice for the panels. Thanks to the reflective panel façade, the Commercial Complex integrates seamlessly with the surroundings, merging with the Future Garden into a single, open, luminous space.


**Perforations and alternating angles in the Commercial Complex's façade reflect a watercolor-like version of the Future Garden's trees.**

## Cloud Pond Stage

On the eastern end of the Future Garden lies Cloud Pond, a suspended water pool reminiscent of a flooded, decommissioned quarry. Cloud Pond is flanked on its southern side by a cliff, whose huge rocky surface serves as the background and projection screen of a light show or other performances that interact with the pond's water surface. Spectators can watch the show from a vantage point on the northern side of the pond, where the slope is arranged into platforms and steps. Stainless steel is widely used in this location for several applications, but it features most notably in two places: complex-structured stone cages, used for slope protection and as wall façade decoration, and the rippling, water-like stainless steel ceiling panels.

Stone cages are often used in landscaping due to their good price-to-performance ratio and the natural feeling they emanate, thanks to the use of coarse stone. The designers of the Jiangsu Garden Expo applied this popular building


**Stainless steel cages allow for a unique stone façade that contrasts with the watery-metal ceiling panels above (left). The panels line a spectacular overhanging wall that visually balances the adjacent cliff face (right).**

technique in many locations, but with a twist: for the cage structure withholding the stones, Type 316L stainless steel was selected to attain maximum life duration and aesthetics.

The water-ripple stainless steel panels can be found on all ceilings and overhangs within the Cloud Pond Stage precinct. The Type 316L panels are installed at different angles, and they produce stunning blurred reflections of lights and colors from the surroundings: the natural stone of the walls, the rocks of the quarry cliffs, the pond water, and all the other elements. The effect is further enhanced through the light and sound show at night.

## Mirror Plaza

The last main site where a large amount of Type 316L stainless steel is used is the Mirror Plaza, serving as an access lobby to the Main Expo Hall. This is a canopy structure offering shelter from heat and rain, with a ceiling made of mirror-polished stainless steel panels. Some of the panels bear perforated patterns, allowing for a continuous dance of light underneath, even in poor weather. The panels are installed at various inclination angles, reflecting each other as well as the surroundings to a stunning distorted mirror effect.

## The role of Type 316L stainless steel

The design team preferred locally sourced and natural materials that would easily blend in with the environment. Alternatively, “unnatural” materials, namely stainless steel, create interaction with nature through reflecting and re-rendering the colors, lights, and hues of the landscape. At the same time, materials for the Expo needed to be readily available, easy to handle and install, and provide a long service life with minimal cleaning and maintenance needs. This combination of requirements made the more corrosion resistant, molybdenum-containing Type 316L stainless steel an obvious choice, and one that reflects the spirit of innovation in the designers. (FR)

**The Mirror Plaza Hall uses a blend of perforated and mirror-polished surface finishes to create a miraculous natural light show.**

# Printing a stainless steel dragon

Most 3D printed objects are less than 30 cm long. So, how is the 10 m long Oregon Dragon Bench possible? Instead of using powder, the bench was built layer by layer applying a robotic welding technology called “WAAM”. Made with 2209 duplex stainless steel weld wire, the Oregon Dragon Bench exemplifies how 3D printed metal structures can do more with less.

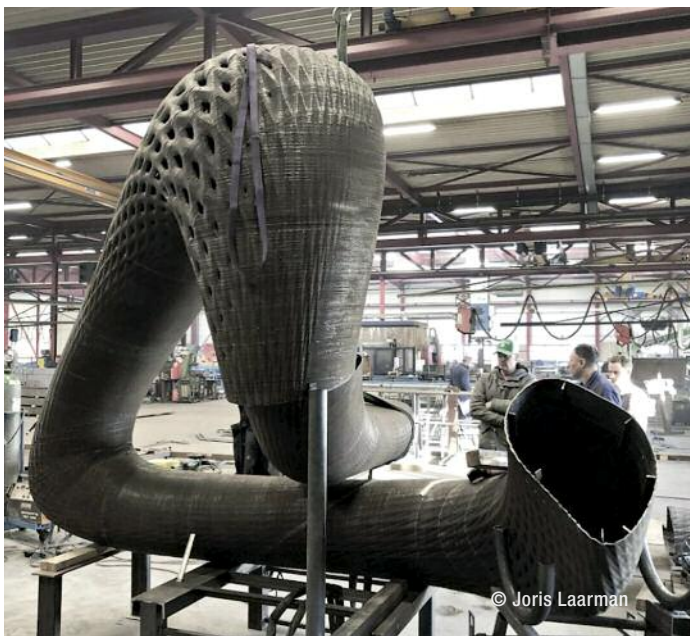

**The elegant structure was shipped from Europe to the US West Coast in three parts and welded together on site. The surface undulations contribute to stiffening the structure.**

Take a rest on the serpentine Oregon Dragon Bench at the Nike Headquarters, but don't be surprised if you want to get up and move. The bench's textured, perforated surface pattern evokes the flexible fabric and lightness of athletic sneakers. The ridges are not only stylistic but also hint at how the bench was made: by layering melted metal wire. Wire Arc Additive Manufacturing (WAAM) works similarly to powder-based additive manufacturing (AM), which makes up the bulk of 3D metal printed objects and structures. But unlike powder AM, which is restricted to the size of the printing unit, WAAM structures are built without these limitations by a welding robot in an open or enclosed space. Dutch designer Joris Laarman developed the technology less than a decade ago, and it's quickly catching on. In 2021, the spin-off company dedicated to robotic WAAM, MX3D, installed the world's first 3D printed stainless steel footbridge in Amsterdam. Robotic WAAM also produces structures less expensively and faster than powder AM, largely because welding wire costs a fraction of metal powders and the deposit rates of welding are much higher.

One consideration for the future of 3D printed stainless steel structures is the rougher-surface finish produced layer by layer. The small crevices between each layer can be hotspots for corrosion, and thus the process favors selecting more corrosion resistant grades like molybdenum-containing duplex stainless steels. The Oregon Dragon Bench has the potential for salt, dirt, and pollution to accumulate in its many tiny ridges, so the 3% molybdenum in 2209 duplex stainless steel helps resist these additional corrosion risks.

3D printing will be increasingly important to modern economies worldwide. The undulating Oregon Dragon Bench helps explain why: 3D printing allows for fantastic shapes not possible with traditional manufacturing. Importantly, the greater range and complexity of possible designs applies to industrial applications, including oil and gas and maritime, where molybdenum-containing stainless steels are already standard. (KW)

**WAAM enables the light but sturdy design: the wall thickness is thin where the load is small and thick where it is large, minimizing overall weight.**



# Sluice gates brave the shifting tides

**Sluice gates are movable barriers that regulate water levels and flow rates in waterways. In a world of changing climate and increased flooding risks, these gates need to be taller and stronger than ever before. Thanks to their strength and corrosion resistance, molybdenum-containing duplex stainless steels are the ideal construction material.**

Traditionally made of wood or metal, sluice gates make life possible in the world's most populous places: along rivers or coastal regions, which are often vulnerable to flooding. The basic technology behind sluice gates is ancient – Sri Lankan society used them over 4000 years ago – but their refinement continues today. Some modern sluice gates use duplex stainless steel, which offers substantial benefits over other construction materials. The projects detailed below showcase how these gates conserve material, capital, and emissions throughout their service lives.

## Mont St-Michel, Avranches

Mont St-Michel is a tidal island with an abbey that appears to float on the ocean. The granite rock lies about 1 km off the north-western coast of France, near Avranches. Since the 8th century, religious pilgrims crossed the muddy sands, revealed only at low tides, to reach the abbey. But the everchanging display of water and light around the monastery was under threat. A steady flow of silt from the Couesnon, Sée, and Selune rivers and sand, brought into the bay by high tides, accumulated between the rock and the coast, continuously joining Mont St-Michel with the land.

The reasons for this buildup of silt and sand go back to the 19th century, when the rivers were diverted to create pasture land, preventing them from properly carrying the deposits into the sea. To make things worse, a dike built in 1869 to provide visitors with a permanent connection to the island, further impeded free drainage. Now the sands at the foot of Mont St-Michel are 3 m higher than they were 200 years ago. To reduce this deposit buildup, the French government had a dam built on the Couesnon river. Eight sets of sluice gates, clad with 2205 duplex stainless steel, retain the river water at high tide and release it at low tide, allowing it to flush sediment out to sea. Additionally, the old dike that blocked water flow was replaced by a light bridge on stilts. The bridge allows the free flow of water around the island, improving the efficiency of deposit removal from the bay.

Some 36 tonnes of duplex stainless steel plate, supplied by Industeel, clad the gates' coated carbon steel frame. 2205 duplex stainless steel, containing 3% molybdenum, was chosen for its superior corrosion and abrasion resistance. The molybdenum content helps fend off both corrosion from seawater and abrasion from sediments. With lots of abrasive particles and high flow rates, "erosion corrosion" is a significant risk for corrosion-prone, softer materials like aluminum or carbon steel. Wet-dry interfaces, inevitable in a water management system, can also exacerbate corrosion. A carefully welded duplex stainless steel surface, with its high hardness and corrosion resistance, will resist these perils far better than other metals or lesser alloyed grades.


**Twice a day, at high tide, Mont St-Michel is surrounded by water.**

The Couesnon dam, which faces the abbey and the open bay, has become its own tourist attraction. Project architects designed a public space atop the dam, which offers unobstructed views of Mont St-Michel and attracts millions of people to visit this UNESCO World Heritage Site every year.

**During high tide, slightly lowering the rotating sluice gates allows sea water to flow over their top edge, filling the Couesnon river while reducing the influx of sediment. During low tide, the sluice gates are gradually lifted, so that the river water, along with silt and sand, can rush out under the gates.**

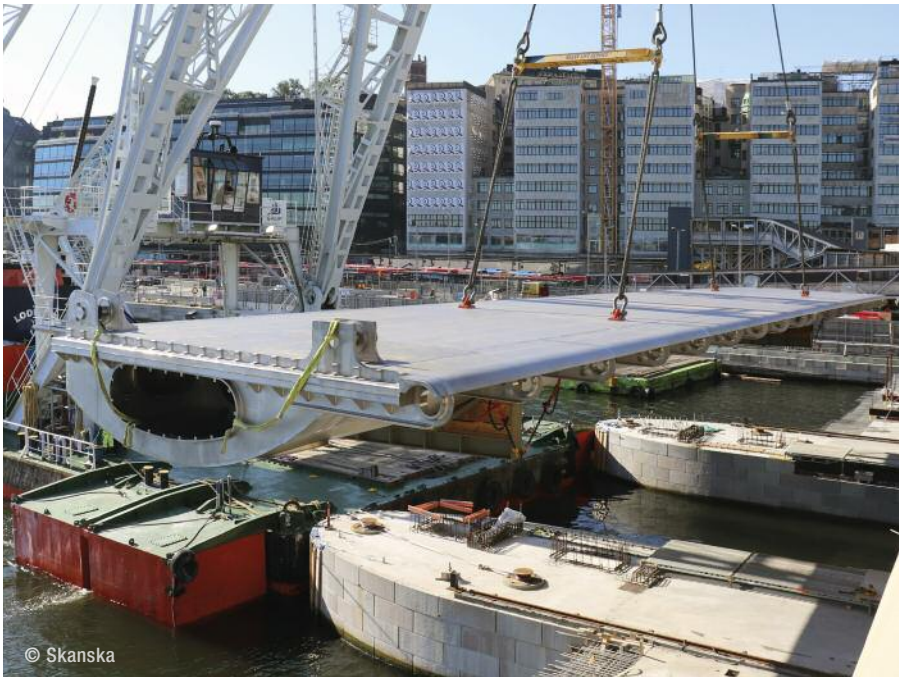
# Slussen, Stockholm

Slussen is a lock right in the middle of the historic city center of Stockholm, Sweden. It was first built in the 17th century. This lock protects the two million people of Mälardalen, the area around lake Mälaren at the eastern end of Stockholm, and their drinking water from inflows of brackish water. The lock is such a defining feature of the area that the neighborhood itself is called “Slussen”. The neighborhood is one of Stockholm’s busiest, and its heavily traveled, water-traversing infrastructure can be difficult to access for maintenance. A massive urban planning project is underway to widen Slussen’s discharge canals, transform its public transportation throughways, and install new sluice gates. The new gates, two for control of water level and two for boat traffic, are designed to withstand brackish flood waters for a century. That is a tough ask of steel, which wants to rust under such conditions. But 2205 duplex stainless steel is perfect for the job.


**The new sluice gates will be a central element of the redevelopment of the Slussen neighborhood.**

Flooding around lake Mälaren is a major concern due to increased rainfall and warmer winters in recent years. The year 2000 was Sweden’s rainiest since 1860. In that year, significantly more water flowed into lake than could be let out through the sluice gates. The flooding was so bad it almost reached the central underground station tunnel of Stockholm. Nearby, the train station of Gamla Stan (i.e. the Old Town) wasn’t so lucky; water infiltrated its ticketing hall, leading it to close for a brief time. In the two decades that followed, climate modeling confirmed this event was not an anomaly. Rather, similar extreme flooding events are likely to increase in both frequency and intensity. Although Gamla Stan’s train tracks never flooded, the floods of 2000 are perhaps a warning for what is yet to come. Without improved capacity to drain floodwaters from lake Mälaren, the whole Stockholm region would be vulnerable to unprecedented disaster. The new duplex stainless steel sluice gates will be large and strong enough to release significantly more water than their forebears.

**The 2205 duplex stainless steel clad sluice gates were fabricated off site in a machine shop and transported by barge to their destination.**

## Corrosivity of brackish waters

Brackish waters vary widely in their corrosivity to metals – some brackish waters are almost like fresh water while others approach the saltiness of the ocean. However, chloride (salt) concentration is only one variable affecting corrosion in brackish water – temperature, bacteria levels, dissolved solids, and pH also play a role in material degradation. 2205 duplex stainless steel is much more corrosion resistant than Type 316 stainless steel and can withstand higher levels of chlorides. While less corrosion resistant than 2205, 2404 duplex stainless steel is also more resistant than Type 316 and works well in brackish water with lower chloride contents.

Because duplex stainless steel is so much stronger than carbon steel, the gates are light enough to be fabricated off site and delivered. Being able to weld in a fabrication shop versus on site not only conserves costs and resources, but it also allows for better quality control. Stål and Rörmontage fabricated and supplied the behemoth flood gates – now the world's largest at 70 tonnes. The gates will protect against the surges of storms, which will increase in intensity and frequency throughout the lock's service life. The entire Slussen project is expected to finish in 2025.

## Gårda Damme, Gothenburg

Gothenburg, a Swedish port city, stretches over a series of islands intersected by canals and bridges. With so many waterways, rising sea levels pose a major flood risk to the community. In 2013, the rotten wooden sluice gates that once controlled the water flows in and out of the archipelago were replaced. The old gates were in such bad condition that a temporary support structure was necessary to hold them together. The new gates are designed to withstand 120 years of rising tides. Though Gothenburg's canals usually hold fresh water, sea water occasionally backwashes in and increases the chloride content. Outokumpu's 2404 duplex stainless steel, containing 1.6% molybdenum, was chosen for both its strength and enhanced resistance to salts. The structure could last several times its specified service life if the rubber seals used on the gates are properly maintained. There are five gates altogether, each measuring 3.1 by 2.2 m and weighing roughly 7 tonnes.

Rotten as they were, the original wood sluice gates were a beautiful landmark in the city, and residents wanted to emulate some of their character. The fabricators pieced together the new gates with over 400 specially-crafted components to replicate the wooden aesthetic.

## The gate to safer communities

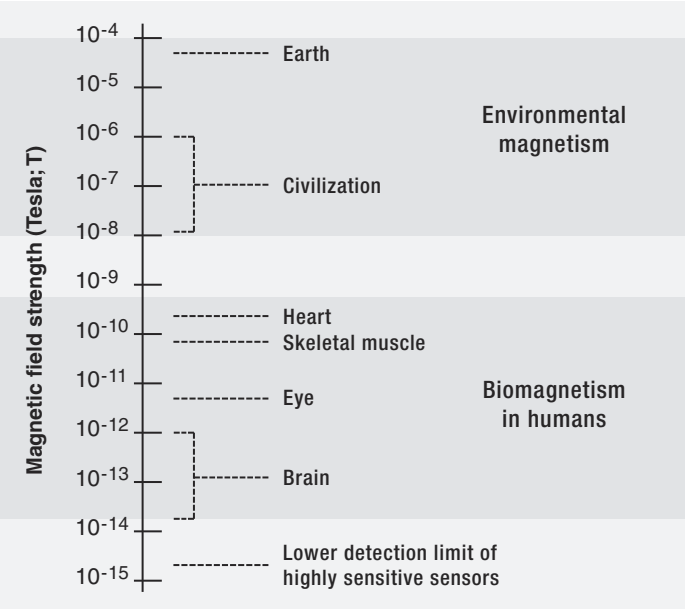
Duplex stainless steel has a longer service life, requiring less maintenance, than other materials. Even though duplex stainless steel is more expensive upfront, when the total life cycle costs of a project are considered, it usually emerges as a more cost-effective solution. Not having to repaint, recoat, or replace components on the sluice gates means no chaotic road closures for maintenance, no gaps in flood protection for the city, and less greenhouse gas emissions from producing and moving new materials. Managing the shifting waters of the 21st century will not be easy, but duplex stainless steel will help resist the rising tide. (KW)

**Even though the new sluice gates are strong and safe, they were designed to resemble their wooden predecessors.**

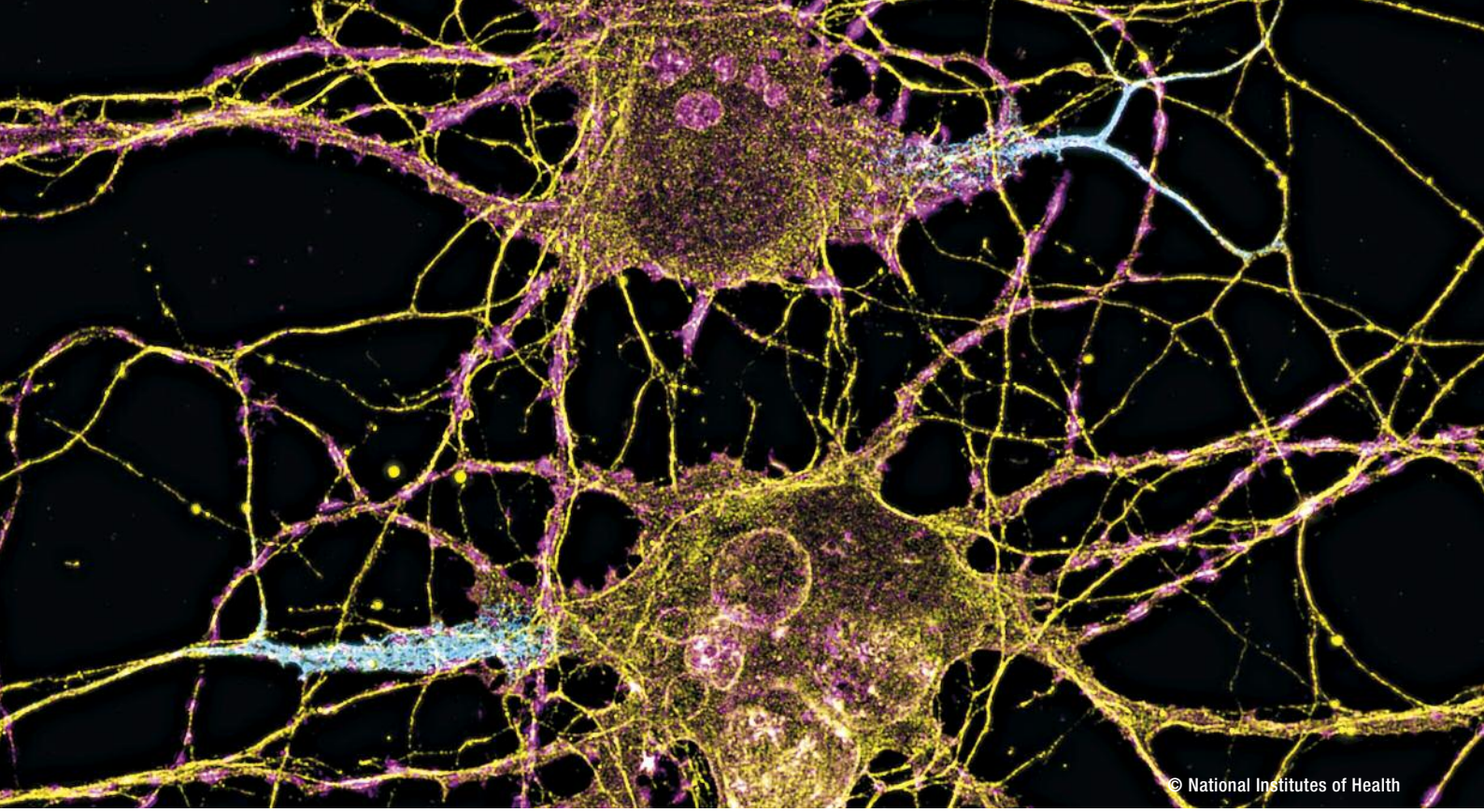
# Molybdenum in magnetically shielded rooms

**Detecting nature's tiniest magnetic activity for medicine and research relies on suppressing a constant barrage of external magnetic influence. For decades, a molybdenum-containing alloy called mu-metal has been used as a magnetic shielding material due to its ability to divert both the Earth's natural magnetic field and manmade sources. Today, rooms clad in layers of mu-metal and similar alloys provide unfathomable levels of magnetic shielding for procedures that save lives and extend the frontiers of science.**

The typical strength of magnetic signals generated by human brain activity is around one billionth of the strength of the earth's magnetic field. To measure and analyze such weak signals without them being drowned out by the environment's much stronger magnetic field, a magnetic shielding room (MSR) is necessary to provide passive shielding. MSRs are critical for diagnostic imaging techniques of the heart and brain, such as magnetoencephalography (MEG), a non-invasive procedure used in planning for surgeries and epilepsy treatment. MEG is also very important to psychiatric and neuroscience research. For example, university researchers in Pittsburgh, US, placed subjects in an MSR and used MEG to measure their brains' magnetic activity while listening to music, revealing key insights about how humans perceive sound. Indeed, MSRs are used in a variety of research applications ranging from cognitive science to aerospace. A stable MSR with consistent performance over the years is crucial in maintaining the precision of the multi-million-dollar systems within.



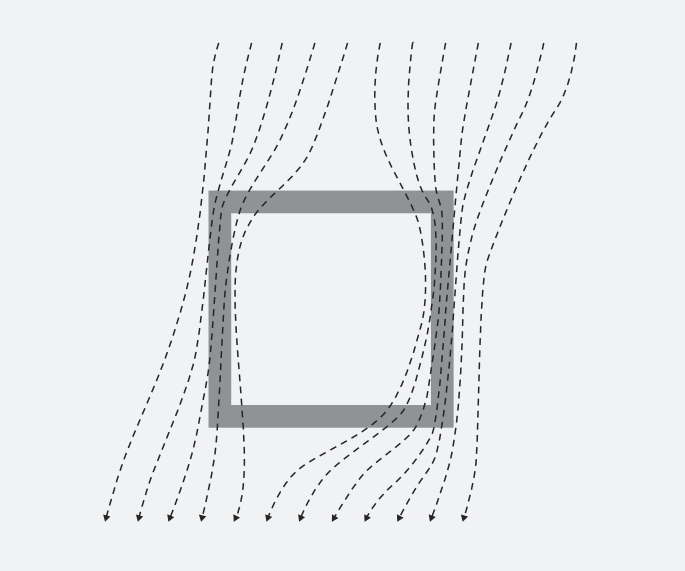

The magnetic fields of human brains and other body parts are many orders of magnitude smaller than that of the earth.




Neurons are the structures in the brain that produce magnetic fields – it is the interaction between neurons that magnetoencephalography (MEG), performed inside of magnetically shielded rooms, detects.

## MSR history

Since the 1960s, scientists attempted to construct a magnetically shielded room for research in physics and biology. The first commercial MSR became available in the 1970s, with key standardization efforts in the 1980s. Today, modern MSRs are constructed by forming a room-sized enclosure using layers of both a metal with high magnetic permeability, mu-metal, and a metal with high conductivity, usually aluminum. A typical MSR consists of two or more layers of mu-metal and one layer of aluminum in the wall construction. As shown in the figure on the right, this combination of construction materials can effectively cancel out the external magnetic field inside the MSR. The MEG-system or other sensing unit is placed in the center of the room where it is essentially free of any magnetic field. The effectiveness of an MSR is quantified by the "shielding factor" – a ratio between the external field strength and the internal field strength. Today, commercial MSRs can suppress external magnetic fields by several thousands of times.



Mu-metal/aluminum walls deviate and block external magnetic fields around the magnetically shielded room. The space inside is practically free of a magnetic field.

The multi-layered MSR wall relies on two different mechanisms to block external magnetic fields, depending on the frequency of the external magnetic field. At a higher frequency, the MSR wall can react to a varying magnetic field by forming an internal electrical current (eddy current). The internal current forms a counter magnetic field that cancels out the external magnetic field. However, for static or slowly varying magnetic fields, this counter current effect becomes negligible. Therefore, the magnetic shielding solely relies on the high permeability of mu-metal, which provides an easy path for the external magnetic field, causing the field to deviate inside the wall.


**The walls of magnetically shielded rooms consist of layers of mu-metal and aluminum.**

## Mu-metal background

A typical mu-metal consists of nickel and iron and contains 2–6% molybdenum. When mu-metal was initially developed, it contained no molybdenum. In the 1930s, researchers added molybdenum to mu-metal intending to improve its electrical resistivity and mechanical properties. They coincidentally discovered that the addition dramatically increased magnetic permeability. Modern mu-metals and mu-metal similar alloys have various alloy compositions, depending on the application and manufacturer. However, all formulations contain molybdenum.

Due to its high permeability, mu-metal can deviate slowly-changing magnetic fields. Compared to other conventional soft magnetic materials, mu-metal's permeability is orders of magnitude higher, providing a stronger shielding effect without increasing the quantity of material used. Mu-metal is also a ductile alloy making the industrial production of thin gauges in relatively large quantities possible, and allowing flexibility in MSR design and assembly. The alloy is named after the Greek letter μ, mu (pronounced "myoo"), the symbol used to represent "magnetic permeability".

## Mo makes mu-metal better

The industrial production of mu-metal for MSRs uses vacuum induction melting (VIM) technology. The alloy is processed into desired shapes before the final annealing step, where it is heated to around 1100°C in a hydrogen atmosphere. At that temperature, the metallic grains grow rapidly, leading to larger grains with increased magnetic permeability. The addition of a small amount of molybdenum increases the magnetic permeability further by optimizing the intrinsic magnetic properties of the alloy. By helping effectively shield the inside of MSRs from the external magnetic field, molybdenum enables the proper function of essential medical devices that have saved or improved the lives of thousands of patients.

The end-use applications for MSR are niche but have the potential to expand. This expansion is not only driven by a developing healthcare infrastructure globally, but also by the emergence of new research areas. Several prestigious laboratories worldwide have installed magnetic shielding chambers to study the fundamental principles of particle physics. For example, the Paul Scherrer Institute in Switzerland, in partnership with VACUUMSCHMELZE GmbH & Co. KG, developed an elite MSR that dampens external magnetic influence by a hundred thousand times. This allowed researchers to detect subatomic magnetic signals previously invisible to the latest-generation sensing technology. To achieve greater sensitivity, over 10 times more precise than its predecessor, this MSR uses more and thicker layers of mu-metal shielding than standard units. Regardless of the application, with molybdenum nickel-iron soft magnetic alloys will remain the ideal material for magnetically shielded rooms. (PZ)

**MSRs are typically around 4 x 4 m, big enough to contain relatively large equipment. Here a projector (top right of the door) displays images. The MEG detects the activity of the subject's brain neurons as a reaction to viewing the images.**

# IMOA news

## IMOA enters collaboration with Copper Mark

Demonstrating responsible sourcing across global supply chains is imperative. At the end of 2021, IMOA began collaborating with Copper Mark with the aim of developing a molybdenum specific option to demonstrate responsible production practices. Copper Mark offers our molybdenum-producing members the option to access a credible assurance framework with an established set of criteria readily applicable to the molybdenum supply chain. Approximately two-thirds of all molybdenum produced is a by-product of copper mining, making a collaboration with Copper Mark a sensible way forward.

IMOA is working on behalf of its membership to develop a Molybdenum Mark under the Copper Mark umbrella. As demand for more responsibly produced metal increases, our collaboration with Copper Mark can help members meet increasing market demands and growing regulatory requirements. The Copper Mark assurance framework covers site-based activity and therefore any materials, including by-products, that are produced at the participating site.

IMOA is working with Copper Mark to include Molybdenum in the Joint Due Diligence Standard for Copper, Lead, Nickel and Zinc. Additionally, TDi Sustainability has undertaken a gap analysis in Q2 2022 to identify the differences between the Q2 2022 draft of the updated Copper Mark standard and the draft of the revised Q2 2022 ResponsibleSteel standard and shared the findings with Copper Mark to assist with their review of the draft Copper Mark Standard.

Copper Mark also agreed to a formal collaboration with both the International Zinc Association and the Nickel Institute, expanding the assurance framework to nickel and zinc producers. For further information, please visit https://coppermark.org/molybdenum-zinc-and-nickel-join-the-copper-marks-assurance-framework.

## Malta begins stainless flexible service line trial

Malta's Water Service Company (WSC) recently began trialing stainless flexible service lines at four sites on the island and was impressed with the simplicity of installation. WSC is now planning additional laboratory testing and monitoring of the trial performance before deciding whether to use these service lines more widely.

Stainless flexible service lines, made from stainless steel partially corrugated tubing, are a robust, safe, and highly durable solution for service line applications. Already proven to dramatically reduce water loss in some of Asia's largest cities, they offer water utilities major benefits. The lines are easy to install, cost-effective, and offer an environmentally sustainable solution that will ensure the delivery of safe water supplies for generations to come.

Team Stainless promotes the use of stainless flexible service lines globally and consults with water authorities that are interested in installing them. An upcoming brochure offers expanded information on installation practices and benefits of using stainless flexible service lines.

## IMOA is delighted to welcome four new members:

**Bauer Energy Design Inc**
**MTALX Ltd**
**Palvi Industries Limited**
**Sunshine Gold Ltd**

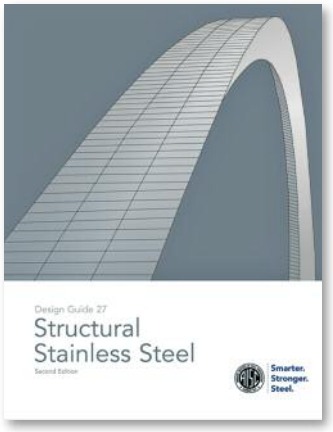
The new members will now enjoy the benefits that IMOA membership offers, including access to market updates and research results, HSE guidance and regulatory liaison, and the opportunity to influence global market development programs.

# Updated AISC Design Guide 27 published

A second edition of the American Institute of Steel Construction (AISC) Design Guide 27 was published in spring of 2022. Written for audiences experienced with carbon steel structures, the guide introduces the benefits of design with structural stainless steel. It accompanies the 2021 AISC *Specification for Structural Stainless Steel Buildings*. AISC standards are influential in several major markets including China, the Middle East, and the Americas. The updated guide includes design rules for structural hot-rolled and welded open products such as channels and I-shaped members. The rules apply to thicker sections of austenitic, duplex, and precipitation hardened stainless steels.

Design Guide 27 contains numerous tables and examples written with designers in mind. These include dimension and property tables for various thicknesses and alloys of stainless steel. Download the guide as a PDF or request a print copy at aisc.org/publications.

IMOA consultants Nancy Baddoo and Catherine Houska both helped draft and promote the guide. In March of 2022, Nancy and Catherine gave talks introducing Design Guide 27 and its associated structural specifications at a major structural steel conference in Denver, US. Three webinars, each of which had 275 to 300 participants, in the spring of 2022 further promoted the guide and standards. Recordings of the NASCC presentations and accompanying slides are available for free at aisc.org/education-archives. With Design Guide 27 in place, we hope to see expanded opportunities for austenitic and duplex stainless steels in the built environment.




# IMOA member discounts

IMOA members receive a 15% discount off the delegate fee to this year's Ryan's Notes Ferroalloys conference, held 31 October and 1 November 2022 in Scottsdale, Arizona, US. Please contact the IMOA office for the discount code via info@imoa.info. To find out more and to register visit Home | CRU Ferroalloys Conference (crugroup.com)

IMOA members are also eligible for a 25% discount off the delegate fee to this year's Stainless Steel World Asia event, held in Singapore on 26 and 27 October 2022. Please contact the IMOA office for the booking QR code. To find out more visit Stainless Steel World Asia 2022 - Conference & Expo (stainless-steel-world-asia.com)

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The breathtaking Lac d'Emosson reservoir, which serves Nant de Drance. © Nant de Drance, Sébastien Moret

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