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MOLY REVIEW

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Taylor Yard Bridge: a duplex connection

The Taylor Yard Bridge spans the Los Angeles River, reconnecting two neighborhoods long divided by geography and history. Its bold, oversized design, pays homage to the area's industrial past as a bustling railyard and serves as a striking landmark. Slender 2205 duplex stainless steel tension rods provide the strength and resilience needed to hold this iconic structure together.

The Taylor Yard Bridge with its bold, 10-meter-high cubic tube outlined in bright orange, commands attention as it spans the Los Angeles River. Far more than a functional crossing, it symbolizes a massive effort to revitalize and naturalize the river. In the 1930s, the river was sealed with concrete to control flooding, leaving a paved canal that rigidly divided the communities along it's banks.

A new way across

The section of the river where the bridge now stands was once home to the bustling Taylor Yard railyard on the north bank. Train bridges spanned the gritty river bed for about a decade, connecting the railyard to the larger network, until the rise of the US highway system in the mid-20th century shifted freight transport to trucks. By the 1950s, the abandoned railyard became a hotspot for fights and organized crime. The Taylor Yard Bridge's bold orange color nods to the film *Rumble Fish*, where sparring orange beta fish symbolize conflict and tension in the story of two brothers caught in gang violence.

The 123-meter-long bridge, which opened in 2021, offers a rare pedestrian-focused crossing in one of the world's most car-dependent cities. Traversing the bridge is a sensory experience, with views of the softening river ecosystem and the Santa Monica Mountains. Two cantilevered overlooks, positioned to follow the river's natural curvature, invite visitors to pause and connect with the surroundings.

Overcoming initial design challenges

The river and now abandoned railyard posed significant geographical challenges for the design. Large powerlines and city ordinances limited the potential height of the construction, with a maintenance road and bike path on either side further restricting available build space. On top of these limitations, a 3 m elevation difference between the two concrete riverbanks added another layer of difficulty.

To address these constraints, the bridge employs a minimalist design using 36 cm square tubes for its main structure. This framework is reinforced by 2205 duplex stainless steel tension rods, which provide the necessary stiffness. This design allows the bridge to function as a single beam without the need for pylons or counterweights.

The Taylor Yard bridge showcases a stunningly simple and elegant design, achieved despite the complex constraints imposed by the site's location. The bridge was designed by the architectural firm SPF:architects.

When viewed from the outside, the orange box carrying the deck remains level, cleverly concealing the 3-meter height difference between the riverbanks. Inside, the pathway slopes at a 3% grade, creating an illusion for those walking through the bridge, where the structure ahead seems to grow or shrink as the path appears to float through it.

Why designers chose 2205 duplex stainless steel

2205 duplex stainless steel with 3% molybdenum was chosen for the tension rods for its superior strength and corrosion resistance. While alloys like Type 316 stainless steel might have provided sufficient corrosion resistance, their lower strength would have required thicker, more obtrusive rods. The slimmer profile of 2205 ensures the tension rods blend seamlessly with the surroundings, without competing visually with the brightly painted superstructure.

The simple yet bold Taylor Yard Bridge has drawn attention from the design world for its striking and thoughtful design. While the bridge provides a vital pedestrian and cyclist crossing over the LA River, its connection to the larger bike path network is currently limited by unfinished segments in the surrounding area. Architect Zoltan Pali, the project's principal designer, noted "in a little way, [the bridge] adds to the betterment of the communities, [and] to the ease of people being able to connect and interact with each other." The bridge stands as both a functional crossing and a symbol of LA's commitment to revitalizing the river and its communities. (KW)

2205 duplex stainless steel tension rods in the shop before installation.

The relatively thin and reflective tension rods allow for open views while crossing.

Stainless steel tames wild wires

Cable trays weave order into the chaos of cables and tubing, transforming sprawling installations into clean, efficient systems. From oil platforms to food production facilities and tunnel infrastructure, molybdenum-containing stainless steel trays deliver exceptional performance, with unmatched resistance to corrosion and high temperatures.

From tunnels and skyscrapers to factories and homes, cable trays support and protect the cables that power modern life, preventing damage, contamination, and disruption. Ranging from basic configurations to custom installations spanning tens of thousands of meters, cable trays ensure safe and reliable functionality. They are available in a variety of designs such as solid trays for full coverage, ladder trays for heavy duty installations, and open wire baskets for improved airflow. Even though aluminum and galvanized steel are the most widely used tray materials, stainless steel excels where these materials fall short.

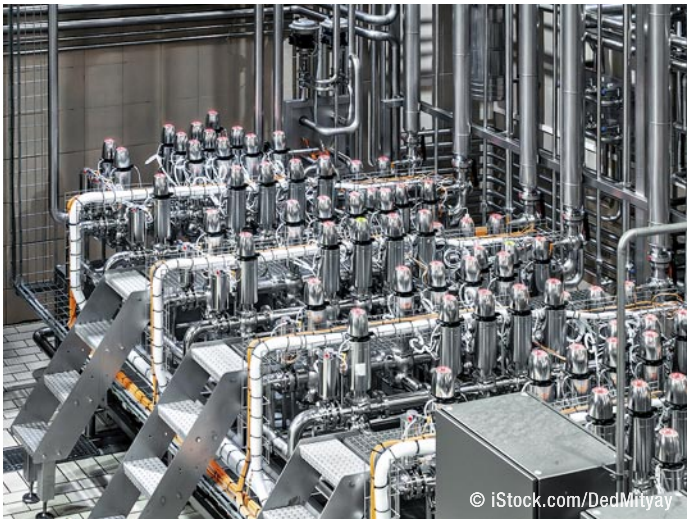
Where stainless steel cable trays are critical

Corrosive environments

Maintaining oil, gas, and offshore wind platforms is challenging and costly. Cable trays secure and organize wiring in tight spaces, preventing hazards from loose cables while performing reliably in harsh conditions like high winds. They also reduce the need for maintenance in areas that are difficult to access. To address these challenges, molybdenum-containing stainless steels are chosen for their exceptional resistance to seawater and salt spray corrosion, which reduces the need for frequent maintenance.

While coated carbon steel components are still common on these platforms, molybdenum-containing stainless steels are preferred in more aggressive environments due to their superior durability and lower life cycle costs. Type 316 stainless steel with 2% molybdenum is often used for topside cable trays. In five-year exposure tests conducted on the French Atlantic coast at Brest, Type 316 stainless steel outperformed lean duplex grades with lower molybdenum content. 2205 duplex stainless steel with 3% molybdenum demonstrated even greater performance, as also shown in a four-year coastal exposure test in Dubai. Only 2507 super duplex stainless steel, with 3.5% molybdenum, remained completely stain free under these conditions, proving its unmatched corrosion resistance.

Open, wire form cable trays in a brewery allow for air circulation and reduce opportunities for bacteria to grow.



High temperatures

Elevated temperature environments, such as those near boilers, furnaces, or heat exchangers, demand materials that can maintain stability and resist degradation. Stainless steel excels in these conditions, especially molybdenum-containing grades, making it the most resistant material for cable trays in heat-intensive applications.

While all materials weaken at high temperatures, stainless steel retains more strength, even under fire. At 400°C, stainless steel remains stronger than low-carbon steel at room temperature, and Type 316 stainless steel outperforms Mo-free Type 304 at higher temperatures. These properties make stainless steel indispensable for high-temperature and fire-prone environments where safety and durability are critical.

Hygienic applications

Stainless steel is essential in the food and beverage industry due to its smooth, non-porous surface, which resists bacterial growth and ensures thorough cleaning. Its durability and ease of sterilization make it ideal for environments requiring strict hygiene. Type 304 stainless steel is widely used, while Type 316 is preferred in corrosive conditions, such as in the production of ketchup, soy sauce, or brine-based products. Ingredients like salt and acids from these processes can become airborne and settle on cable trays, increasing the risk of corrosion.

Cable trays in these settings are also frequently exposed to aggressive cleaning agents, either directly during washdowns or through overspray. These products often contain chlorides or acids that corrode less resistant materials. As global hygiene standards rise, stainless steel cable trays are becoming essential in sterility-sensitive settings, from food production to pharmaceuticals and healthcare facilities.

Supporting the world's most extreme rail tunnels

Traffic tunnels for automobiles and trains are another critical application where molybdenum-alloyed cable trays reduce risks from humidity, fire, and the challenges of limited maintenance in difficult-to-access locations. Tunnels are typically humid enough for corrosion to pose a significant problem. For example, Switzerland's Mont Blanc tunnel experiences humidity levels ranging from 40 to 95%, well above the threshold where most environmental salts become actively corrosive. Despite the high humidity, tunnels face significant fire risks due to the presence of combustibles, confined spaces, and ventilation challenges. Albeit rare, these blazes can be devastating: a fire in the Mont Blanc tunnel in 1999 killed 29 people and cost €450 million in repairs.

Type 316 stainless steel's fire performance is well documented, reducing the risk of falling debris and structural collapse during such emergencies. This fire resistance was a reason for installing Type 316 stainless steel cable channels and supports for handrails along an emergency evacuation path in Switzerland's Gotthard Base tunnel, the world's longest and deepest rail tunnel. More than 8,000 meters of channel and 60,000 supports were installed in 2016. The inherent difficulty of maintaining tunnels, especially in remote mountain locations or high traffic areas where closures disrupt operations, underscores the importance of durable, low-maintenance materials like stainless steel.

Stainless steel cable channels carry wiring and support composite escape handrails in the Gotthard Base Tunnel.

Type 316 stainless steel cable trays will also serve one of the world's most extreme tunnelling projects: the Udhampur-Srinagar-Baramulla Railway Link (USBRL) in the Indian Himalayas, comprising over 100 km of tunnels. This span connects Jammu and Kashmir provinces, providing a passage through rugged, sparsely populated, mountainous terrain. Not only is maintenance extremely difficult, but this span faces major corrosion risks from humidity and industrial fumes. Approximately 6,000 tonnes of Type 316 stainless steel cable trays were selected for their corrosion resistance, long lifespan, and low maintenance. The 2 mm thick, cold rolled trays with a 2B surface finish will be integral to India's longest transportation tunnels, set to open in 2025.

Molybdenum-containing stainless steel cable trays, with their exceptional resistance to corrosion, high-temperature stability, and hygienic properties, are essential where reliability and durability are critical. From tunnels and offshore platforms to pharmaceutical and hygienic facilities, these trays ensure safety and performance in demanding conditions where failure is not an option. (KW)

Newly installed Type 316 stainless steel cable trays in the USBRL rail tunnel.

Agriculture's quiet powerhouse

In today's rapidly changing agricultural landscape, efficient and sustainable crop production is more important than ever. Fertilizers are key to meeting this need by providing nutrients that help plants grow and produce more. Among these nutrients, molybdenum – only needed in minute amounts – plays an essential but often overlooked role.

Plants require a variety of essential elements to grow and reproduce healthily. This understanding was first advanced by the pioneering 19th-century chemist Justus von Liebig, whose studies revealed how plants absorb nutrients from soil and air. Nutrients needed in large quantities are known as macronutrients, while those required in smaller amounts are called micronutrients. Nitrogen is arguably the most important macronutrient for crops. However, even when nitrogen is abundant in soil and air, plants cannot effectively utilize it without sufficient molybdenum.

Molybdenum plays a particularly vital role for key global crops such as cereals, legumes, and leafy greens, which have notably high nitrogen requirements. While the essential nature of molybdenum as a micronutrient is well-established, ongoing research continues to document cases where even minimal applications of molybdate fertilizer significantly enhance crop health and productivity.

Essential plant nutrients

Primary macronutrients:
nitrogen (N), phosphorus (P), potassium (K)

Secondary macronutrients:
calcium (Ca), magnesium (Mg), sulfur (S)

Micronutrients:
iron (Fe), boron (B), chlorine (Cl), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni)

How plants use molybdenum

Plants rely on molybdenum because it enables them to synthesize nitrogen into a usable form through processes such as nitrogen fixation and nitrate assimilation. Without adequate molybdenum, these vital processes cannot occur, hindering plant growth and productivity. In legumes such as soybeans and chickpeas, molybdenum is a crucial part of the enzyme nitrogenase, which helps nitrogen-fixing bacteria convert nitrogen from the air into ammonia, a form of nitrogen plants can use. These plants form partnerships with rhizobium bacteria in their root nodules, and molybdates are necessary for these nodules to work. This process allows legumes to use nitrogen from the air for their growth. Some of the nitrogen also stays in the soil, improving fertility for future crops and reducing the need for synthetic fertilizers, which supports sustainable farming.

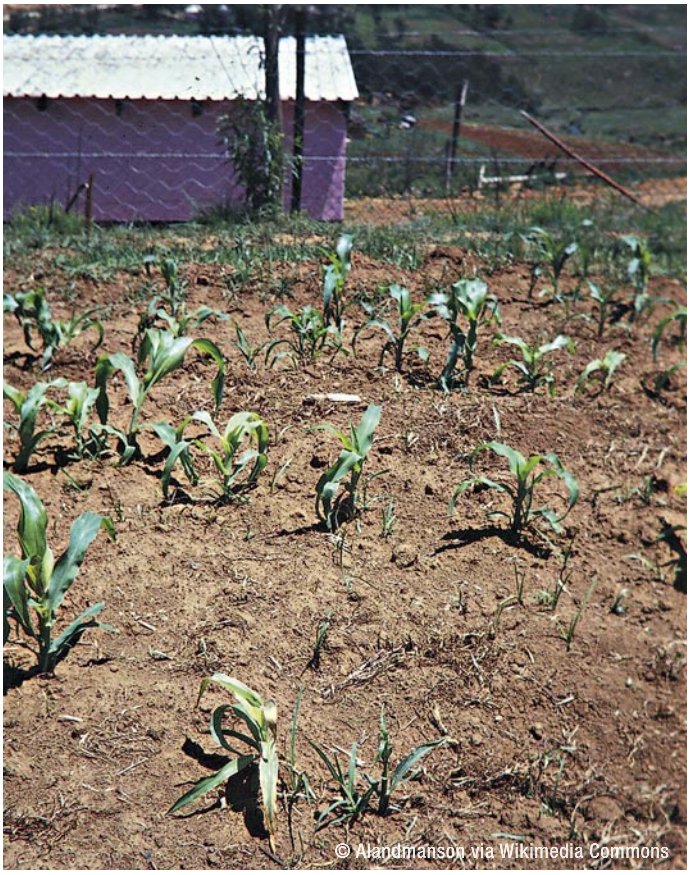
As part of the enzyme nitrate reductase, molybdenum also helps convert soil nitrate into nitrite, which plants can further process into ammonia and eventually into amino acids, the building blocks of proteins. Crops like cauliflower and melon, which depend on nitrate from the soil as their nitrogen source, cannot efficiently build proteins without molybdenum. Adequate molybdenum levels further support plant health by enhancing protein synthesis and chlorophyll production, which are essential for photosynthesis and growth.

Deficiency and fertilization

Although molybdenum deficiency is not a universal issue, it is a significant concern in regions with acidic, weathered or sandy soils. Such soils are commonly found in tropical, subtropical, and arid zones, including parts of South America, Africa, Southeast Asia, and Australia. When molybdenum deficiency occurs, it can significantly reduce crop yields by limiting nitrogen uptake. For example, poor soil molybdenum levels in Australian croplands have been estimated to reduce cereal yields by as much as 30%. However, addressing this deficiency can lead to remarkable improvements, as demonstrated in a study from Egypt, where treating mandarin orange trees with molybdenum increased yield by more than one third.

In some cases, molybdenum is sufficiently present in the soil but in an unavailable form. This can occur when the soil

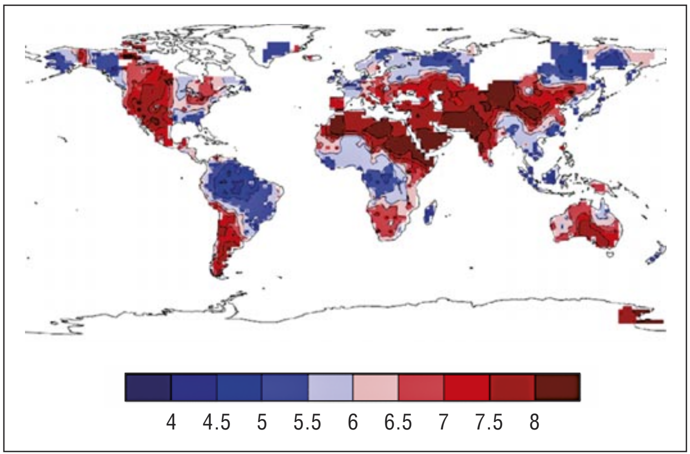
Molybdenum deficiency symptoms include delayed flowering, stunted growth, yellowing leaves, and low seed production.



Justus von Liebig: the father of chemical fertilizers

Our current understanding of molybdenum's significance in agriculture is built on the work of Justus von Liebig, a pioneering 19th-century chemist. Born in 1803 in Germany, Liebig was among the first to advocate for the artificial supplementation of nutrients to improve soil fertility and boost crop yields. He challenged the dominant theories of his time by demonstrating that plants need mineral nutrients from the soil for healthy growth. His identification of essential nutrients, such as nitrogen, phosphorus, and potassium, laid the foundation for modern fertilizer practices.

One of Liebig's most influential contributions is the "Law of the Minimum," also known as "Liebig's Law," which states that plant growth is limited not by the total amount of resources available, but by the scarcest nutrient.



Global distribution of soil pH. © Meng et. al via ResearchGate

is acidic (<5.5 pH). In most cases, adding lime or dolomite will correct the problem slowly over several months, but this usually isn't fast enough to be viable. Unless the lime amendment provides secondary benefits, adding a molybdate fertilizer is often quicker and less expensive.

Molybdates are added to fertilizers primarily as sodium molybdate (Na_2MoO_4) and ammonium molybdate ($(NH_4)_2MoO_4$). These compounds are highly soluble in water, making them easily available for plant uptake. Molybdates can be applied through various methods, including:

- soil application that incorporates molybdates into the soil, where plant roots can absorb them
- foliar spraying that delivers molybdenum directly to plant leaves, providing a quick remedy for deficiencies
- seed treatments that involve coating seeds with molybdates before planting, ensuring that young plants have immediate access to molybdenum as they germinate and grow.

Sodium molybdate or ammonium molybdate are typically effective in small amounts. Monitoring soil molybdenum levels and understanding the specific needs of different crops is crucial for avoiding over-fertilization.

Increasing crop yields

Recent studies have found that increased use of molybdate fertilizer can improve agricultural outcomes. For example, Nakai and Maruyama-Nakashita report that spraying dry bean leaves with a molybdenum fertilizer at 40 ppm – the highest concentration tested – increased seed yield by over 80%. Similarly, Osman et al. found molybdate amendments in chickpeas significantly improved productivity. These findings highlight the critical role of molybdenum as a micronutrient in crop production.

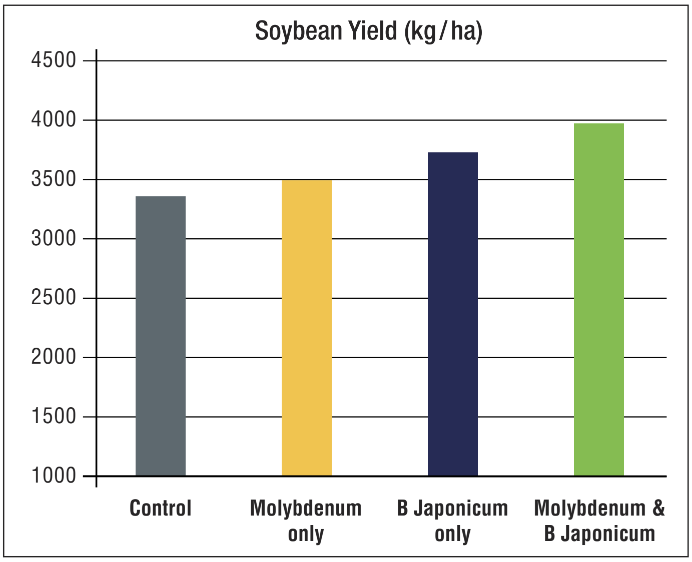
Adding tiny amounts of molybdate delivers significant economic benefits, with improved crop yields and reduced fertilizer use far outweighing their costs. By enhancing nitrogen fixation, molybdates also help minimize fertilizer waste and nutrient runoff. Whether included in synthetic fertilizers, organic amendments, or soil inoculants, molybdates play a key role in optimizing nutrient availability and supporting sustainable agriculture.

Soybean case study

Soybean is the world's most significant source of plant-based protein and oil, cultivated on 120–130 million hectares – an area roughly five times the size of the UK. The largest producers include the US, Argentina, China, and Brazil, with Brazil currently leading global production and exports. In the 2021–2022 season, Brazil harvested an impressive 124 million tonnes.

A key region for soybean cultivation in Brazil is the Cerrado, a tropical savannah. While this region benefits from low land and clearing costs and is easily mechanized, the soils are among the oldest and most leached in the world due to heavy rainfall. This nutrient depletion has rendered them some of the least fertile, requiring significant supplementation with minerals like molybdenum. Continuous farming has further worsened the problem, underscoring the importance of effective fertilization strategies.

Given the vital role of soybeans, increasing productivity without expanding cultivated land is essential. Recent studies have explored the synergy between micronutrients and beneficial microorganisms in enhancing soil fertility. In 2023, Jarecki reported that soybeans inoculated with *Bradyrhizobium japonicum* and supplemented with molybdenum showed improved growth, higher nitrogen content, and increased seed production, collectively boosting crop performance. Inoculating soybeans with *B. japonicum* enhances biological nitrogen fixation, especially in soils lacking native bacterial populations. Molybdenum further supports this process by promoting nodulation and nitrogen uptake, ultimately leading to higher yields.



Meeting evolving challenges

As agriculture confronts increasingly complex challenges, including climate change, soil degradation, and resource limitations, the role of molybdates in fertilizer innovation becomes more critical than ever. Current research seeks to uncover the mechanisms of molybdenum's interactions with plants and soil microbiota, optimize fertilizer formulations, and develop sustainable practices that leverage the full potential of molybdates. These efforts aim to advance global food security while promoting environmental stewardship. (JT)

A healthy soybean plant, important not only for food but also cosmetics, cleaners, plastics, paints, and even crayons!

Inflated stainless steel profiles

The NAWA Pavilion is a mesmerizing fusion of art and architecture, inviting visitors to step into its walkable embrace. Its mirror-polished Type 316 stainless steel arches appear to flow and transform with the shifting light and seasons, echoing the vitality of their surroundings.

© Zieta Studio

Daliowa is the smallest of over a dozen islands in the Polish city of Wrocław along the Oder River. Surrounded by lush greenery in a prime downtown location, it was long regarded as a "forgotten" island. The spectacular NAWA pavilion by Zieta Studio brought Dailowa back to life, transforming it into a meeting place and event venue, thus becoming an integral part of the growing city.

The tunnel-like installation consists of 35 arches arranged in a row, ranging from 4.5 m to 7.5 m in height. Their upward tapering shape references the historical vaults of nearby buildings. Together these arches create an organic form that appears to grow from the ground, harmonizing with the river and the surrounding nature.


© Zieta Studio

The mirror-polished stainless steel arches form a gate-like passageway with fascinating reflections.

Incredibly lightweight, remarkably strong

The arches were manufactured using a technology known as FiDU, which comes from the German term *Freie Innendruck-Umformung* (Free Internal Pressure Forming). In this process, two or more thin, laser-cut metal sheets are welded together at their edges. Then, high-pressure air is blown into the flat shapes, transforming them from two-dimensional forms into readily usable, ultra-light yet durable three-dimensional objects.

This seemingly simple procedure is the culmination of years of research. In 2008, Oskar Zieta, founder of the studio, first used the novel technique he developed to create a stool called "Plopp". Today, the stool is exhibited alongside other FiDU-blown pieces in prestigious art and design museums worldwide. The studio has developed a variety of objects, including mirrors, lamps, and other furniture, as well as sculptures. With a total weight of 11.2 tonnes and a size of 7.5 m x 10 m x 11 m, NAWA is by far the largest project to date realized with FiDU.

The arches were fabricated in a shipyard, allowing ample space and Oder River access for transport.


© Zieta Studio

Controlled loss of control

Starting from the technique of hydroforming, where metal tubes are pressed into a mold under high pressure using a liquid, the studio now also works with air. Instead of using expensive molds, the final shape in FiDU is parametrically calculated. The metal deforms freely according to its properties, with unpredictable undulations manifesting on the surface. While engineers and standards view these curvilinear deformations as defects, Oskar Zieta calls it a "controlled loss of control".

Despite being only 2 mm thick, Type 316 stainless steel withstands vandalism while offering the corrosion resistance needed in a humid riverside climate. FiDU technology uses this single material to create lightweight, easily transportable profiles that inflate into strong loadbearing structures. This technology holds the potential to move beyond art and design, paving the way to industrial applications. As demonstrated by NAWA, molybdenum-alloyed stainless steel will remain integral to FiDU's future, combining durability, simplicity, and strength to drive innovation. (MH)

Molybdenum: a key to carbon capture

As the world strives for climate neutrality, Carbon Capture, Utilization, and Storage (CCUS) is an essential bridge to a sustainable future. By capturing CO_2 from industrial processes for storage or reuse, CCUS can prevent harmful emissions from reaching the atmosphere. The reliability and durability of this technology depend on molybdenum-containing materials.

© Clare Jackson / Alamy

Tackling the climate crisis and achieving net-zero emissions by 2050 is one of the greatest challenges of our time. Transitioning to renewable energy, improving energy efficiency, and developing carbon-neutral technologies are crucial steps forward. In the interim, CCUS has emerged as a critical strategy for capturing CO_2 emissions at their source.

CCUS technology involves removing CO_2 from the exhaust of industrial or power generation facilities and transporting it for storage or reuse. The CO_2 is either securely stored underground – known as Carbon Capture and Storage (CCS) – or repurposed for industrial applications such as the production of chemicals, synthetic fuels, or building materials. This dual-purpose approach not only reduces emissions at the source but also reduces the need to extract virgin fossil fuels, further cutting emissions in downstream processes. However, the success of CCUS relies heavily on the quality and safety of its infrastructure, where molybdenum plays a critical role.

Barriers to decarbonization

Achieving full decarbonization remains a challenging process. Rising standards of living and increased digitalization mean that the global energy demand continues to grow despite the need to lower emissions. Carbon- and energy-intensive industries, such as steel production, are exploring solutions like replacing coke with hydrogen produced from renewable energy. While pilot projects are underway, it will likely take years before such practices become standard globally.

Other industries, such as glass manufacturing, ethanol production, power generation, hydrogen and ammonia synthesis, fertilizer production, natural gas processing, and various chemical processes, continue to emit CO_2 even as efforts to decarbonize them intensify.

However, in some cases, CO_2 emissions are unavoidable in specific chemical processes, like cement production in the concrete industry. Here, limestone is heated to 1500°C in coke-fired furnaces, and while the combustion of coke contributes to CO_2 emissions, the majority – around two-thirds – comes from the release of CO_2 stored within the limestone itself during calcination.

The challenges of handling CO_2

While pure, dry CO_2 is non-corrosive, captured CO_2 in CCUS systems often contains impurities such as water, oxygen, and sulfur compounds. During liquefaction, these impurities condense into corrosive acidic solutions, including sulfuric, nitric, carbonic, and hydrochloric acids, which can severely damage pipelines, storage facilities, and other CCUS components.

In addition to corrosion, sudden fluid depressurizations can rapidly cool liquid CO_2 as it expands, sometimes to temperatures as low as -80°C – a phenomenon known as the Joule-Thomson effect. This rapid cooling introduces the risk of brittle fracture, a sudden and catastrophic failure of some materials due to their reduced toughness at low temperatures. Similarly, the subzero temperatures required for shipping liquid, impure CO_2 present another scenario where brittle fracture becomes a significant concern.

To address these challenges, tougher materials without a ductile-to-brittle transition, such as austenitic and super austenitic stainless steels or nickel-based alloys, offer both the low-temperature toughness and corrosion resistance required. Duplex and super duplex stainless steels provide excellent corrosion resistance and have been proposed – and successfully used – for CO_2 injection wells. Although they experience a ductile-to-brittle transition at subzero temperatures, they provide very high strength and are suitable to be used under the given environmental conditions.

Selecting an appropriate stainless steel for the environment improves safety and helps to ensure a long service life.


© BUTTING Gruppe GmbH & Co. KG

Carbon capture projects, like this one in Iceland, are being developed all around the world.

Carbon capture

Carbon capture isolates CO_2 from industrial emissions using chemical absorption or similar techniques. Post-combustion capture (PCC) units in fossil-fired power plants, for instance, use amine-based solvents like monoethanolamine to selectively absorb CO_2 from flue gas. The PCC unit includes an absorption tower, where the solvent captures CO_2, and a desorption tower, where heat releases the CO_2 from the solvent for collection. The regenerated solvent is then recycled for continued use.

Unlike process-based carbon capture, which isolates CO_2 from industrial emissions, direct air capture (DAC) removes CO_2 directly from the atmosphere. This technology draws in air and passes it through a liquid or solid absorption medium. To prepare the captured CO_2 for transport and storage, it must be released using heat and vacuum technology. DAC follows the same principles as other carbon capture methods for transport and storage.

The original concept for CCS involved integrating CO_2 capture units with compression, transport, and storage systems directly within individual facilities, such as power plants, positioning them immediately behind emissions control systems. However, today, the preferred approach is the use of CCS networks known as “clusters”. In these networks, multiple CO_2-producing sites are connected via a pipeline system that gathers CO_2 from various sources and transports it to centralized separation, cleaning, and liquefying facilities. In this setup, molybdenum-alloyed, corrosion-resistant pipelines and equipment can be essential due to the varied and potentially corrosive impurities in the CO_2 stream. By sharing infrastructure, CCS clusters reduce equipment costs for individual CO_2 emitters.

This direct air capture equipment extracts CO_2 out of the atmosphere.

Case study: Northern Lights joint venture (JV)

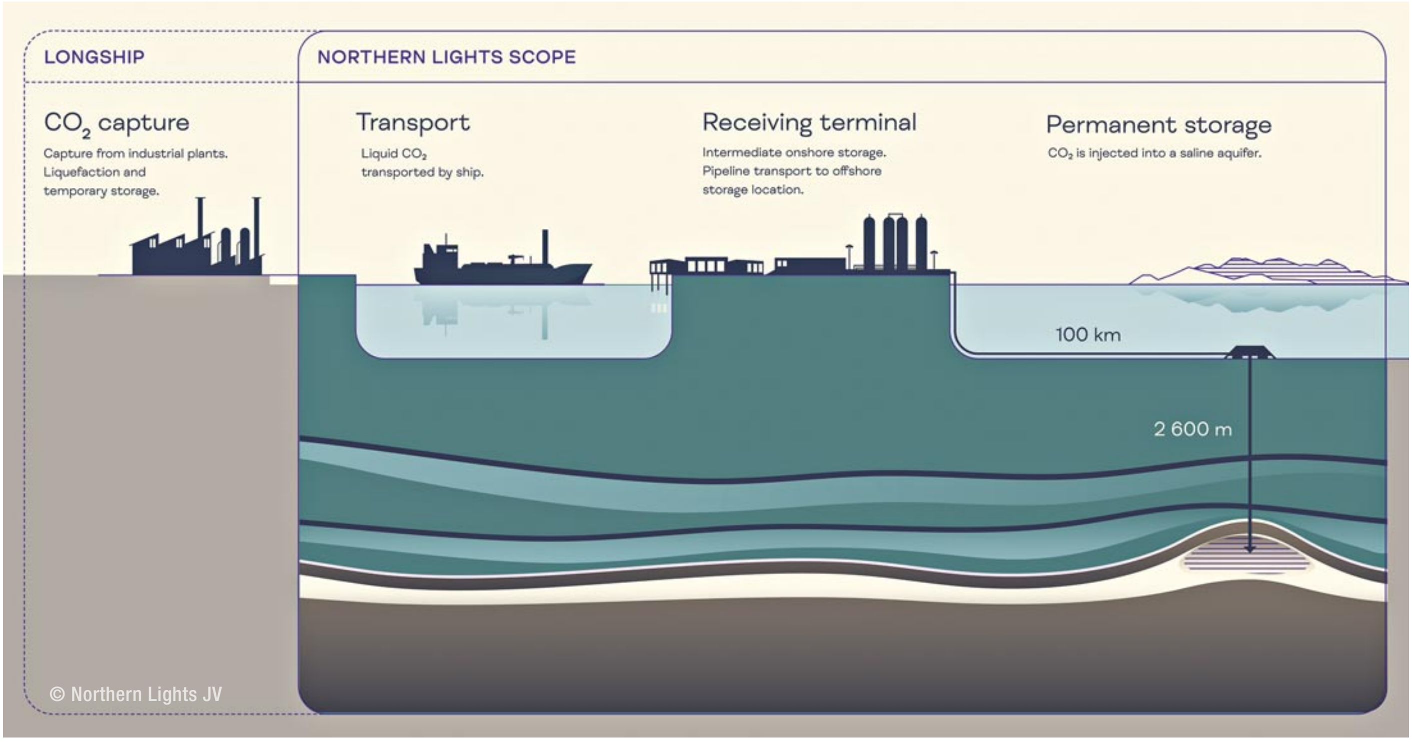
The Northern Lights JV, a partnership between Shell, Equinor, and TotalEnergies, is a CCS project designed to collect, liquefy, and transport CO_2 from multiple sources. Two 7,500 m^3 liquefied CO_2 vessels will carry the CO_2 to a receiving terminal in Øygarden, western Norway. The shipping technology adapts liquefied natural gas (LNG) transportation methods for CO_2. At the terminal, where some systems are made of Type 316 stainless steels, the CO_2 is temporarily stored before being transported via a 100 km offshore pipeline to a saline aquifer 2,600 m below the seabed for safe, permanent storage.

At the injection site, the bottom 200 m of the injection casing and tubing in the well are constructed from UNS S82551, a duplex stainless steel with 1% molybdenum, and UNS S39274, a 25Cr super duplex stainless steel with 3% molybdenum. These corrosion-resistant alloys are expected to withstand the aggressive conditions caused by temporary well closures, ensuring the long-term integrity of the well and the safe containment of CO_2 deep underground. The diameter of the tubing and casing is up to 25 cm.

The CO_2 receiving terminal in the municipality of Øygarden in western Norway.

The project began operations in 2024, with an initial capacity of 1.5 million tonnes per annum (Mtpa). Phase one will store 0.8 Mtpa of CO_2 from a cement plant in Brevik, Norway, and a waste-to-energy plant in Oslo. In phase two, capacity will expand to over 5 Mtpa, including 0.8 Mtpa from Yara International's ammonia production facility in the Netherlands and 0.43 Mtpa from Ørsted's power plants in Denmark, with further volumes expected in the future.

The Longship CCS value chain of the Northern Lights Project



CO_2 utilization

Carbon capture and utilization (CCU) complements CCS by repurposing CO_2 as a feedstock for producing chemicals, synthetic fuels, and polymers. By using captured CO_2 instead of hydrocarbons like natural gas or oil in chemical synthesis, CCU reduces the need to extract and process additional virgin fossil resources. Typical applications include the production of urea, salicylic acid, and polycarbonate.

CO_2 can also enhance concrete production, where it is mineralized into carbonate, improving the material's mechanical strength. Additionally, CO_2 is widely used in the beverage industry for carbonating drinks.

Materials and components for CCS and CCUS

In addition to long-distance CO_2 pipelines, typically made from submerged arc welded (SAW) carbon steels, CCS and CCUS facilities rely on a range of typical process industry equipment. Components made with molybdenum-containing stainless steels are essential to address corrosion concerns, particularly in the supercritical or liquefied state of CO_2.

According to "AMPP guide 21532", Type 316 stainless steel could be considered for compressors and cooling devices, which are critical for densifying or liquefying CO_2. The guide also mentions Type 316 stainless steel for onshore pipelines transporting dense or liquid-phase CO_2 at temperatures as low as -80°C. Offshore and coastal pipelines, which are more exposed to chlorides, could benefit from 6% molybdenum or coated Type 316 stainless steel.

Other equipment, such as valves, flowmeters, and adsorption or desorption towers, also requires stainless steels. Alloy 625, a nickel-based alloy with 9% molybdenum, can be used for wellheads and trees where water flow-back and acidic condensates increase corrosion risks. At the same time, casings may rely on low-alloy, often molybdenum-containing steels such as L80 carbon steel, F22, or AISI 4130. Finally, well tubing may use 3.5% molybdenum-containing 25Cr super duplex stainless steel, which provides excellent strength and corrosion resistance.

❯ Installation of super duplex stainless steel downhole tubes.

State of the industry

The Global CCS Institute reports rapid growth in CCS projects worldwide, with 628 facilities in the pipeline by mid 2024 – a 60% year-on-year increase. These projects represent a cumulative CO_2 capture capacity of 416 Mtpa, reflecting a seven-year compound annual growth rate of 32%.

Of the 50 facilities in operation, the United States leads in CCS deployment, with 19 operational facilities, followed by China with 14, Canada with seven, and Norway and Iceland with two. Australia, Brazil, Hungary, Qatar, Saudi Arabia, and the United Arab Emirates each have one operational project.

Europe has seen rapid growth, with the number of CO_2 transport and storage facilities in development doubling over the past year to 77. This expansion highlights the increasing adoption of CCS technologies across the industrialized world.

While eliminating CO_2 emissions remains the ultimate goal, some industries face emissions that cannot yet be avoided. CCUS provides a crucial pathway for capturing carbon and securely storing it underground or repurposing it for beneficial applications. The success of this transition depends on robust infrastructure, where molybdenum is indispensable for the resilience and durability needed to meet the challenges ahead. (IR, NK)

IMOA news

36th Annual General Meeting

160 delegates from 52 member organizations gathered in Tokyo for IMOA's 36th AGM, hosted by members Taenaka Kogyo Co Ltd, Taiyo Koko Co Ltd, Advanced Material Japan Corporation, and Kohsei Co Ltd. Attendees were treated to a beautiful host dinner at Happo-En Gardens with live musicians, an interactive sumo wrestling demo, and stunning grounds.

This year's presentations included global and regional market insights, a 20-year study of Taipei's stainless steel water line installation program, the future of molybdenum recycling, the current state of global logistics, and a novel water purifying device from member Bauer Energy Design.

The AGM concluded with a tour of Nippon Steel's headquarters in Chiba, one of the world's largest steel mills. The entire facility covers almost 12 km^2. Nearly 100 members visited one of the site's several blast furnaces to witness the continuous casting of massive steel slabs. The enormity of the mill and the thoroughness of the tour were both impressive.

Next year's AGM will be hosted by Codelco in Viña del Mar, Chile, from 10–12 September, 2025.

Updated LCI of Molybdenum Products for Metallurgical Applications

The *Executive Summary* and *Summary Report of the 2024 Update Study of the Life Cycle Inventory and Carbon Footprints of Molybdenum Products for Metallurgical Applications* are now available to download from the IMOA website. The results are expressed as IMOA LCI global average values. Participating IMOA member companies provided data from 24 facilities in 10 countries across Asia, Europe, North and South America to generate the LCI carbon footprint values shown in the Table below.

Sandra Carey, IMOA's Health, Safety, and Environment (HSE) executive, commented "the significant reductions in carbon footprint between 2018 and 2024 are a very positive reflection of ongoing de-carbonization initiatives by companies within IMOA membership. In particular, increased use of renewable energy sources to replace fossil fuels are driving these improvements. The results will be welcomed by downstream users, such as the steel industry, for whom the molybdenum products are Scope 3 greenhouse gas (GHG) emissions".

Comparisons of the carbon footprint of 1 kg of each product

Year	Unit	Molybdenite Conc. (~50% Mo)	Tech Oxide (~60% Mo)	Briquette (~59% Mo)	FeMo (~67% Mo)
2024	kg CO_{2-eq}	2.84	3.79	4.03	7.41
2018	kg CO_{2-eq}	not calculated	4.96	5.04	8.04
% change from 2018		**n/a**	**24% lower**	**20% lower**	**8% lower**

Welcome new IMOA members

Five new members were ratified this September at IMOA's 36th annual general meeting in Tokyo:

- **Compañía Minera Antamina S.A.,** with mining operations in Peru.
- **London Chemicals & Resources Ltd,** an industrial chemical and recycling company in the UK.
- **Metrex B.V.,** a waste treatment and recycling company in the Netherlands.
- **Mingzuan Metal Limited,** trading non-ferrous, ferrous, and rare earth metals in Hong Kong, China.
- **Thompson Creek Metals Company,** with conversion facilities in the US, which includes roasting and FeMo conversion.

Following our AGM, we also welcomed **Alleima Tube AB*** to the Association.

These organizations now have access to specialized market insights, HSE and regulatory guidance, networking, and the opportunity to influence global market development programs. IMOA is excited to involve the unique perspective that each new member brings into the association.

* Formal ratification at the next AGM

ResponsibleSteel recognizes Copper Mark

Over the past year, Copper Mark has engaged in extensive discussions with ResponsibleSteel with the intention of becoming one of their recognized input material programs that credibly verifies the ESG performance of suppliers. ResponsibleSteel has now confirmed that they have recognized the Copper Mark, which includes the Molybdenum Mark, for levels 1, 2, and 3 of the Principle 3 responsible sourcing requirements as described in ResponsibleSteel's International Production Standard V2.1. As part of the recognition process, Copper Mark agreed to two pre-conditions. More information on those conditions can be found here.

Eva Model, IMOA's Secretary General, commented that "molybdenum is an important contributor to the steel value chain, so we are delighted at the successful outcome of this process, which has resulted in ResponsibleSteel's recognition of the Copper Mark".

Mo4Steel Symposium

The first Mo4Steel Symposium took place in Vienna, Austria, from November 13th to the 15th. IMOA worked closely with the Austrian Society for Metallurgy and Materials (ASMET) over the past two years to plan the event and recruit experts from across the spectrum of molybdenum and steel-related fields. Over 30 speakers presented the latest research on molybdenum in steel making, with topics ranging from the element's basic effects in physical metallurgy to its role in sustainable mining and manufacturing.

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The once gritty Taylor Yard is now updated with this sleek pedestrian bridge. © Mike Kelley

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