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01/2022

MOLY REVIEW

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Replacing old rail bridges

The historic center of Stockholm, Sweden, stretches over 14 islands. The bridges that connect these islands are in constant use, so any maintenance closures cut off vital transportation arteries. A solution that spares future generations from disruption was therefore crucial for the renovation of the city's busiest rail bridges: the four Söderströms. The new molybdenum-containing duplex stainless steel superstructure will provide enough strength and corrosion resistance to outlast the 120-year design life, with minimal upkeep.

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The Stockholm archipelago, like many settlements on the water, cannot function without a network of bridges. Over 340,000 people move across its Söderström rail bridges every day. But after 60 years of heavy use, they needed serious repair. In 2013, local traffic authorities determined that while the foundations were in good condition, the carbon steel structures that undergird the tracks were badly corroded. The bridges also surpassed their specified fatigue life. Hence, in 2017, an effort began to replace all four aging carbon steel structures with 2404 duplex stainless steel. Each of the Söderströms is 192 meters long and consists of 12 prefabricated sections. In total, the new rail bridges are the longest ever made with stainless steel.

Structural duplex: more than meets the eye

When duplex stainless steel (DSS) bridge structures first came to market, they were praised for their beauty. Whimsical designs such as Singapore's Helix bridge come to mind. But designers increasingly think beyond aesthetics with DSS, harnessing its strength and corrosion resistance even in non-visible applications, to create lighter structures that use less material and require less maintenance than their carbon steel predecessors. All DSS grades are at least twice as strong as Type 316 stainless steel. They also offer good weldability, making them suitable for a wide range of applications. The longer service life and lowered maintenance requirements conferred by DSS make these structures increasingly popular around the world.

Even though structural use of DSS is now established in design codes worldwide, carbon steel continues to dominate the bridge building market. Carbon steel bridges are perceived as less-expensive than stainless steel. They've also been around for over a century and enjoy familiarity within the bridge building and maintenance industries. Building steel bridges with duplex stainless steels, by contrast, began in the 2000s and is generally thought of as costly.

The Söderström rail bridges, surrounded by water, are a critical commuter traffic node in the center of Stockholm with a train passing every 3 minutes, some 500 per day.

The real cost of a “lower cost solution”

The Stockholm archipelago is a marine environment with brackish water and deicing salt use in winter – a double-threat of corrosion. Without the anticorrosive benefits of chromium, molybdenum and other alloying elements, a carbon steel bridge must be painted or otherwise protected to resist such harsh conditions. At first glance, carbon steel appears less expensive at €2 million for the four substructures – the duplex stainless steel ones cost double that at €4 million. But these figures are misleading; they only consider the initial fabricated cost. In fact, the carbon steel structures are expected to have a much higher overall cost during their life cycle, as they would need to be repainted every 30 years – three times over the 120-year design life. Repainting and repair costs, which do not include indirect costs from rail closures, are estimated to amount to €60 million over this time – 30 times the initial material investment. Looking at the total life cycle costs, the duplex design is considerably less expensive.

While all steels are 100% recyclable, the duplex stainless steel option also has a lower environmental footprint. The structure will not deteriorate over time if the stainless steel is correctly chosen. With proper care and specification, stainless steel can achieve a nearly unlimited life expectancy. It also does not require any environmentally hazardous surface treatments to protect it from corrosion. Such coatings or paints degrade over time and risk polluting the environment as they spall and chip off. They require regular inspection, touch up every few years and, eventually, complete removal and re-application every 25–30 years. This sounds simple enough but implies closing off the bridge, installing scaffolding, encasing it completely to capture the paint fragments that are blasted off to prepare the surface before applying the new coating and proper discarding of the old paint. Any such maintenance work also carries a certain risk of injury for the people involved. Duplex stainless steel largely eliminates these potential health and environmental costs.

The Swedish traffic authority, Trafikverket, also estimated indirect costs to the public due to the temporary loss of infrastructure amenities during repair and maintenance of a carbon steel structure at a further €1.3 billion over the 120-year span. This underscores the region’s dependance on these bridges and the immense disruption caused by closure for maintenance and repairs.

Construction and installation

The Söderström bridges are made with 2404 duplex stainless steel – the first ever bridges designed in this grade. The 1.6% molybdenum contained in this stainless steel contributes significantly to its crevice and pitting corrosion resistance. In fact, 2404 duplex stainless steel offers not only twice the yield strength of Type 316 stainless steel but also improved resistance to atmospheric corrosion.

Because stainless steel use in large-scale structural applications is a relatively new practice, steel mills do not typically produce the metal in standard sized I-beams, as is the case for carbon steel. However, mass produced I-beams often use more material than necessary. Customization allows engineers and designers to specify the exact cross

Manual welding of a prefabricated bridge section in the shop.

Seafaring cranes lifted the bridge sections off the barge and into place.

The new tracks were installed just a couple of meters from active trains.

section dimensions needed, saving unnecessary metal. As such, every piece on the Söderström bridges is tailor-made for life in the brackish archipelago.

The one-meter-tall I-beams were fabricated at Outokumpu's plate service center. There, pieces were water-jet cut from plates, submerged arc welded and subsequently pickled. Stål & Rörmontage then manually TIG/MIG welded the bridge sections from the prefabricated I-beams. The 48 bridge sections, ranging in length from 16 to 24 meters and weighing up to 18 tons, were then transported by barge to the site and installed. To minimize disruption, the bridges were replaced one by one, with commuters rerouted onto a spare maintenance track. It took two weeks to replace each of the 12 sections per bridge, demolishing the old structure by night and welding the new one by day. Altogether, the new sections use an impressive 600 tonnes of 2404 duplex stainless steel.

With replacement completed in 2021, activity has returned to normal along Stockholm's most heavily-traveled rail route. This enormous restoration effort in Sweden is not unique, as many bridges around the world are nearing the end of their service lives. The Söderströms' forward-thinking design in DSS highlights the benefits of structural stainless steel for bridges near coasts or places with deicing salt usage. To the benefit of both the environment and people who rely on this infrastructure, molybdenum-containing duplex stainless steels are likely to play an increasing role in much needed upgrades and new construction worldwide. (KW)

Molybdenum: essential for wind turbines

To prevent the worst outcomes of climate change, renewable energy sources like wind and solar must more than triple their share of global power production. While molybdenum plays a role in several green technologies, it is particularly crucial in wind power generation. Therefore, as the demand for wind turbines increases, so will the demand for molybdenum in many of their components.

According to the World Meteorological Association, both 2020 and 2021 set new records for the level of greenhouse gasses in the atmosphere. And July 2021 was Earth's hottest month on record. The economic slowdown caused by the pandemic did little to curb ambient levels of greenhouse gases, despite a temporary decline in emissions. Too many essential activities like heating and transportation continue to rely heavily or exclusively on fossil fuels. According to the Intergovernmental Panel on Climate Change (IPCC), if the world keeps emitting at current levels, severe negative effects of climate change are expected, including extreme droughts and floods, mass human displacement and threatened food supplies. While renewable technologies, mostly wind, solar and hydropower, already account for 25% of all electricity generated today, their share will need to approach 80% by 2050. Vast quantities of both land and raw materials are needed to make this transition. Molybdenum is one such material – an irreplaceable alloying element that provides the mechanical properties needed to withstand the massive forces at play in wind power generation.

Overcoming drivetrain issues

Wind power generation focuses the huge and varying forces of wind caught by enormous blades onto relatively small gear teeth and other components. The immense stresses applied by the wind onto components can even damage or destroy the drivetrain. Gearless wind turbines or "direct drive" systems were developed to overcome gearbox failure and raise efficiency. In these systems, the rotor is connected directly to the generator, eliminating the drivetrain. However, most direct drive systems rely on large magnets made from "rare earth" (RE) metals like neodymium. This reliance poses potential supply risks, as demand for RE metals is increasing exponentially for renewables over the next decades. Other applications such as electric vehicles and consumer electronics are also competing for these critical resources. At the same time, RE mining and especially refining is concentrated in just a few countries, adding to the supply risks. Fortunately, drive train issues can also be resolved by improving the gear steels with the addition of molybdenum. It increases the hardness, strength and toughness of these steels and its supply is not at risk. Major deposits are found throughout the Americas and China, making it geographically balanced.

Currently, gearless drive systems are used primarily in high-power offshore turbines and part of the 3 MW land-based turbines, mostly in Europe. But in addition to the supply chain risks associated with RE magnets, the future trend towards higher-powered onshore turbines also favors designs using gearboxes. Direct drive systems would require extremely heavy, cumbersome generators given the torque requirements of future designs, which makes their widespread use impractical.

Wind turbine overview

Currently, of all renewable technologies, wind power has the greatest potential for added molybdenum use. Windmills require by far the largest amount of steel and iron castings, compared to other power generation technologies. While steel accounts for the vast majority of the tower weight (~98%), both materials find use in components of the nacelle – the part of the turbine housing all generating components, including the gearbox. Regarding the latter, steel represents approximately half of the weight. Cast iron is mainly found in the nacelle (40%) and in the rotor (30%). The nacelle and rotor hub can weigh up to 900 tonnes in offshore wind turbines, not including the mass of the blades made from glass fiber reinforced polymers. Offshore windmills additionally require anchoring structures to the seabed, which are usually steel-fabricated monopiles or tripods.

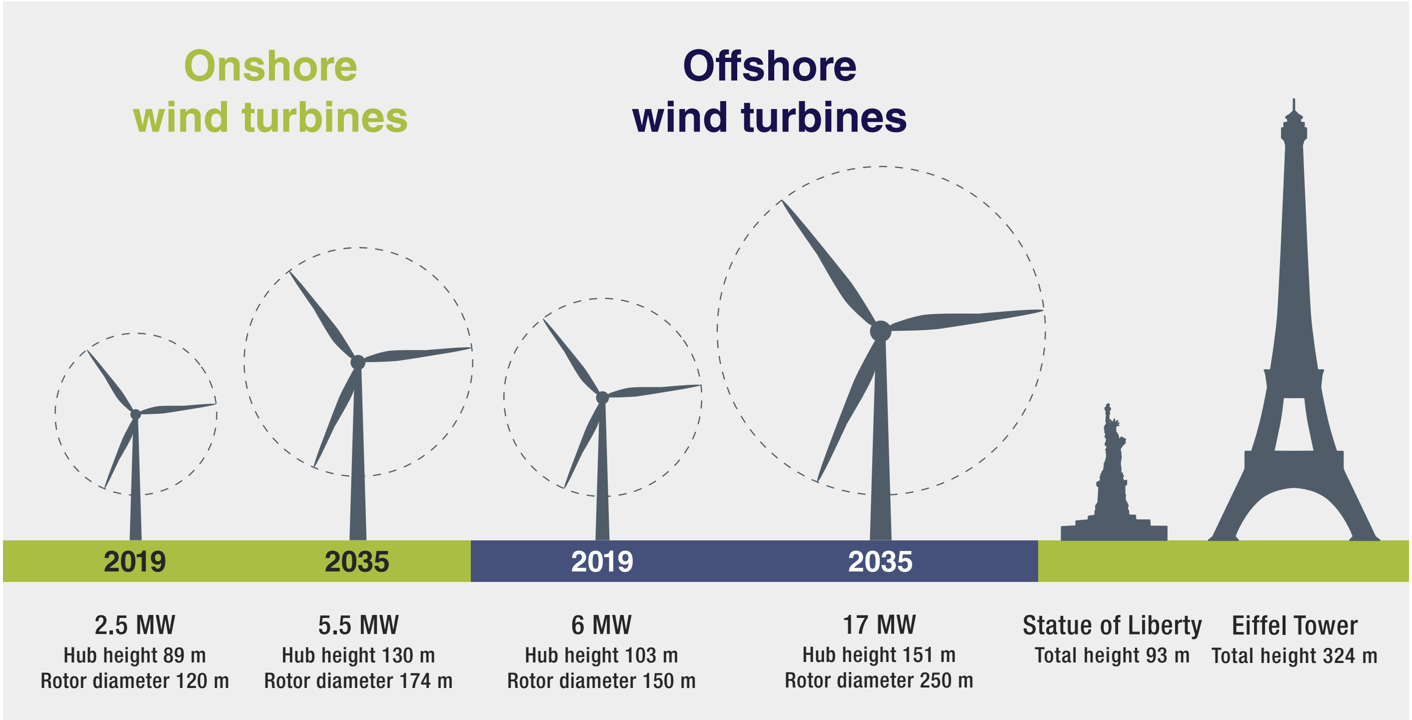
Wind turbines are rated by the amount of power they can produce under ideal conditions and wind speeds. Onshore wind turbines currently operate at an average rated power of 3 megawatts (MW), but major turbine manufacturers have already started targeting the market for larger power output in the 5 MW range. For reference, 5 MW of a recently built wind turbine with a capacity factor of 42% is enough to power around 5,000 average-sized EU homes. Offshore wind turbines are much larger and capable of generating more power: currently they operate at 7 MW but designs for turbines generating up to 16 MW are being explored.

In Europe, the current onshore-to-offshore capacity ratio of 80:20 is not expected to change significantly. Other geographical regions operate a much lower share of offshore turbines, but are expected to approach the European ratio in the future.

The tower of a wind turbine consists of individual ring segments. These are 20–25 meter in length, produced from flat-rolled heavy plates made from carbon steel. Most modern wind towers have heights of 70–140 meters and diameters of 4–5 meters. The latest and largest offshore towers are typically manufactured from steel grade S355 (AISI A276) having a yield strength of around 350 MPa (or 50 ksi). Since molybdenum is only required for the production of plate steels with yield strength levels of 500 MPa and above, it will not be used in the ring segments of the tower for the foreseeable future. But molybdenum plays an important role holding the tower together. Tower segments are usually assembled using nuts and bolts up to size M72 (diameter 72 millimeters). Typical bolt steel alloys fulfilling the high demands for strength and toughness are 34CrNiMo6 (1.6582) or 30CrNiMo8 (1.6580), containing molybdenum additions in the range of 0.2–0.5%.

Gearing up for the wind

Molybdenum-containing alloys are most widely used for powertrain components of windmills. The low rotational



Size and power rating comparison of recent and future models of onshore and offshore wind turbines (Source: Berkeley National Laboratory). For height comparison, the Statue of Liberty in New York City and the Eiffel Tower in Paris are added on the right.

The interior of a wind turbine nacelle with drivetrain.

Wind turbines are difficult to access for maintenance and repair as the nacell sits high above ground. Better materials can reduce the need for costly interventions.

speed of the rotor must be transmitted and transformed into a higher one, suitable to drive the generator. Therefore, shafts and gearboxes are required. Due to the criticality of these components in terms of reliability and performance, a combination of excellent strength, toughness and fatigue resistance properties is required. Quenched and tempered steels such as 42CrMo4 (AISI 4140) are a perfect solution for shafts. Carburizing steels with a CrNiMo alloy concept are the first choice for gear components. Normally, molybdenum is added to such steels in the range of 0.2–0.3%.

How much steel, cast iron and molybdenum do wind turbines use?

110–140 t steel / MW*
18–21 t cast iron / MW*
100–120 kg molybdenum / MW*

* Specific metal need per MW

Examples:

3 MW onshore turbine: 400 t steel
Largest offshore turbine: 1,500 t steel

Estimated need through 2050:**

400,000,000 t steel
65,000,000 t cast iron
300,000 t molybdenum

** Based on IEA's "Beyond 2 degrees scenario", 3,500 GW of additional wind capacity is needed by 2050. Steel needed for special equipment, such as installation vessels, jackup rigs, cranes, is not included in these estimates.

However, due to the increasing torque density with the ever increasing size and power rating of windmills, gear steels are facing more demanding performance requirements. Recent developments in gear manufacturing, inspired by past IMOA projects, indicate that substantial performance improvements are possible by raising the molybdenum content towards 0.5–0.8%. Other potential molybdenum applications could develop in the future, driven by weight reduction demands. As such, austempered ductile iron castings and ultra-high strength plate steels may play an increasingly important role for carrying frames and housings of powertrain aggregates. These alloys today typically have molybdenum additions in the range of 0.3–0.8%.

Detailed analysis of the various components in current windmills indicate a molybdenum requirement of 100–120 kg Mo per rated MW. Given the technological development, in particular the increasing power rating of wind turbines, a significant share of the wind power market is predicted to be molybdenum intensive. Projecting the International Energy Agency's "Beyond 2 degrees scenario" onto the expected mix of geared and gearless technologies, suggests that the molybdenum demand by the wind power industry between now and 2050 should be in the order of 300,000 metric tons, more than the total amount of molybdenum mined in one year. The molybdenum use in alloys for constructing the necessary heavy-duty transportation and installation equipment, including vessels, cranes and jackup rigs, will appreciably add to this figure.

Powering the world without carbon emissions might seem impossible, but like developing effective Covid-19 vaccines and adapting to the pandemic, humanity is more than capable of rising to the challenge. Whichever of the future scenario for renewable power generation proves true, molybdenum goes with the wind, and the required volume will be big. (HM)

Keeping Tabs

Under the guidance of supporting philanthropists, artists and architects, a group of school children turned trash into a timeless memorial. *Keeping Tabs* holds six million soda tabs, each symbolizing a life lost decades ago. Molybdenum-alloyed stainless steel provides the corrosion resistance to keep this sculpture beautiful and untarnished through the deicing salt-laden winters of the midwestern United States.

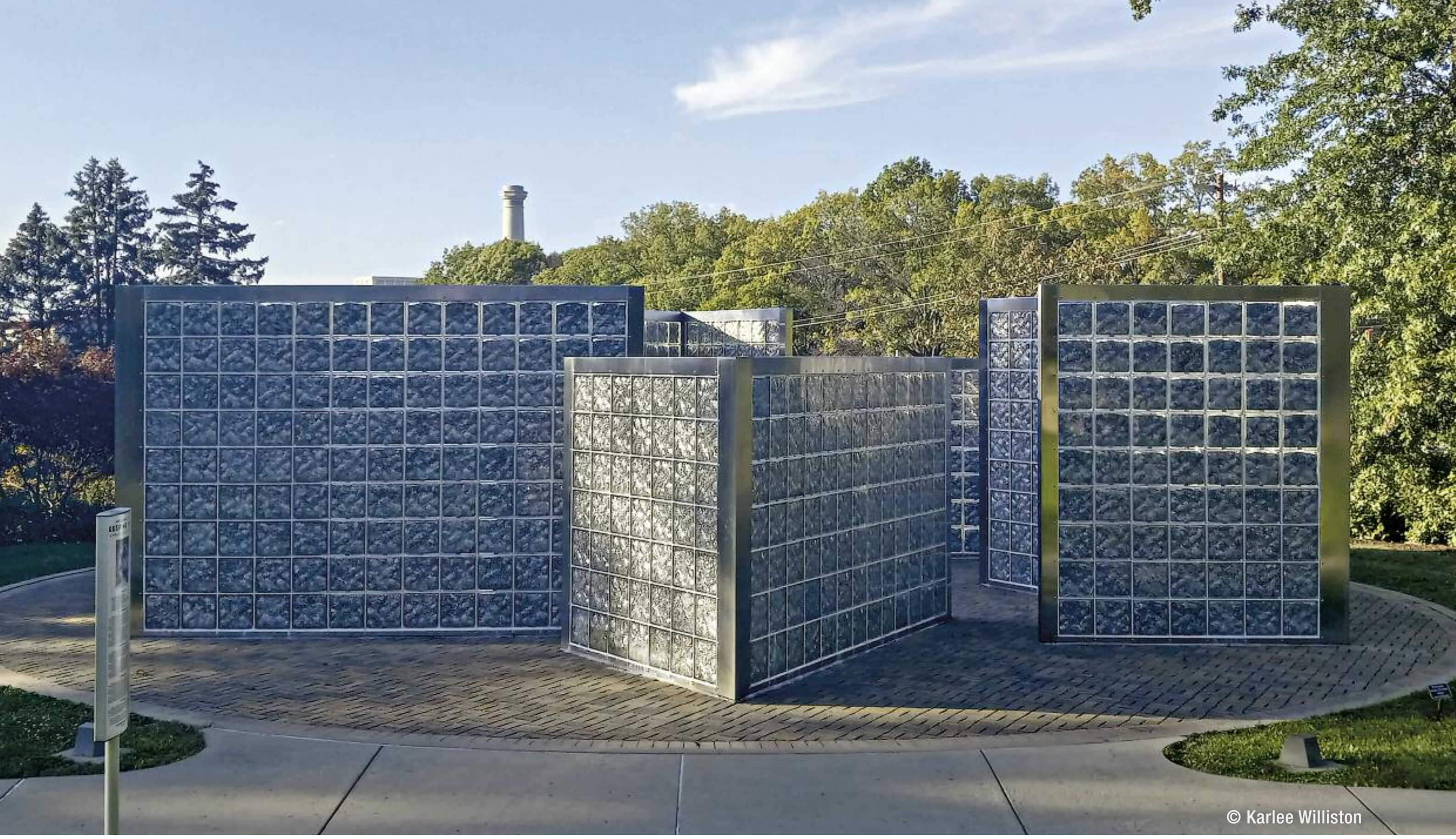
In 1996, Bill Walter, a history teacher from Pittsburgh, searched for a tangible way for his middle-school students to comprehend the enormity of the number six million. That represents the number of Jewish people killed in the Holocaust. An additional six million Roma, disabled, Catholic clergy, political dissenters and LGBT people also perished in the holocaust. To visualize this number, Walter selected a commonplace item that they could hold and count – the often-discarded snap-top can tab. Accepting their teacher's challenge, students began collecting can tabs from around the globe. Regardless of shape, color, or size, no can tab was discarded. Today, they're displayed in the Nancy and Gary Tuckfelt Memorial *Keeping Tabs*: A Holocaust Sculpture. The sparkling and labyrinth-like Type 316 stainless steel and glass sculpture, which sits on Community Day School's grounds, is at once understated and unavoidable.

The sculpture forms an abstract Star of David when viewed from above.

Visualizing six million

Over a four-year period, Walter's classroom filled with glass aquariums brimming with tabs so heavy that the floors of the nearly 100-year-old building heaved under the weight. Already accomplishing what seemed impossible, the students were confronted with just what to do with 1,179 kilograms of tabs. At the time, the school was hosting artist Elena Hiatt Houlihan, who often works with schools and community organizations. A collaboration began between the students and Hiatt Houlihan, who shared her expertise in fashioning public art from recyclable materials. A design proposal from three 6th grade girls won out. Their simplistic vision would eventually become an internationally renowned landmark and one of the largest and most complex pieces of public artwork designed by young people worldwide.

Displaying the tabs presented another issue. Imbedding the tabs in concrete or placing them in hollow acrylic walls were considered and found to be unsuitable. Inspired by a child's glass coin bank, a local glass company was asked to fashion square glass blocks with a slot in the top that would be ideal for storing the tabs. Teams of students



Community Day School students are trained to conduct tours of the sculpture for visiting groups.

working under the artist's guidance first created a clay mockup of the sculpture, then transformed it using plexiglass for the walls and crumpled aluminum foil to signify the tabs' appearance. After receiving the local government's approval, an architectural firm suggested modifications and developed the schematic design and contract documents, moving the project closer to the build phase.

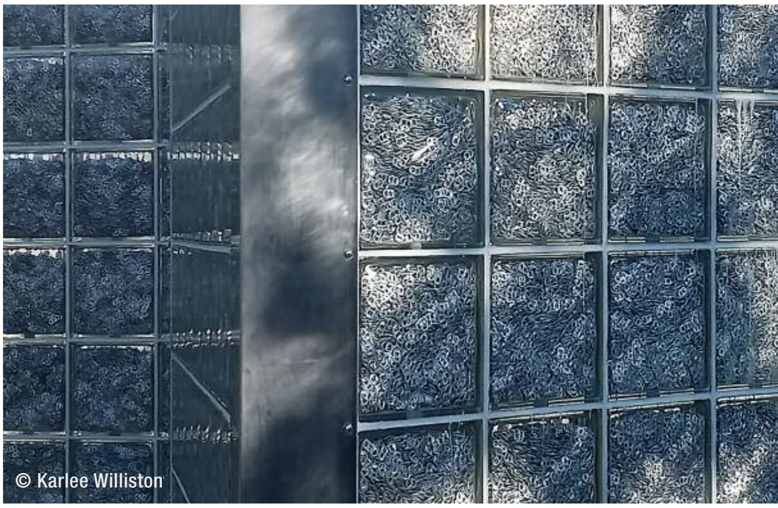
Embracing the weight

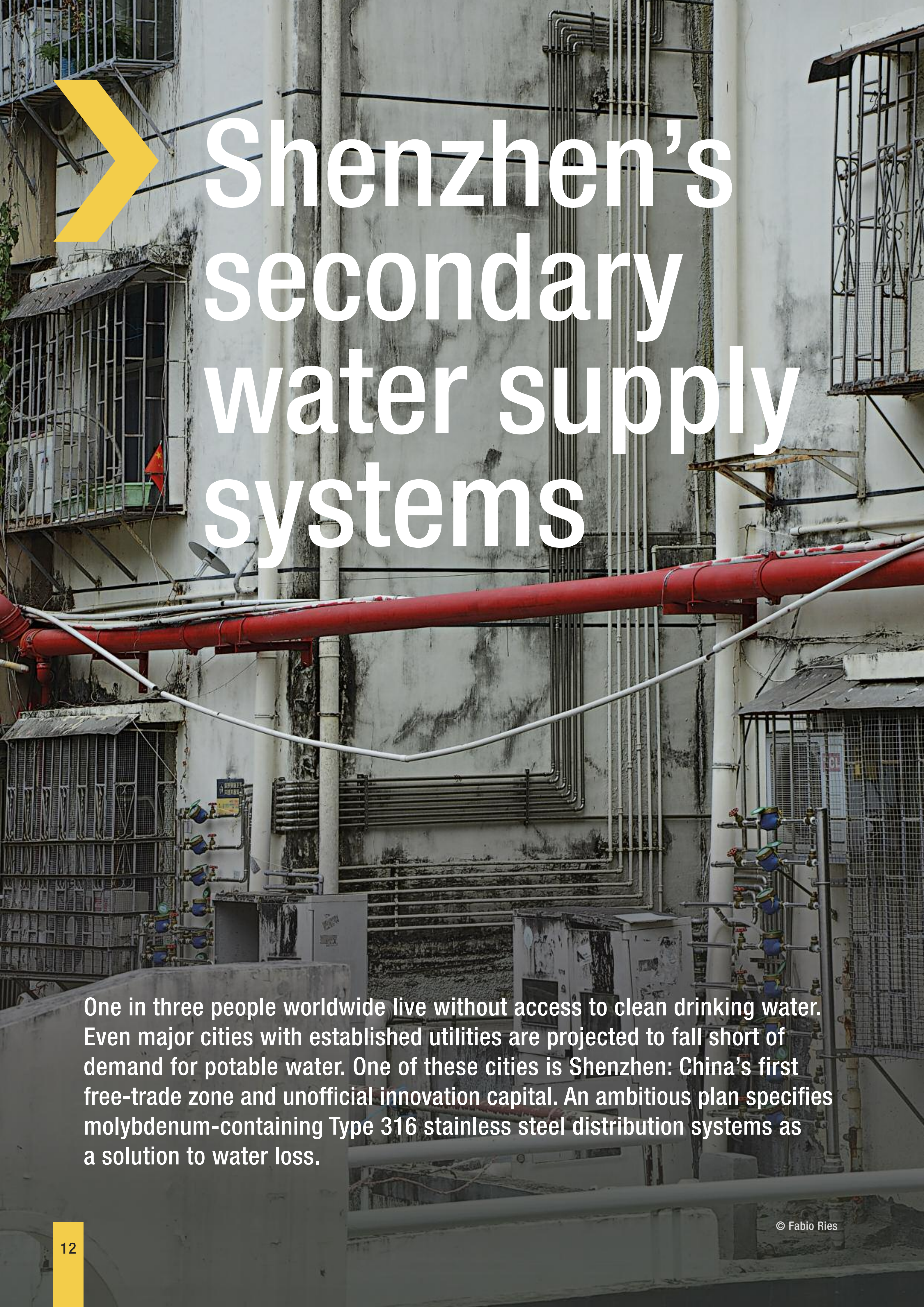
The memorial consists of 960 individual glass blocks, each filled with 6,250 tabs painstakingly counted and inserted into the glass blocks by the students. Each block weighs approximately 9.1 kilograms. They are stacked on a concrete base to form walls standing at varying dimensions between 2.1 meters and 2.7 meters in height.

To stabilize the nearly nine tonnes of glass block, a strong backbone was essential. The architect and fabricators chose Type 316L stainless steel for its strength and its ability to resist the local environment's corrosion challenges. Pittsburgh heavily uses deicing salts, famous for staining and degrading outdoor metal. The memorial faces a moderately-busy intersection at the edge of the school grounds, so over time deicing salts accumulate on its lightly textured surface. However, the 2% molybdenum in Type 316L stainless steel help resist corrosion from this buildup of chlorides. Indeed, the stainless steel remains flawless and stain-free after eight years in service.

Keeping Tabs appears to come to life as the changing light patterns strike the tab-filled glass blocks throughout the day. At night, the use of ornamental lighting provides another perspective. The sculpture is open for guided and self-guided tours. Visitors to the site can absorb its meaning by viewing the exterior or entering the chapel-like meditative space at its center. Its shimmering stainless steel draws the attention of passersby, beckoning them to "keep tabs on our humanity" and be prepared to confront prejudice and injustice while making the world a better place. (RB)

Keeping Tabs uses a No-4 surface finish for a uniform look that detracts from fingerprints left by visitors.





Shenzhen's secondary water supply systems

One in three people worldwide live without access to clean drinking water. Even major cities with established utilities are projected to fall short of demand for potable water. One of these cities is Shenzhen: China's first free-trade zone and unofficial innovation capital. An ambitious plan specifies molybdenum-containing Type 316 stainless steel distribution systems as a solution to water loss.

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In 1980, Shenzhen was a sleepy fishing village of a few thousand. One taxi pulling a wooden cart served the whole town. Today, it's a bustling city of 17.5 million people and an innovation and tech hub, indispensable to the global supply chain. Shenzhen's location on China's southern coast, adjoining Hong Kong, made it the ideal testing ground for the export-driven economic model that defines the modern era. Shenzhen sees the growing reliance on its strained water resources not as a hurdle, but as a catalyst for better infrastructure. The city unveiled targets for improved water resources by 2025, even promising a clean drink from the tap – a first for modern China. Type 316 stainless steel secondary water supply systems are being implemented across Shenzhen to minimize wastage of this most precious resource. With support from the central government, it is expected that other municipalities will emulate Shenzhen's plan and reduce leakage throughout the country.

Secondary water systems

Secondary water supply systems transport water from the mainline under the street to the tap in multi-story buildings. These systems began to proliferate in China during the late 1980s and early 1990s. It was the first time high-rise apartment communities with indoor plumbing were built for ordinary city dwellers, and these facilities soon became symbols of the new prosperity.

The typical secondary water supply system starts with the "snap tap". Water is directed from the main through this snap tap into a secondary pipe and then to a tank for buffer storage. In higher buildings, pressure is added through pumps, regulated by frequency inverters to adjust to variable flow rates, which guarantees reliable supply with maximum energy efficiency.

Troubled waters

In China, secondary water systems were made traditionally with galvanized steel, ductile iron or plastic, which all suffer leakage problems. The World Bank estimates global water demand will exceed supply by 40% in less than 10 years. Yet, approximately 25% to 30% of the world's treated drinking water supply is wasted through leakage. Some regions lose well over half of their water during distribution. It's not just water that's wasted – the resources used to treat, store and transport it are also squandered. But most importantly, this loss creates a risk for water shortages, especially during droughts, which are increasing due to climate change. Most leakage occurs in the final leg of distribution, in the "service lines", underground pipes that carry water from the mainline to the meter at individual residences and businesses. Installing stainless steel service lines is associated with dramatic reductions in both leakage rates and repair cases, saving cities like Tokyo valuable water resources as well as billions of dollars over the life of the system.

China is home to almost 20% of the world's population, but only to 7% of its freshwater resources. Water is unevenly distributed: the north and west are parched while the south swells with seasonal heavy rains. Severe pollution, which makes over 60% of ground water and 25% of rivers and lakes unfit for human contact, does not help. 20% of China's fresh water is unfit even for industrial or agricultural use. The signature South-to-North Water Diversion Project, the costliest engineering work in human history, has shown only meager results in alleviating chronic water scarcity in Northern China's densely populated plains.

Shenzhen, with major pollution and an ever-growing population, knows these water woes all too well. Shenzhen does not have any deep major rivers, only rain-dependent surface waters, fed by seasonal monsoons. Quality and availability of water varies widely from month to month and year to year. The estuaries that once helped to clean and stabilize water levels have been drained for industrial development. Shenzhen must look for other solutions. By 2025, the city hopes to increase the volume and quality of its water supply through capturing and reusing rainwater, better integration of stakeholders and maintenance practices, establishing new reservoirs and outfitting all residences with stainless steel secondary water systems.

Made with galvanized steel, ductile iron or plastic, the original systems suffered from corrosion and leakage, leading to water loss and contamination.

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Shenzhen has some 17.5 million inhabitants and continues to grow at an average rate of 5.35% per year.

China's secondary water system upgrade in numbers

Country-wide **200+ million** homes need upgrades.

1st phase target: (2019–2023)	**160,000** residential areas **110 million** people
By 2020 completed:	**60,000** residential areas **41 million** people

Spotlight on Shenzhen

Shenzhen's water utility identified the secondary water supply systems as key failure points during distribution. This is where energy consumption is highest, as well as where leakage and contamination are most likely to occur. The new secondary systems in Shenzhen are therefore fully automated, with flow meters and cameras installed at various points of the line to monitor rates and regulate valves and pumping capacity. They are integrated into one smart control system together with the water works and the main municipal supply line.

Trials for system replacement have been carried out in Shenzhen since 2010 in selected urban districts, before the complete campaign began in 2017. After testing and comparing different materials, Type 316L stainless steel was specified as mandatory for all tubes, fittings and water tanks in secondary systems, no matter whether installed outside, underground or in the walls. For valves, pumps and meters, the use of Type 316L stainless steel is not yet mandatory but strongly recommended.

The Shenzhen Water Group (SWG) chose Type 316L stainless steel for strength, resistance to corrosion, ease of maintenance and cleaning, long service life and recyclability. Corrosion is a major issue in Shenzhen due to its humid coastal location with a high salt content both in the air and in the soil. Elevated levels of air pollution also create conditions for particulates to stick to surfaces, which can cause atmospheric corrosion. In addition to improved corrosion resistance, thanks to its 2.2% molybdenum content, Type 316L stainless steel offers a long-lasting clean and neat appearance when installed on the exterior of retrofitted buildings. One further factor is the broad availability of stainless steel products in China. In the past five years, Chinese tube and pipe manufacturers have increased three-fold.

Installation of the new systems is supported through a publicly-funded campaign to overhaul residential areas built before 2000 to comply with new standards. The water authority aims to install compliant secondary systems for all Shenzhen residents by 2025. In 2018, Shenzhen's Yantian District, home to 2.7 million people, became the first district with stainless steel secondary systems and increased tap water quality.

Thanks to stainless steel, the new systems look neat and are easy to clean and maintain.


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Beyond Shenzhen

Following in Shenzhen's footsteps, a campaign to overhaul older secondary water systems took off nationwide in 2018, targeting 110 million people from 160,000 residential areas over five years. 20,000 upgrades were completed in 2019, while more than 40,000 followed in 2020. The outbreak of Covid-19 sparked a new urgency to the campaign, furthering the government's promotion of health and safety while also stimulating the economy. Greeted by general enthusiasm, the campaign is largely ahead of schedule, and more public funds will be available to sustain its long term viability. In total, over 200 million homes are targeted for secondary water system upgrades or installation. As a rough estimate, some 15,000 tonnes of molybdenum may be needed over the next five years to achieve these targets – an annualized average that would be equivalent to more than 1% of all new Mo produced in 2020.


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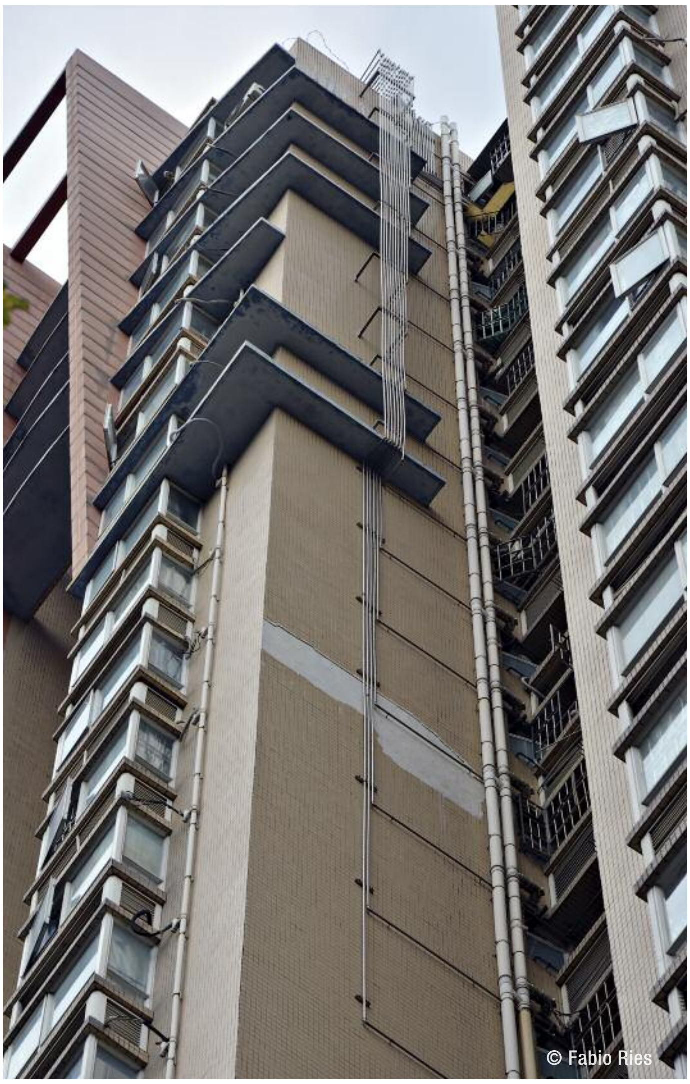
The hygienic and corrosion-resistant properties of stainless steel make it ideal to help China achieve its goal of clean drinking water for all.

Upgrading a typical Chinese residential area with upwards of 1,000 families can require 20 – 25 tonnes of stainless steel tubes and fittings.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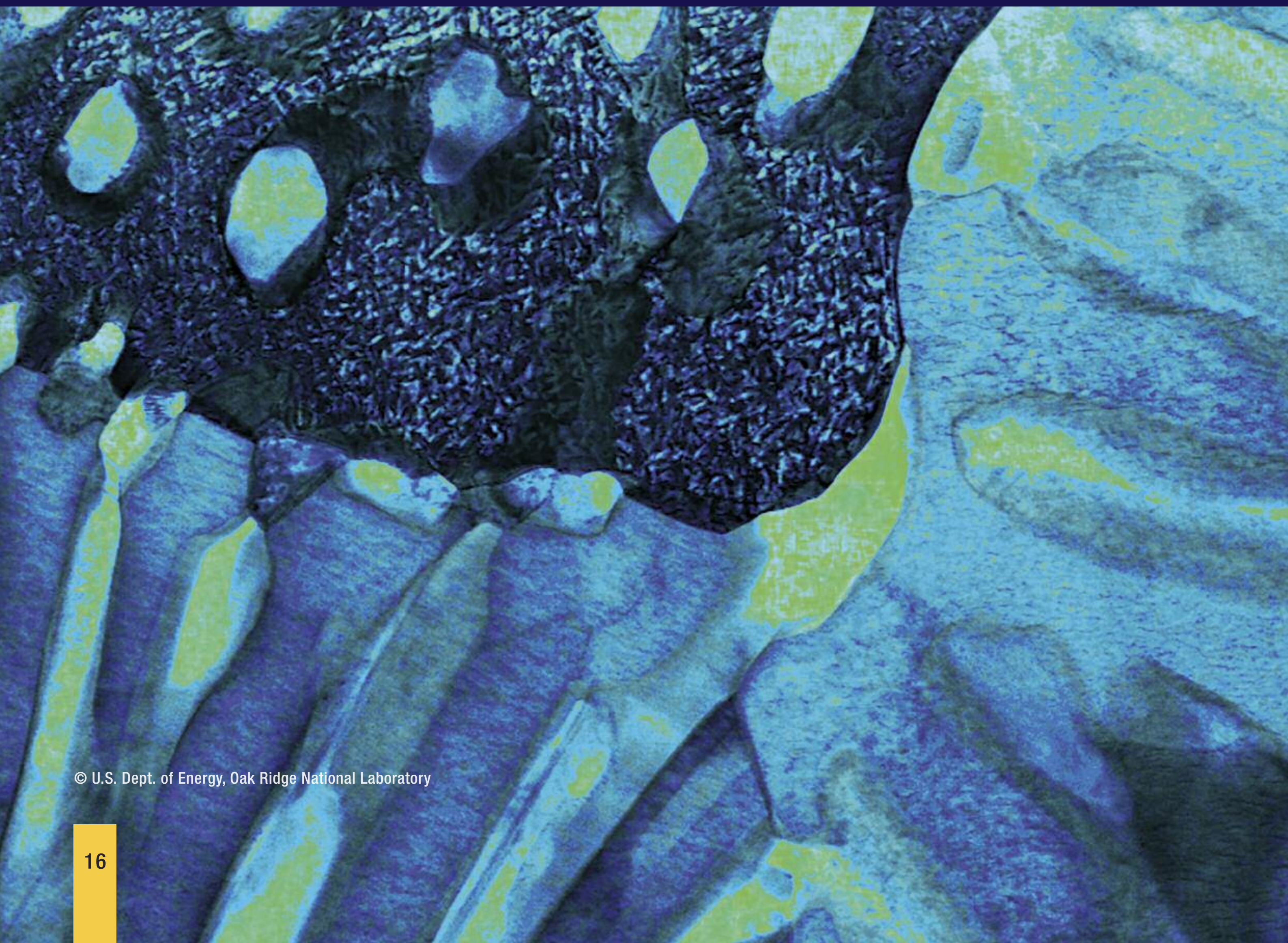
To further promote the stainless steel secondary water systems, the Shenzhen utility held a "National Conference on Secondary Water Supply Systems". This conference brought together academics, utilities, and suppliers from across the country to study the Shenzhen case in depth. "Shenzhen Water University", a platform for research and exchange for stakeholders in the water industry, also helps to promote Shenzhen's approach. By acquiring shares in local water utilities across China, SWG hopes to export its successful model and advanced operational experience across the country.

Already, water utilities in the cities of Fuzhou, Haikou and Zhuhai have shown a strong commitment to "study Shenzhen's experience", while several districts in Shanghai and Suzhou have made Type 316L stainless steel mandatory on a trial basis. In 2020, the city of Hangzhou upgraded over 100 secondary water systems with a combination of Type 304 and Type 316 stainless steel components. Other cities and provinces, while mandating "stainless steel grade 304 or higher" in their local specifications, strongly recommend Type 316L for use in public buildings or external applications.

Time is running out to secure enough clean water for future generations. But cases like Shenzhen highlight that solutions are available, even when the challenges seem insurmountable. The new stainless steel secondary water systems, sparkling in the sun as they climb up the side of the city's high rises, are a visible reminder that clean water for all is possible. (FR)

3D printing a hot commodity

Molybdenum metal is indispensable to several industries because of its strength at high temperatures. But some applications require complex and not so-easily-fabricated shapes. 3D printing is one approach to overcoming production issues with complicated parts, however, when produced in molybdenum metal, such parts often suffer from defects. A new process, alloying it with titanium carbide, may indicate a turning point.



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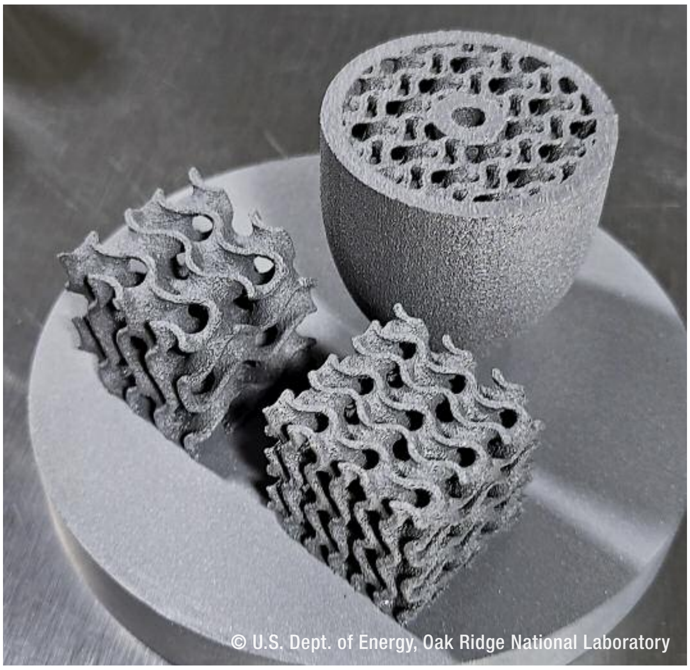
In 30 years, the world is projected to need double the electricity it currently uses. But expanded energy production must coincide with emissions decreasing below current levels to avoid the worst effects of climate change. The solution to increasing the power supply without increasing emissions will be multifaceted, but it's likely to involve raising the operating temperature inside power conversion plants to increase their efficiency. For example, upping the temperature inside nuclear reactors from 900 to 1000°C would raise productivity by 10%.

Although this offers major opportunities to reduce emissions as well as costs, turning up the heat in these sectors is a materials science conundrum. Only a few materials are potential candidates for such infernos. Mo-metal and Mo-metal alloys can tolerate temperatures that warp or liquify others. This is because molybdenum has one of the highest melting points of any element in existence (2622°C). Most importantly, it retains its shape and strength at high heats. Other metals that tolerate extreme temperatures well, like rhenium and niobium, are naturally less abundant than molybdenum and can be expensive or confer supply risks. Mo-metal is sometimes used in tandem with carbon-composites, which offer even greater stability at high heats. However, carbon-composites are wildly expensive and time consuming both to design and to manufacture. Thus, the scientific community continues to consider Mo-metal as a solution – but it also presents challenges.

Printing a paradigm-shift

Parts for highly-specialized industries are increasingly produced through additive manufacturing (AM), also known as 3D printing. AM originated in the mid-1980s to accelerate the development of product prototypes. The process is characterized by fusing layers of material together, often at the microscopic level. The "printer" references a computerized 3D model, producing an exact replica layer by layer. Unlike the "subtractive" methods of traditional milling, cutting, drilling and grinding – successful AM produces virtually no waste. It is often more cost-effective to add complexity to a part with AM because the design can be simply altered on the computer. Some designs that are difficult or even impossible to make with traditional manufacturing, such as parts with hollow portions that lack a connection to the external part surface, can be realized with 3D printing.

The ability to 3D print Mo-metal in the complex shapes required by the aerospace, defense and energy conversion sectors could result in increased thermal efficiency, which ultimately means more power generated with fewer resources. The challenge, however, is that 3D printed Mo-metal can suffer a loss of mechanical properties and stability that can render it unusable. This is because the 3D printing of Mo-metal and Mo-alloys is prone to the formation of defects such as porosity and cracks under improper print conditions. However, through carefully controlling the 3D print process, Mo-metal and Mo-alloys such as titanium carbide Mo-matrix alloys can result in high quality crack-free parts with consistent properties. Scientists at the Oak Ridge National Laboratory (ORNL) in the southeastern United States are now partnering with external stakeholders to trial Mo-metal and Mo-alloy objects at scale.

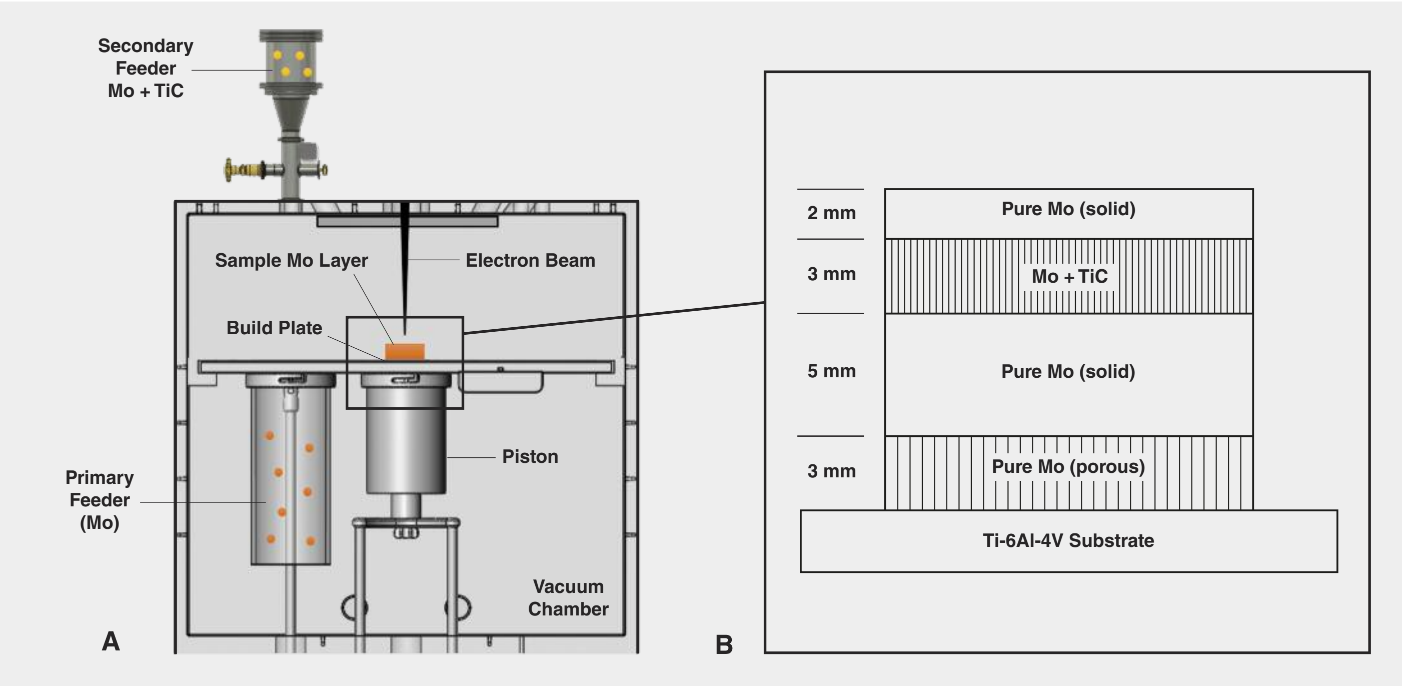


3D printing allows complex shapes to be printed which cannot be fabricated in any other way. These are prototype parts for highly efficient Mo-TiC heat exchangers.

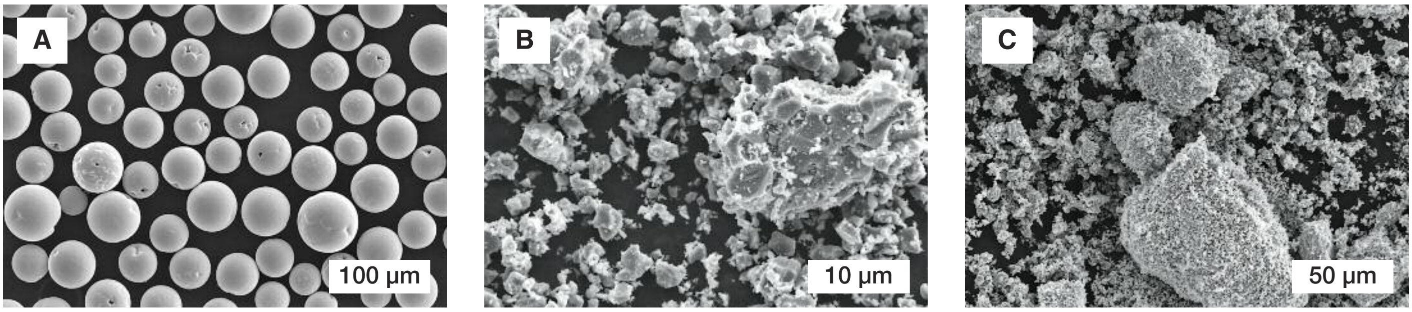
No more slipping through the cracks

This manufacturing process uses an AM method called "powder bed fusion" (PBF) to melt the powdered feed material into a solid. PBF requires either a laser or an electron beam to melt and fuse the powdered constituent. The researchers used the latter method, citing better control over temperature variation during printing. PBF with Mo-metal has yet to be successful at commercial scale due to the defect prone nature of these materials during processing, but recent findings suggest that soon may change.

The researchers demonstrated the ability to print high-quality Mo-metal with unique grain structures not achievable through traditional Mo-metal manufacturing routes. These PBF processing advancements have enabled Mo-metal to be successfully printed into structural parts used in nuclear thermal propulsion systems.



Schematic of the customized electron beam PBF build chamber and secondary feeder (A) and a Mo-Mo + TiC-Mo sandwich sample (B). Source: U.S. Dept. of Energy, Oak Ridge National Laboratory



Molybdenum powder (A), TiC particles (B) and the 60% molybdenum/40% TiC powder created by mechanically alloying the two feedstock powders. © U.S. Dept. of Energy, Oak Ridge National Laboratory

In addition to Mo-metal, the researchers also successfully printed composite matrix Mo-alloy titanium carbide material. In materials science terminology these are known as cermets. To create the cermet, researchers mechanically alloyed feedstock powders of 60% molybdenum powder and 40% titanium-carbide and printed them. After printing, there were no defects detected. Such materials offer the potential to enable advancements in energy systems requiring materials to operate in extreme environments such as super critical CO_2.

Other research teams have also yielded promising results. In 2019, the Beijing Institute of Technology developed 3D printed Mo-metal components for ion thrusters in the aerospace industry. The research group also combined Mo-metal powder with a titanium carbide powder to form a stable, oxidation-resistant composite product. The composite approach seems to yield positive results, not only with pure Mo-metal but also with other Mo-containing alloys. A research team in Singapore mixed titanium diboride nanoparticles with the molybdenum-loaded nickel base alloy Inconel 625, also resulting in better printability. These developments further attest to the future viability of vastly improved 3D printed Mo-metal and Mo-containing alloy components. Such projects demonstrate the unique properties of molybdenum and their increasing value in a decarbonizing world.

Raising the efficiency of thermal powerplants like nuclear reactors depends on the developments of better materials, particularly those with high temperature strength. Molybdenum is arguably the best candidate for the job. The ability to 3D print the material in the shapes required by industry could have major implications for generating more power with fewer resources. (KW)

IMOA news

Prop 65 comes into force

On 19 March 2021, California's Office of the Environmental Health Hazard Assessment (OEHHA) added Mo Trioxide (CAS No. 1313-27-5) to the Proposition 65 List of substances known to the State of California to cause cancer. The ruling means it is essential that companies, both within and outside the US, whose products potentially may be sold in California are aware of Proposition 65 and what's needed to comply with its provisions.

By 19 March 2022, any business with 10 or more employees that causes an employee or consumer in California to be exposed to molybdenum trioxide must place a clear and reasonable warning on the product or post a warning sign in the workplace such as: "WARNING: this product contains chemicals including molybdenum trioxide, which is known to the State of California to cause cancer". For more information, go to www.P65Warnings.ca.gov.

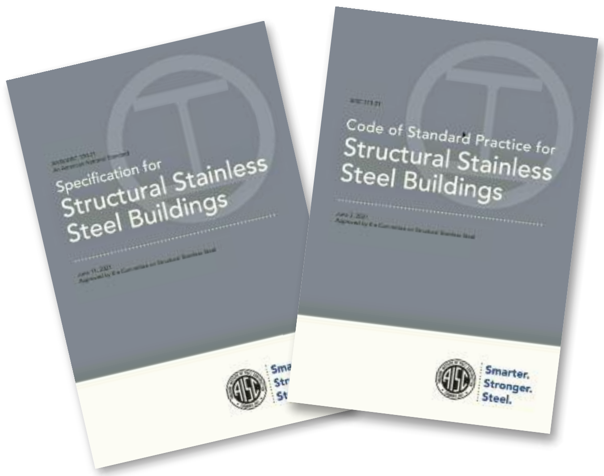
Prop 65's formal name is the Safe Drinking Water and Toxics Enforcement Act of 1986, and therefore also prohibits California businesses from knowingly discharging significant amounts of a listed chemical into drinking water sources.

Molybdenum supply chain profile issued

TDi Sustainability, in collaboration with IMOA, published *Molybdenum profile for supply chain due diligence and responsible sourcing* in November. The paper provides stakeholders with a clear understanding of the molybdenum supply chain as it pertains to environmental, social and governance (ESG) matters. It reports on the ESG implications for industry participants and the current responsible sourcing standards, certifications and initiatives that are applicable to molybdenum and is available for download from the IMOA website.

AISC stainless steel standards

ANSI/AISC 370-21 *Specification for Structural Stainless Steel Buildings* and ANSI/AISC 313-21 *Code of Standard Practice for Structural Stainless Steel Buildings* are available to download free of charge at Current Standards | American Institute of Steel Construction (aisc.org).



These standards will help engineers, materials specifiers and designers take full advantage of the outstanding properties of stainless steel in various construction projects, including large infrastructure projects such as bridges. These codes are significant because they are the first U.S. specifications for structural use of heavier gauge hot rolled and welded stainless steel sections. The AISC codes are also used by engineers in many other regions globally.

IMOA and Team Stainless consultants Nancy Baddoo (Steel Construction Institute, UK) and Catherine Houska, along with steel producers and product manufacturers, have worked closely with AISC over the last three years to develop these important new standards.

IMOA welcomes

a new member **Advanced Material Japan Corporation (AMJ)** back to the Association. AMJ, a Japanese professional trading company with a particular focus on rare and minor metals, including molybdenum, which is one of their main trading commodities. "We are very glad to be back as a member of IMOA" said AMJ.

IMOA Annual Review 2020/21

IMOA recently published its *Annual Review* for 2020/2021, detailing the activities and achievements of the Association on behalf of its members over the last year. It can be downloaded from the IMOA website.

CRU Ryan's Notes Ferroalloys conference

IMOA members are entitled to a 15% discount off the delegate fee to this year's Ryan's Notes Ferroalloys conference. This conference will take place in-person at Hotel Jakarta in Amsterdam, The Netherlands on 7–8 June 2022. For more information and to register visit https://bit.ly/3IAZMZA

IMOA Mandarin website launched

The Mandarin Chinese language version of IMOA's website (http://www.imoa-cn.info/) was released in the fall of 2021 and includes the core content of the IMOA website, popular IMOA brochures, MolyReview, videos and more!

German austenitics brochure released

IMOA is proud to release *Verarbeitung austenitischer nichtrostender Stähle – Ein praktischer Leitfaden*, the German translation of the recently updated Practical Guidelines for the Fabrication of Austenitic Stainless Steels. The brochure includes comprehensive information on how to select, design, fabricate and care for the world's most popular stainless steels, the austenitics family. It covers the whole range from the standard grades all the way up to the High Performance Austenitic Stainless Steels (HPASS). The translation is a joint effort of Informationsstelle Edelstahl Rostfrei (ISER) (the German Stainless Steel Development Association) and IMOA and is co-produced with the Nickel Institute and the International Chromium Development Association (ICDA). Download all versions from the IMOA website.

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Cover photo:
Lifting a section of the new Söderstrom bridge into place by crane. © Stål & Rörmontage

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