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Plants need molybdenum

Molybdenum is an essential trace element for the growth of plants. The amount needed is small, and when required, it can be supplied through specific fertilizers.

Yellow, wilted leaves? Stunted growth? Whiptail? Sounds like these plants are suffering from a molybdenum deficiency! Molybdenum is usually associated with inorganic systems such as corrosion-resistant steel; but along with sixteen other elements, it is also essential to healthy plant growth. Molybdenum is a trace nutrient or micronutrient, meaning that it is necessary in plant nutrition, but only in small amounts.

The role of molybdenum in plants

So, what exactly does molybdenum do for a plant? It plays a primary role in two ways, both of which are essential for a plant to function properly: forming an enzyme which enables plants to use nitrate from the soil, and forming an enzyme which enables certain plants to use nitrogen from the atmosphere (nitrogen fixation). Nitrogen is necessary for a plant to grow and molybdenum helps the plant to use nitrogen for compounds such as amino acids, proteins and chlorophyll, making the plants healthy and well fed. Without molybdenum, plants cannot perform the biochemical process of making essential nitrogen compounds.

In citrus fruit molybdenum can improve yield, juice content and skin thickness. © Linleo-fotolia.com

Molybdenum deficiency

Owing to the strong link to nitrogen (the most important nutrient to crops), molybdenum deficiency symptoms in plants resemble nitrogen deficiency: The plants do not grow properly, the leaves become pale, deformed and withered, and flower formation and fruit setting may be restricted. These symptoms affect the health of the plant and its yield.

Since the scientists Arnon and Stout[1] first recognized the need for molybdenum in tomatoes in 1939, deficiency symptoms have been identified in a number of crops. The element is crucial for the nutrition of legumes, cereal, lettuce, tomatoes, cabbage, cauliflower, duckweed, grapes, citrus and horticultural plants.

Molybdenum in soil

Plants pick up molybdenum (as molybdate) from the soil and only small amounts (0.1 to 1.0 ppm) are necessary to meet their dietary requirements. Most soils can provide sufficient quantities. However, in acidic soils, the element is not available to plants even if there is sufficient molybdenum in the soil. A remedy is to add lime to the soil to reduce its acidity, ›

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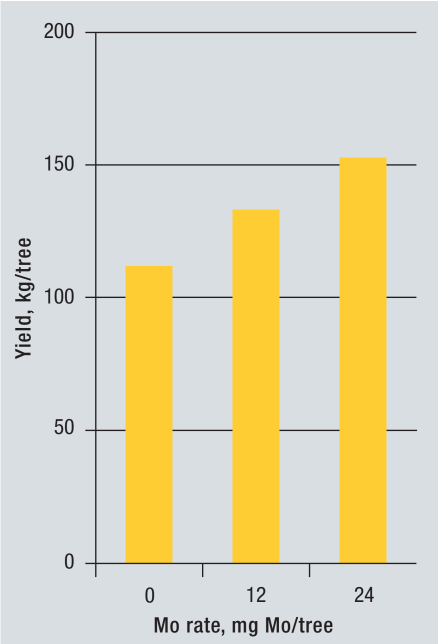


Adding 24 mg of molybdenum per tree raised the production of mandarins in Egypt by 37%.[2]

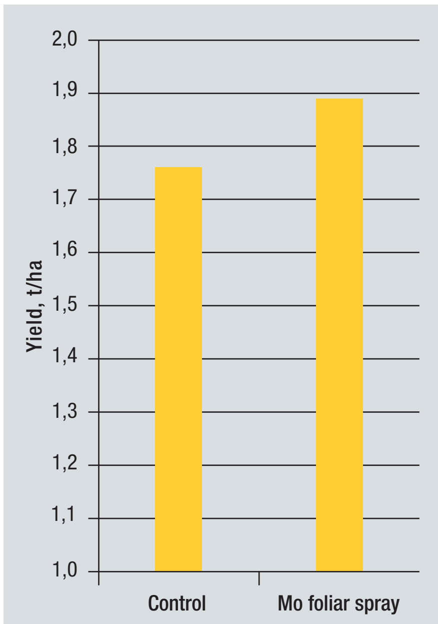
The importance of molybdenum in plant nutrition was first discovered in tomatoes. © el lobo-fotolia.com

making molybdenum in the soil available for plant uptake. A deficiency can also occur in peat soils and highly weathered soils with low levels of nutrients.

How can deficiencies be treated?

In addition to liming it is important to provide crops with balanced nutrients. The fertilizer industry offers complex fertilizers, which provide all the necessary nutrients. Based on sound agricultural practices and research and development, fertilizer companies can offer optimized recipes (including molybdenum) for different crops and soils around the world. Alternatively, growers can apply specially formulated foliar sprays where a particular deficiency is identified.

For example, in a study in Egypt[2], adding 24 mg of Mo per tree in the form of a foliar spray containing ammonium molybdate increased the yield of mandarins by 37%. Another study in Sweden[3] showed that applying just 0.25 liters per hectare of a molybdenum-based foliar spray increased the yield of rapeseed plants from 1.76 to 1.89 tonnes per hectare. In this way, adding the missing molybdenum through fertilizers can help to restore plant health and crop productivity. (LW)



Adding 0.25 liters per hectare of molybdenum foliar spray increased the yield of rapeseed in Sweden. Source: Yara database

1 Arnon, D.I, and Stout, P.R., Molybdenum as an Essential Element for Higher Plants, Plant Physiology, V 14: 599–602, 1939.
2 Ezz, T.M. and Kobbia, A.M., Effect of molybdenum nutrition on growth, nitrate reductase activity, yield and fruit quality of Balady mandarin trees under low and high nitrogen levels, Alexandria Journal of Agricultural Research; 44; 1; 227–238; 1999.
3 Yara database, study in Sweden.

For more information on molybdenum in plants and soils please visit the IMOA database of molybdenum in human health and the environment
http://www.imoa.info/HSE/environmental_data/biology/plants_soils.php

Molybdenum scrap saves resources

A recent study found that about one quarter of the molybdenum used each year is recycled material from scrap sources. The rest is newly mined, primary molybdenum. Scrap therefore plays an important role in meeting demand and contributing to sustainability.

Like most metals, molybdenum is fully recyclable. This is one of the key sustainability benefits of metals.

Recycling of scrap for the production of new materials requires less energy than the production of primary metal and it causes fewer emissions. It is also often sourced locally, so transport routes are short. For the steel producer, scrap is the most economical material to add to the melt. Because recycling is so important, IMOA wanted to know more about how much molybdenum is recycled and where. The market research company SMR therefore carried out a study on the scrap market for molybdenum.

Molybdenum comes from two sources: mining and recycling. In 2011, almost 80,000 tonnes or about 25% of all moly used was recycled, making scrap an important part of the molybdenum supply chain.

Steel and metal alloy scrap – the source of recycled molybdenum

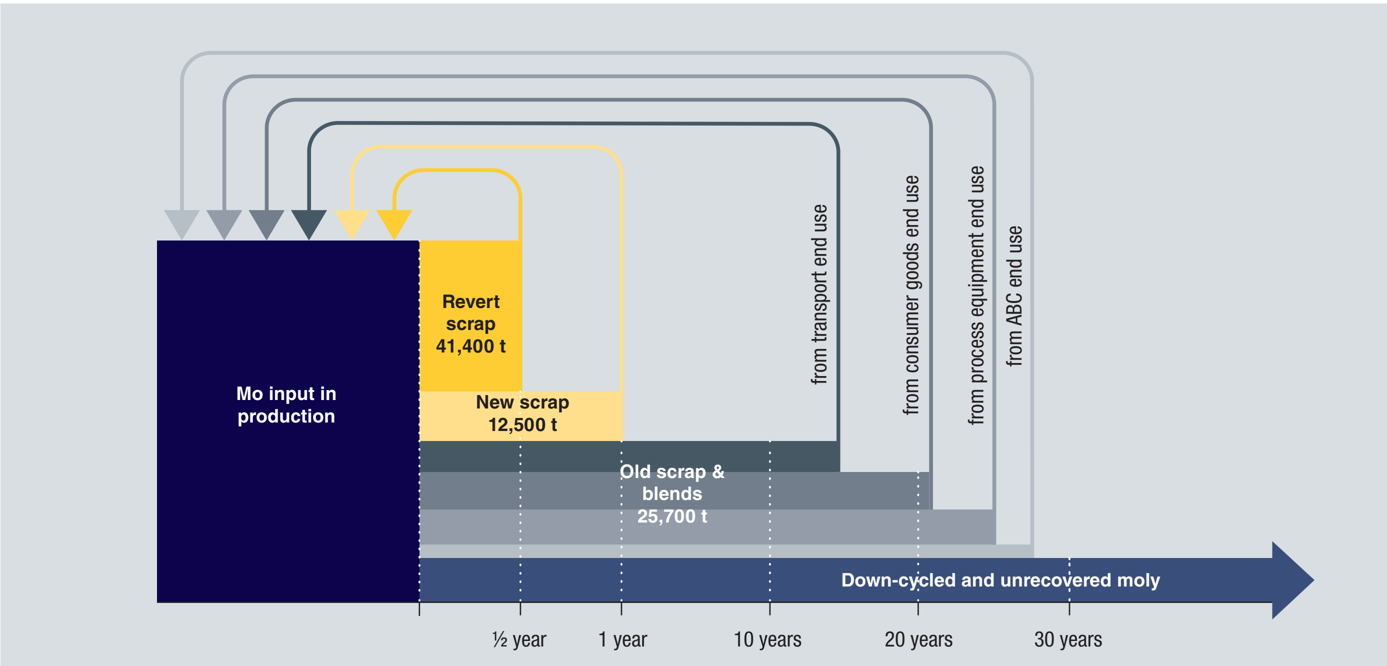
By far the largest use of molybdenum is as an alloying element in steels. It is therefore mostly recycled in the form of steel scrap. Molybdenum 'units' are returned to the furnace where they are melted together with primary molybdenum and other raw materials to make steel. There are four major categories of scrap:

Revert scrap – remnants produced in the steelmaking process like cut-off ends or edge trimmings. This scrap is usually returned to the furnace and re-melted quickly after its generation.

New (or first use) scrap – remnants generated by the steel mill customers – the service centers and fabricators of the steel. This scrap returns mainly via scrap collectors and processors, mostly within half a year after production in the steel mill.

Old (or end use) scrap – steel products at the end of their useful life – for example old washing machines or cars. This scrap is collected by scrap dealers. The age of old scrap ranges widely, between five years for some consumer goods to over 50 years for building products and process equipment. The average is around 25 to 30 years.

Blends – Mo units that come from a different scrap source than the product for which it is intended. For example, ›



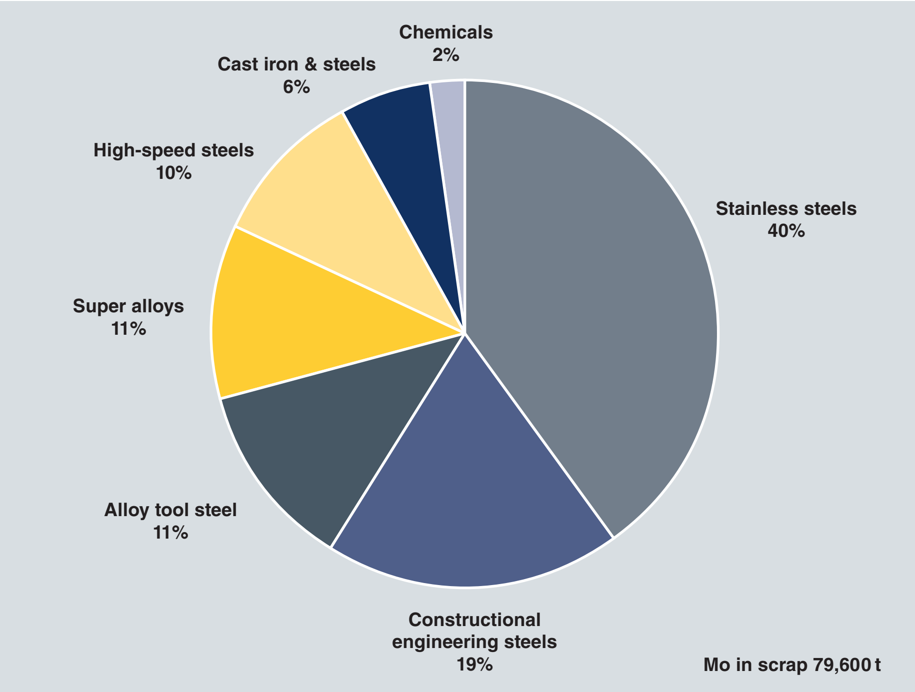
The molybdenum scrap reuse cycle for 2011. Of the 25% total scrap input 13% was revert scrap and 4% each new scrap, old scrap and blends.

a blend intended for the production of Type 316 stainless steel may contain molybdenum from nickel-based alloy scrap. Blending is a core competence of the major scrap processors. They use sophisticated programs to create scrap blends, tailored to the specifications of a particular customer. Treated spent refinery catalysts are also sometimes used in blends for stainless steel, nickel alloys and special alloy engineering steels due to their high moly content of over 60%.

Major markets using moly scrap

About 60% of Mo scrap is used to produce stainless and constructional engineering steels. The remainder is used to produce alloy tool steel, super alloys, high-speed steel, cast irons and chemicals.

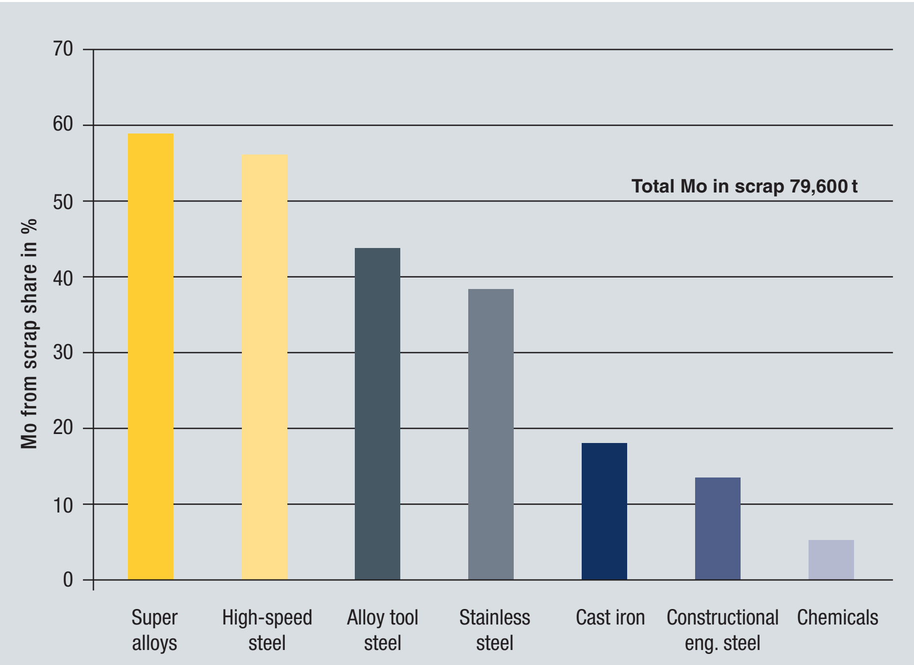
Stainless steels – A producer of Mo-containing stainless steel could use molybdenum almost entirely from scrap, if sufficient scrap were available. However, the popular Type 316 stainless steel is produced using, on average, only about 38% Mo units from scrap. The balance comes from new primary Mo. The main reason for the limited availability of Mo-containing stainless steel scrap is the continuing increase in demand for these grades. Their superior corrosion resistance, and therefore their longer service life, could be a contributing factor. Some 40% of all molybdenum recycled in scrap is used for stainless steel production.



The proportion of scrap reused varies by product segments.

Alloy steels – The production of alloy steels uses around 19% of all molybdenum containing scrap. Most of this is revert scrap from within the steel mill. Because engineering steels generally contain less than 0.5% Mo, the incentives for its collection are relatively low. Engineering steels are recycled, but usually not for their molybdenum content. The molybdenum is therefore 'down-cycled' into general steel production, where it may or may not have a material value. Hence, primary molybdenum is the main source of Mo units for engineering steel.

Tool steels and super alloys – Scrap is very important for the high-speed tool steel and nickel-based super alloy industries – where over 50% of Mo input comes from scrap. Most of it is revert scrap, due to the significant amount of scrap generated in the production process. This in-house recycling is crucial for cost control of these expensive alloys. High-speed tool steel and super alloy new and old scrap are valuable due to their high Mo content. They are also often used in blends for other steels. However, these first uses are relatively small for both Mo scrap and primary Mo.



Molybdenum from scrap as a percentage of total Mo input.

Molybdenum-containing stainless steels like these Type 316 solar water heaters are diligently collected at their end-of-life due to their high value. © Centro Inox

Trends in scrap usage

The near future – The ratio of recycled molybdenum to primary molybdenum used in moly-containing products has fallen in recent years. Molybdenum from scrap represented 25% of the total usage in 2011, compared to 27% in 2000, chiefly because the rapid growth of demand for molybdenum in this period outpaced the availability of scrap. Nowhere has this been more evident than in China: The domestic market is too young to generate significant volumes of stainless steel scrap, while production of moly-containing steels has flourished. The use of recycled molybdenum in the developing markets is expected to readjust to more typical levels in the future when end-of-life scrap becomes available in larger quantities.

Stainless steel scrap is a raw material for new stainless steel. © Cronimet

The longer term – The use of molybdenum from scrap is expected to grow to about 110,000 tonnes by 2020, representing a return to about 27% of all moly use. By that time, scrap availability in China will increase to over 35,000 tonnes annually. Today, Europe is still the region with the highest first use of moly scrap with about 30,000 tonnes per year. Unlike China, Europe's use of scrap is expected to stay at more or less the same proportion of the total until 2020.

By 2020, approximately 55,000 tonnes annually of Mo units worldwide will originate from revert scrap; about 22,000 tonnes from old scrap and the remainder will be split between blend material and first use scrap. By 2030, Mo from scrap is expected to reach 35% of all Mo used, a result of further maturing of the economies of China, India and other developing countries and an increasing emphasis on separating and recycling valuable streams of material.

IMOA members can order the full SMR report from the secretariat. (MM)

Shale energy revolution

The world's recoverable oil and natural gas reserves have increased dramatically in just a few years. Trapped deep underground in layers covering huge areas, shale reserves have only recently become accessible. The combination of two techniques, horizontal drilling and hydraulic fracturing, makes it possible to extract these precious natural resources economically. The United States, a pioneer in this area, has experienced a shale-gas revolution over the last five years. High-strength molybdenum steels are needed to drill the wells and extract the oil and gas.

Around the world, the cost and supply security of fossil fuels is a great concern. However, the United States is initiating a revolution in fossil energy production by extracting oil and gas from shale rock with horizontal drilling and hydraulic fracturing, or 'fracking,' techniques. As recently as 2008, there were serious concerns about dwindling U. S. domestic oil and gas production and growing dependence on foreign oil and gas. This has completely changed with the rapid increase in production of these fuels from shale.

The immediate impact

The U.S. Energy Information Agency (USEIA) shows that the U. S. produced 36 billion cubic meters of shale gas in 2007. That number had risen to 151 billion cubic meters in 2010 and 272 billion cubic meters in 2012. As a result, shale gas now accounts for over 40% of U. S. natural gas production, up from 10% in 2008.

The unprecedented volume of shale gas has kept gas prices low and encouraged industry to switch from coal to gas. This shift, combined with other factors, produced a dramatic decrease in U.S. CO_2 emissions of 12% since 2005. An analysis by The Yale Forum on Climate Change and the Media estimates that half of the decrease is attributable to natural gas conversions. A major factor is electric power plants, the largest source of atmospheric carbon. Gas-fired plants emit only about 40% of the CO_2 emitted by coal-fired plants per kWh of electricity produced.

Energy for years to come

The U.S. has a number of active shale plays containing thousands of producing wells, including the Bakken in North Dakota, the Barnett and Eagle Ford Shales in Texas and the Marcellus Shale across sizeable portions of Pennsylvania, New York, Ohio, and West Virginia. However, shale oil and gas is not limited to the United States. A few hundred shale formations exist around the world and other countries are moving to exploit them as well. Poland and China have drilled and fracked their first few wells. The United Kingdom moved to lift its bans on shale gas exploration in 2012, and Germany followed suit this year. Shale gas production is expected to help reduce the European Union's dependence on energy imports, which account for over fifty percent of consumption.

The Marcellus Shale

Interestingly, the formation with the largest reserves in the United States, the Marcellus Shale, is in the region where the famous 'Drake Oil Well' kicked off the world's oil energy economy 150 years ago. Though wells existed in the Marcellus before the year 2000, their yields tended to be unimpressive. In 2003, one pioneering company found substantial returns using horizontal drilling and fracking, which drew attention to the Marcellus. A 2008 Pennsylvania State University study increased

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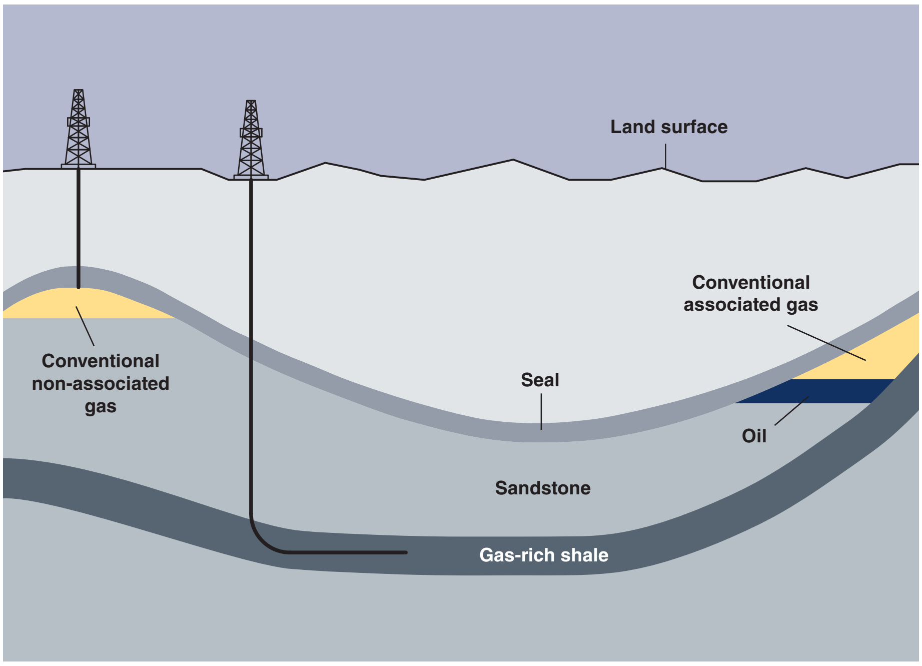


Schematic geology of natural gas resources.

Fracking of a gas well in the Eagle Ford Shale formation. The trucks with the fracking pumps are lined up to pump fracking fluid at high pressure into the shale. © Jim Blecha previous estimates of the Marcellus gas reserves significantly, further heightening interest in the formation. A 'conservative estimate' placed the total amount of recoverable gas at a staggering 4.7 trillion cubic meters. For comparison, the U.S. consumption of natural gas in 2012 was a little over 700 billion cubic meters, about 20 to 25% of the world's consumption. In a drive to tap these resources, several thousand wells have been drilled in the Marcellus Shale under Pennsylvania alone, and intense activity proceeds throughout the Marcellus and in other plays in the U.S.

Two rigs drilling horizontal oil and gas wells in the Bakken Shale formation. © Jim Blecha

The fracking process

Conventional deposits are pools of oil or gas collected in an underground reservoir and sealed by layers of impermeable rock. The producer has to determine the exact location of a reservoir and drill directly into it. In contrast, shale deposits are not discreet underground pools. The fuel is dispersed in pores and fissures throughout vast layers of very low-permeability shale rock. It is easier to strike oil or gas, because the layers are vast, but a conventional vertical well does not yield much production. Only the small amount of oil and gas stored immediately around the bottom of the well can flow out of the rock.

The breakthrough for shale gas production came with combining horizontal drilling and fracking. Horizontal drilling inside the deposit dramatically increases the surface area between the well and the gas-containing rock, enabling much more gas to be collected than with a vertical well. First, operators drill straight down to depths of up to 3,000 meters, to a point just above the deposit. They then turn the drill gradually and bore horizontally in the deposit for as much as another 3,000 meters. The top of the vertical well is lined with three or four steel casings, each embedded in cement to separate the extraction process from the surrounding rock. The number of casings is reduced with increasing depth, until there is only the production casing, which starts at the surface and reaches to the end of the horizontal well.

The horizontal part of the production casing is then pierced with a perforating gun. The holes in the casing allow the fracking fluid to flow out to fracture the deposit, and later, during the production stage, for the gas from the deposit to be collected in the well. During fracking, the fluid, a mixture of around 90% water, 9.5% proppant (sand and ceramic particles) and a remainder of chemicals, is pumped into the well at pressures up to 550 bar. This pressure opens the fissures, fractures the shale rock and forces the proppant into the cracks. Proppant is needed to keep the cracks open after the hydraulic pressure is released so that the fuel can flow out of the rock, into the well, and up to the surface.

Molybdenum's role in OCTG

The rapid development of the Marcellus and other plays has created a boom in demand for oil country tubular goods (OCTG), steel pipe specially tailored for oil and gas applications. Between 2002 and 2012, U. S. annual OCTG consumption rose from 1.5 million to 5.8 million tonnes. Driven by this increase in demand, North American OCTG annual production capacity grew by about 1.85 million tonnes.

The drill pipe, which drives the drill bit, must withstand large stresses because of its own weight and the friction created when drilling kilometer-deep holes. The well casing lines the well and contains the gas and fluids. It must resist high pressures and thermal stresses from the fracking fluid. Pipe designers must select steel grades and sizes to withstand these conditions.

Producers and users rely on three specifications for material selection: The American Petroleum Institute (API) specifications API 5 DP and API 5CT are used for drill pipe and casing, respectively. The National Association of Corrosion Engineers (NACE) standard ❯

NACE MRO 175 is used for material selection when hydrogen sulfide is present. The API specifications focus primarily on strength and toughness, leaving some alloying details to the producer. However, molybdenum is essential in most of the stronger steels and is explicitly specified in API 5CT for the grades in the table. Even in the grades where molybdenum is not required according to the specification, it is often added to help achieve the required mechanical properties with the available processing route. For example, according to a major U.S. drilling product supplier, the majority of shale drill pipe is grade S135 with 0.27% Mo.

Higher-strength grades require precise thermo-mechanical processing (TMP) to create the required properties. One of the key advantages of molybdenum in these high performance OCTGs is that it widens the process window for successful TMP. Furthermore, molybdenum alloying provides the following benefits:

- Excellent hardenability (ability to strengthen thick sections by heat treating or TMP) without reducing sulfide stress cracking resistance,
- Good tempering resistance, ensuring high strength and good toughness,
- Resistance to hydrogen damage, and
- Minimal segregation of impurities (e.g. phosphorous) that promote brittle fracture.

Select casing steels with their strength and chemical composition in weight percent (according to API 5CT and ISO 11960)

Grade	Yield strength min.- MPa (ksi)	C max.	Mn range/max.	Cr range/max.	Ni max.	Mo range/max.
L80	550 (80)	0.15	0.30–0.60	8.0–10.0	0.50	0.90–1.10
C90	620 (90)	0.35	1.20	1.50	0.99	0.25–0.85
T95	655 (95)	0.35	1.20	1.50	0.99	0.25–0.85
Q125	860 (125)	0.35	1.35	1.50	0.99	0.85

In addition to drill and casing pipe there are pipe couplings, wellhead equipment, and line pipe required to support increased drilling, further adding to the volume of steel required. Analysts expect steady growth going forward which is welcome news for a market segment in the U. S. that had suffered due to dwindling economically exploitable reserves.

Balancing risks and rewards

Though abundant supply of low cost domestic fuel and reducing the dependence on foreign sources are clear advantages, the technology is not without controversy. Many groups are studying the potential long-term health and environmental effects to better define its risks. Environmental issues being studied include water consumption, water-table contamination, and the handling and disposal of process waste. The possible risk that fracking may trigger earthquakes and that shale wells may release methane, a strong greenhouse gas, are also being studied. Land clearance issues and increased heavy goods vehicle traffic on rural roads have also been highlighted by opponents of fracking.

On the other hand, the availability of low-cost natural gas has also contributed to some important health and environmental benefits. U.S. power plants have already replaced a significant amount of dirtier-burning coal with natural gas. Since 2005 the energy produced from coal has dropped from 50% to about 40% resulting in a meaningful reduction in air pollution, including particulates that can cause illnesses, sulfur dioxide responsible for acid rain and carbon dioxide, associated with climate change. As noted earlier, it is estimated that nearly half of the reduction in U. S. CO_2 emissions since 2005 has come from coal/gas conversions. This trend is expected to continue, as operators reported last year that they are planning to retire 27 gigawatts of capacity from 175 coal-fired generators by 2016.

Molybdenum-containing oil country tubular goods have been used for oil and gas production in the U.S. for decades, though demand had decreased with falling conventional production. This new energy source looks set to play an important role in meeting the U.S.'s and the world's future energy needs, and it is ushering in a revival of the steel industry supplying these high-performance alloys. (DK, HM)

Drill pipes of 9.4 meters in length are attached to each other with threaded connections to build up a kilometer long drill string. © istockphoto.com/wpohldesign

Protecting vital plant equipment

Molybdenum-bearing stainless steel enclosures for electrical, electro-mechanical and electronic equipment generally go unnoticed, but are very important. These enclosures are used in chemical plants and at other industrial sites with corrosive environments. They protect vital systems and instruments from chemicals, fumes, moisture and even fires or explosions.

More than half of all molybdenum-containing stainless steel is used in chemical, petrochemical and other processing plants. It is used in a variety of applications such as piping systems, tanks, vessels, columns and heat exchangers that hold corrosive liquids and gases. Molybdenum-bearing stainless steels in particular resist a broad range of chemicals in these applications. A less-known but equally common use of stainless steel, in these plants, is for enclosures. They protect the electrical components and electronic equipment from chemical fumes and leaks, steam and other corrosive atmospheres as well as fires or explosions.

Such enclosures are found in virtually every plant throughout all process industries, but not only there. Many other applications with humid or corrosive atmospheres need corrosion-resistant enclosures. Examples include mines and tunnels, and uses where chlorine or chloride ions exist, such as water treatment plants, ships, and coastal structures.

Electrical junction boxes, switch boxes, electro-mechanical devices, and electronic systems and instruments are just a few of the electrical and electronic components that require protection. These are very important components used to power and control plant processes. When selecting the appropriate enclosure, plant designers must consider the kind of environment in which electrical components will operate. If it is non-corrosive, painted carbon steel or aluminum can often suffice. If it is corrosive, the designers can specify either Type 304 stainless steel for mildly corrosive environments or Type 316 stainless steel with two percent molybdenum for more corrosive environments or if maximum integrity is crucial. Manufacturers and users have established a large base of standards and specifications over the years, which prescribe the design and use of enclosures in various environments. Examples include ratings for flameproof, explosion-proof and waterproof enclosures. Alternatively, standards can define the kind of application, for example hazardous areas or exterior use. Various national and international rating and specification organizations are active in producing these standards, including NEMA, UL, ULC, ATEX, IECEx, and many government bodies.

Manufacturers can provide enclosures that meet virtually any requirement. Many enclosures are stock items, available in a variety of materials and sizes. However, as enclosure size increases or performance requirements become more sophisticated, manufacturers produce special enclosures to specific designs that meet the specifications. Such enclosures can be very large, even large enough to walk into. The market is competitive, so new designs with improved sealing, venting, or other features are often introduced. One example is a new investment-cast oblong enclosure made from the cast version of Type 316 stainless steel, CF8M. It has a flat cover plate, which allows for the installation of viewing windows, push buttons, selector switches, and pilot lights.

Type 316 stainless steel electrical conduit is also available to protect wiring running to and from enclosures in harsh environments. The conduit and couplings have standard pipe threads for easy installation. They are essential where wash-down and sanitation operations are carried out, as in food and beverage plants.

Stainless steel enclosures protect equipment from the plant environment. © ADALET

Molybdenum-bearing stainless steels like Type 316 and its cast counterpart CF8M play a vital role not only in major process plant equipment in many industries, but also in less noticeable electrical enclosures and related components. These applications are just as essential to successful plant operation as the process equipment itself. (FS)

Melting glass with molybdenum

We prize glass because of its clarity and beauty, and also for its immense versatility. Molybdenum components help to make the glass and glass products used every day. Moly's high strength at the high glass melting temperature and its resistance to corrosion by molten glass make it the ideal material for this purpose.

Human beings' use of glass predates historical records, going back to the days when primitive peoples used obsidian glass formed naturally from lava for knives and cutting implements. In its progression from ancient history to modern times, glass has shown its utility in countless applications and has become indispensible to everyday life. Today, molybdenum is just as indispensible to glassmaking.

Early glassmaking

Archaeological evidence suggests that the first 'manufactured' glass globules were formed serendipitously in cooking fires. The early humans who discovered these globules probably used them for decoration. Archaeologists think that the first intentionally created glass products appeared 3,000–3,500 BCE in Mesopotamia (modern Iraq and northern Syria). Early glassmakers could not create enough heat to work their glass easily, but with the invention of the blowpipe in Babylonia (modern southern Iraq) in about 1,500 BCE, glassmaking became an important technology. Artisans made most objects for decorative or utilitarian purposes, but they always dreamed of creating windows from their materials. The Romans attempted to make windows by flattening globs of hot glass, but the resulting product was too thick and not clear enough to be a good window.

A glass head thought to be of King Amenhotep II, dating to about 1,500 BCE.
© Corning Museum of Glass

It was not until the 15th century CE that glassmakers in Venice created the first clear glass called 'cristallo', but glass windows remained a luxury because of their cost. The Industrial Revolution greatly increased the ability of manufacturers to melt glass and in 1902 Emile Foucalt of Belgium invented the sheet glass drawing machine, making mass production of window glass possible.

Electricity is introduced

With the advent of electric power, engineers began designing electric furnaces to replace coal or gas fueled furnaces traditionally used to melt glass. Early design attempts relied on electric arcs and radiation to heat the glass, but the technologies did not find wide acceptance. In the 1950s, researchers discovered that molten glass conducts electricity, and that molybdenum metal electrodes could heat glass directly by passing electric current through the molten glass bath. Molybdenum electrodes began to be used to boost the power and production of conventional fossil-fired furnaces. All electric furnaces using molybdenum electrodes soon followed.

Advanced furnace designs

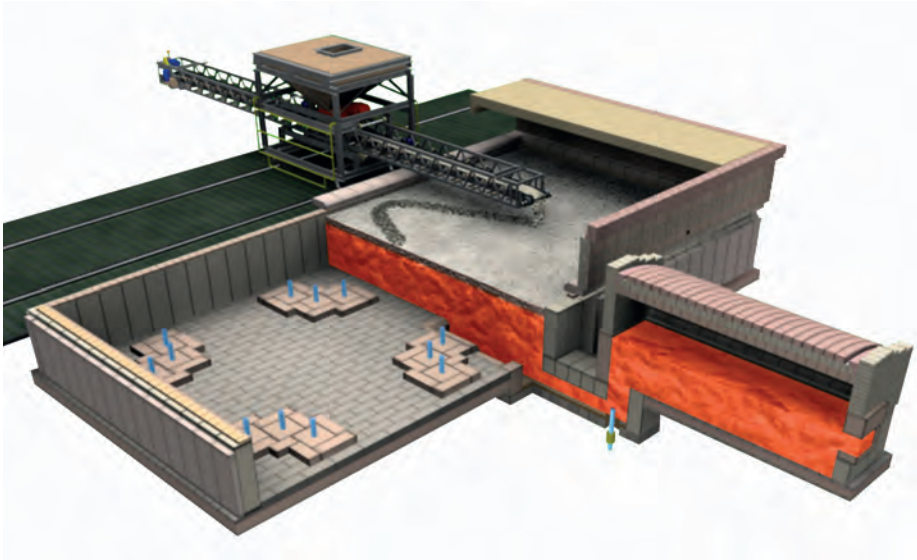
Increased use of electric furnaces in modern glassmaking has also increased the use of molybdenum. Advances have been largely related to electrode design. Side-entry and bottom-entry designs are used, as well as electrodes suspended into the glass tank from above. Molybdenum stirrers help to homogenize the melt. The molten glass bath protects these molybdenum components from the rapid oxidation that would occur at that temperature in air, so that they provide long and reliable life. Designers use inert cooling gases or water cooling to protect the portion of the electrode outside the glass bath from oxidation.

Molybdenum components also protect furnace refractories from wear and erosion as 'armor' covering the refractory brick in vulnerable areas. Advanced coatings allow these components to resist oxidation even when being brought to temperature on a cold start with no molten glass to protect them.

There is always competition

Few other materials can match molybdenum for the job. Platinum heads the list of molybdenum's competitors. It is ideal as a glass electrode in many aspects, but it is very soft and very expensive! It is used only where nothing else will do, often as a cladding material on molybdenum components like stirrers. Tin oxide has limited use because it is fragile. It is found in small furnaces and in furnaces melting glass compositions that are oxidizing to molybdenum. Carbon is another candidate but it is also fragile and can support only low current ›

The New Beijing Poly Plaza has one of the largest cable-net glass curtain walls in the world. It allows a clear view of the surrounding city.



Glass furnaces often use the bottom-entry electrodes, shown as vertical blue components in this cut-away view. The open-top design uses the insulating properties of the raw material to improve thermal efficiency. © Toledo Engineering Company, Inc.

densities that require large electrodes; it suffers from oxidation problems of its own. Sometimes nickel alloys like Inconel® are used but they suffer from low strength at temperatures above 1200 °C (the most common glass, soda-lime glass, melts in the range of 1500 °C), and the electrodes sag and droop during use.

Molybdenum is the material of choice for electric and electric-boost fossil-fired furnaces. It is strong and sag resistant at temperature, resistant to thermal shock, chemically compatible with a wide array of glass compositions, and resistant to corrosion and erosion. These advantages make molybdenum the hands-down winner for electric melting when viewed from the standpoint of total-life cost, even though it is initially more expensive than all the alternatives except platinum.

Molybdenum-made glass is an important part of our world

Glass made with molybdenum electrodes is part of everyday life. It is used for mirrors, the windows that brighten homes and workplaces and provide safety in cars, glass bottles and the ubiquitous flat-panel displays of televisions, computers, tablets and mobile phones. Glass is even used for the optical fibers that support high-speed internet networks, and the panels critical to efficient solar power generation. All of the technologies above and many more are enabled by glass products made with the help of molybdenum glass-melting electrodes. (JS)

The author expresses his gratitude to Mike Friess, Senior Director, Project Management and Brian Naveken, Design Engineer at Toledo Engineering Co. for discussions regarding electric furnace design philosophy and material choices.

Hurricane-proof

Material longevity and its inherent impact on long-term project sustainability are changing the way buildings are designed. Memorials like the new Four Freedoms Park in New York have to last for hundreds of years. Corrosion resistant 2205 duplex stainless steel was necessary so that the sculptural handrails were as durable as the massive blocks of granite in this highly-acclaimed new monument.

On January 6, 1941 President Franklin D. Roosevelt delivered a speech establishing the ideological basis for America's involvement in WWII. He looked forward to a world with freedom of speech and expression, freedom of worship, freedom from want, and freedom from fear. Roosevelt's famous Four Freedoms speech later became the basis for the United Nations Declaration of Human Rights.

The plan

A plan for developing the Franklin D. Roosevelt Four Freedoms Park on the southern end of Welfare Island (subsequently renamed Roosevelt Island) in New York City's East River was announced in 1973. The New York Times said, "It would face the sea he loved, the Atlantic he bridged, the Europe he helped to save, the United Nations he inspired…" A master of 20th century architecture, Louis I. Kahn designed the memorial park, but New York City's subsequent bankruptcy put the project on hold.

Finally, in 2010, the city gave the go ahead for the realization of Kahn's vision. The park consists of a tree-lined garden that narrows to an open-air plaza with the four freedoms inscribed in its walls. The plaza provides stunning views of the city and the United Nations Building. Despite the proximity of crowded Manhattan and Long Island, the park offers great tranquility and is described as a spiritual oasis.

The park is designed to be an enduring tribute to Roosevelt, with massive blocks of North Carolina granite forming its walls and walkways. Kahn designed elegantly minimal, sculptural, dull gray › stainless steel handrails for the project. (Pipe railings were also added to meet modern safety concerns.) The railings were to visually blend with the granite, which has a gray-white background flecked with medium to dark gray spots.

Implementation of the plan

The project team retained an architectural metals consultant to help identify a finish that would achieve Kahn's aesthetic goals and an appropriate stainless steel for essentially maintenance-free service.

A customized dull, relatively rough, abrasive-blasted finish was needed to aesthetically blend the stainless steel and stone. Both this rough surface finish and the unique curving design, creating sheltered areas, meant that the railings would accumulate higher levels of corrosive salt. In addition to adjoining brackish water, the project had to withstand 100-year storm surge events, which could submerge the railings in salt water for days.

Type 316 stainless steel (with 2% Mo) is often used in coastal areas due to its good corrosion resistance, but it would not have met these stringent requirements. Instead, the more corrosion-resistant duplex stainless steel 2205 with 3% Mo was selected.

The traditional architectural fabricators contacted did not have duplex stainless steel experience and were unwilling to make this complex shape. The logical solution was to turn to an industry which uses duplex stainless steels regularly and has demanding surface finish requirements. The pharmaceutical industry is such an industry. A U.S. pharmaceutical industry and architectural fabricator, CMPI, ultimately won the project. In October 2012, the park was finally completed with its unusual handrails.

2205 passed the first test

Just days after the park opened to the public, Hurricane Sandy submerged the railings. They were undamaged and remained corrosion free, confirming that 2205 was an appropriate choice. New York City is home to the world's largest concentration of architects and the performance of these highly visible railings has not gone unnoticed – another testament to the role of Mo in building a sustainable future. (CH)

The custom made duplex handrails blend in with the granite. © Diane Bondareff

The Four Freedoms Park memorial has great views of the New York skyline. © Franklin D. Roosevelt Four Freedoms Park/Paul Warchol

IMOA news

MoNb steel symposium a great success

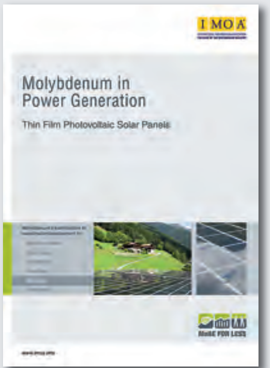
The 2nd International Symposium on Molybdenum and Niobium Alloying in High-Performance Steels was held in South Korea in April. Organized by IMOA and Companhia Brasileira de Metalurgia e Mineração (CBMM) and hosted by the Korean Institute of Metals and Materials (KIM), Posco and Hyundai Steel, the event was a great success.

More than 90 delegates from 16 countries representing some 60 companies and research institutes attended. Delegates from KIM's spring meeting, which was held in parallel with the symposium, also joined some of the sessions. Korean, Chinese and Taiwanese steel mills were very well represented and the Chinese delegation expressed an interest in hosting a similar event in China in the future.

Professor Hardy Mohrbacher, IMOA's technical consultant, was one of the 23 leading steel experts speaking at the event. He said: "Several IMOA-sponsored research projects from recent years were presented and discussed by some of the world's top metallurgists. Delegates were able to learn new techniques, with some producers already considering implementing what they had learned during the event. In addition, several alliances between companies and research and development institutions were formed and the symposium was notable for a high level of technical collaboration."

Delegates representing some 60 companies attended the 2nd MoNb international symposium in South Korea.

He added: "The symposium highlighted the metallurgical properties of molybdenum in different types of steel and its interaction with niobium. Molybdenum and niobium are two of the most powerful alloying elements in helping to adapt microstructures and properties to downstream manufacturing processes for the production of high-performance steels. These steels are increasingly important in the production of lighter, more durable and sustainable vehicles, machines, structures and pipelines.



Sustainability case studies launched

The first three 'MoRE FOR LESS' case studies, highlighting molybdenum's contribution to sustainable development, were published in July. The first show-cases the use of high-strength steel and how molybdenum helped to reduce the amount of steel used in the construction of the Friends Arena, Stockholm, by 17%. The second highlights the role of molybdenum in the energy-saving sun-screens on San Francisco's Federal Building. The third study looks at the use of molybdenum in more efficient thin-film photovoltaic panels to generate carbon-free electricity from the sun.

They are available on the sustainability section of the IMOA website. Further case studies are in production and will be published later in the year.