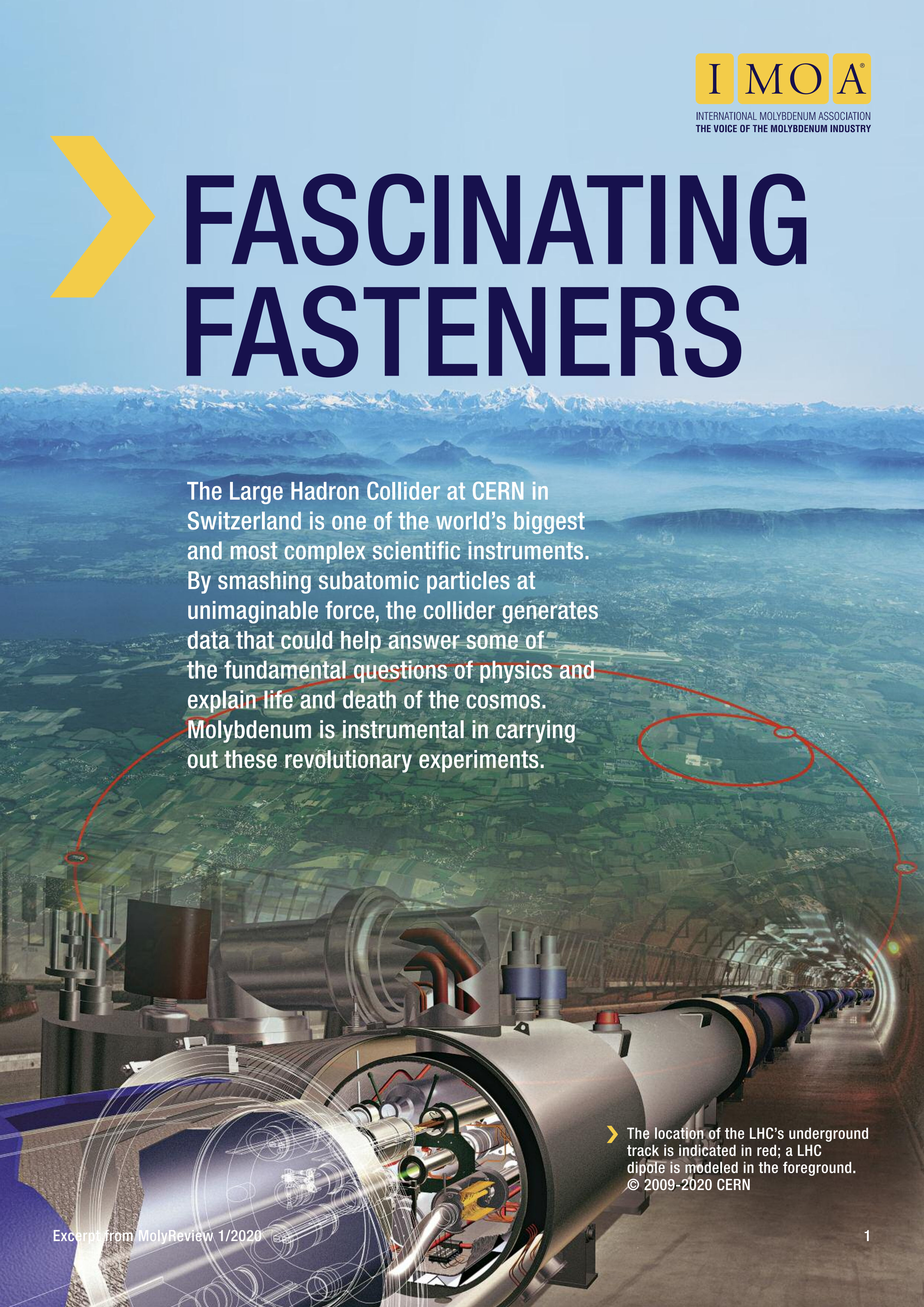
FASCINATING FASTENERS

The Large Hadron Collider at CERN in Switzerland is one of the world's biggest and most complex scientific instruments. By smashing subatomic particles at unimaginable force, the collider generates data that could help answer some of the fundamental questions of physics and explain life and death of the cosmos. Molybdenum is instrumental in carrying out these revolutionary experiments.



The location of the LHC's underground track is indicated in red; a LHC dipole is modeled in the foreground. © 2009-2020 CERN

Engineers test the electrical system of one of the LHC's super magnets.

More than a quarter of a million special-quality, high-strength Type 316L stainless steel fasteners are being used in an upgrade of the Large Hadron Collider (LHC), the world's largest particle accelerator. Located near Geneva, Switzerland, the LHC is a colossal structure designed to unearth secrecies of the smallest known particles in the universe. It is a machine so powerful that at first, some feared it would produce a black hole capable of swallowing a chunk of the galaxy. Fortunately, the accelerator dutifully smashed protons and ions without any such incident, all while generating data for the study of particle physics. However, scientists want to increase the intensity of the accelerator's particle beams for forthcoming projects, and the LHC was due for routine maintenance. Hence, upgrade work on the accelerator commenced at the end of 2018.

This renovation is expected to take two years. In addition to performing system maintenance, the upgrade will allow researchers to collect ten times more data than in the past. Part of this project includes replacing the fasteners that hold the accelerator's vacuum tubes and machinery together. These new fasteners will have to endure much for the sake of science, including temperature swings from -271 to 300 degrees Celsius. But their efforts will be well worth it, as these molybdenum-containing connections will help ensure that experimentation continues into the future.

An extreme machine

The LHC first began operating in December of 2008 and is the latest addition to CERN's particle acceleration complex. It consists of a 27-kilometer long ring of superconducting magnets. Inside, two particle beams race around the track at nearly the speed of light, towards collision with one another, propelled by the superconducting magnets. Before they collide, the beams travel in opposite directions in two separate beam tubes maintained at ultrahigh vacuum. The superconducting magnets are chilled with liquid helium to below the temperature of outer space: -271.3 degrees Celsius. This extreme cooling is necessary so the magnets can remain in a constant, high-energy, superconducting state without resistance or loss of energy. To cope with these extreme conditions, the materials used in the collider must be among the most durable on earth.

By focusing the energy of a moving aircraft carrier into a beam less than a millimeter wide, the LHC splits protons and ions in the hopes of unearthing subatomic particles to study their properties. In 2012, the accelerator yielded the ground-breaking discovery of the Higgs Boson Particle. This find helped fill knowledge gaps in the Standard Model of Physics, a five-decade old theory that explains how mass comes to be in the universe. More than 2,000 papers have been published in the field of particle physics with data provided from the LHC. Of course, discoveries often lead to more questions. Scientists hope that by doubling the number of collisions per second, some of these new questions will be answered. With upgrades in place, the LHC is expected to produce over 15 million Higgs Boson particles per year, compared to three million in 2017. Increasing the number of Higgs Boson provides substantially more data and more opportunity to observe new phenomena.

Upgrading the LHC

Shutting down and preparing the LHC for maintenance requires the collaboration of thousands of international scientists. To replace more than 20 of the superconducting magnets and other parts of the machine, teams have to install lifts to travel 100 meters underground. Just warming the unimaginably cold accelerator to room temperature took some four months and the removal of more than

100 tonnes of liquid helium. Needless to say, maintenance on the LHC is a titanic ordeal requiring the mobilization of countless resources. Therefore, high-strength parts with long service life, such as molybdenum-alloyed fasteners, are of the utmost necessity.

1 Billion: number of collisions per second

10 November 2008: date of LHC's first ever particle beam

26,695: length in meters of the LHC superconducting ring

Approx. 250,000: number of fasteners that will be replaced during the latest upgrade

2178: number of daily staff required to keep LHC running

600: number in Gigawatts for average annual power consumption of LHC

-271.3: operating temperature within LHC magnet dipoles

11,245: number of circuits a particle makes around the superconducting ring each second

4%: estimated percentage of the universe that is known tangible matter

96%: estimated percentage of the universe made-up of little known particles

Formidable fasteners

The fasteners used in the LHC upgrade have special requirements and differ significantly from standard Type 316L fasteners. They must be much stronger and have much lower magnetic permeability. Their minimum tensile strength is 1000 MPa, compared to 800 MPa, the highest strength level in the relevant ISO standard. Their yield strength is at least 900 MPa, compared to the standard's 600 MPa. The non-magnetic nature of these fasteners is critical to avoid disrupting the movement of particles during acceleration. To achieve this outstanding combination of properties, their producer, Bumax in Sweden, specifies a higher molybdenum content of 2.5 to 3%, compared to the typical 2 to 2.5%, among other things. By lowering the stainless steel's magnetic permeability, molybdenum plays a central role in making these fasteners virtually non-magnetic.

❯ Close-up of various size fastener bolts, similar to the ones to be used in the LHC upgrade. © Bumax

The fasteners, made of austenitic stainless steel, must be cold worked to achieve the tensile strength needed to withstand the intense temperatures and forces present in the LHC. However, during this strengthening cold working process, a portion of the non-magnetic austenitic microstructure of Type 316L stainless steel can transform into deformation martensite, which is, indeed, magnetic. These minute defects could derail the functionality of the accelerator by interfering with particle flow between the superconducting magnets. A higher molybdenum content helps to prevent this martensitic transformation. The result is an ultra-strong fastener that also will not influence magnetic forces present in the LHC.

The ability to ward off martensitic transformation is also essential to the structure of the collider itself: the 27.4 kilometer-long vacuum tubes that house the particle beams are therefore made of Type 316LN stainless steel. In this variation of Type 316 stainless steel, the elevated nitrogen content provides higher strength and prevents martensite formation. Here too, without very low magnetic permeability even at cryogenic temperatures, the accelerator would not function properly. Special austenitic stainless steels are therefore widely used in other applications throughout the accelerator's design.

Continuing the collision

In 2021, the Large Hadron Collider is expected to resume operation. Scientists from 29 organizations across 13 countries will begin the project that doubles the number of atomic collisions per second. With new, molybdenum-containing fasteners in place, the particles are free to smash themselves without magnetic interference. The strength of the fasteners means they can gladly endure the intensity of the upgraded particle beam. And perhaps something even more revolutionary will reveal itself, and molybdenum becomes a medium through which the mysteries of the universe are explained. (Karlee Williston)