Feature What is the near-term feasibility of helium-3 fuel for fusion power?





By Sophie Gregory
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Lunar supply ambitions are accelerating, but scarce availability, immature reactor technology and uncertain demand leave helium-3 fusion a longer-term prospect, Sophie Gregory reports

Fusion energy could help address global energy challenges, but the near-term commercial potential of helium-3 as a fusion fuel hinges on two key developments: establishing a reliable supply chain and advancing fusion reactor technology to commercial operation. At present, neither exists at the scale required to support a commercial helium-3 fusion market.

Helium-3 that is available today is obtained from the natural decay of tritium and is extremely rare on Earth. It is, however, continuously deposited on the Moon's surface by solar wind, a stream of charged particles emitted by the Sun that contains helium-3.

Rich Brook, CEO of helium consultancy Garrison Ventures, told gasworld that the near-term development of a helium-3 supply chain from the Moon's surface is currently unfeasible, due to several economic and technical challenges.

He believes it will take around 50 years to begin harvesting helium-3 from the Moon's surface, while meaningful volumes of any lunar resource could take around 250 years to develop.

That assessment, however, contrasts with the timelines being pursued by companies entering the nascent lunar helium-3 market.

In August, Californian fusion energy company TAE Technologies (TAE) announced a partnership with natural resource and lunar development company Black Moon Energy (BMEC) focused on the prospective supply and commercial development of helium-3 fuel for fusion power.

Under the agreement, BMEC would supply helium-3 fuel to TAE for its fusion research and development (R&D) operations. Separately, BMEC is pursuing a longer-term strategy to establish a helium-3 supply chain from the lunar surface.

Dr. David Warden, CEO and co-founder of BMEC, told gasworld the company is targeting the production of 50kg of helium-3 through its first significant lunar production operations planned for 2032.

The target would represent a dramatic increase over the scale of today's helium-3 market and places BMEC's development timetable decades ahead of Brook's assessment.

BMEC also has a partnership with the NASA Jet Propulsion Laboratory (JPL), a federally funded research and development (R&D) center managed by Caltech, to support work towards its first robotic mission to the Moon to collect data and carry out key activities needed to reduce risks associated with future helium-3 production.

Helium-3 fuel in fusion power

Helium-3 is being studied as a potential fuel for fusion energy, but there are currently no commercial fusion power plants in operation. Moreover, most

leading fusion reactor concepts initially propose using deuterium and tritium as fuel. On Earth, helium-3 is produced naturally by the beta-decay of tritium.

Trace amounts of helium-3 are also found mixed in with helium-4, but only at around 150 parts-per-billion (ppb), Brook previously told gasworld. “The helium-3 that we have available for use on Earth is all coming from the transmutation of…tritium,” he added.

“But the only tritium that’s being produced [on Earth] is the tritium that’s being used in nuclear weapons and in the Canadian-designed “CANDU” nuclear power plants where tritium results from neutrons bombarding deuterium atoms in the heavy water that is used as a moderator. The majority of these CANDU nuclear power plants are operating in the Province of Ontario, in Canada.”

Commercial fusion is being targeted by some developers for grid connection in the mid-2030s. The global fusion industry attracted $4.48bn in investment in the past year, according to the Fusion Industry Association.

Warden said, “There are three to four companies that are putting in demonstration plants, and they’re all targeting…2030, 2031, and not all of them are using helium-3.

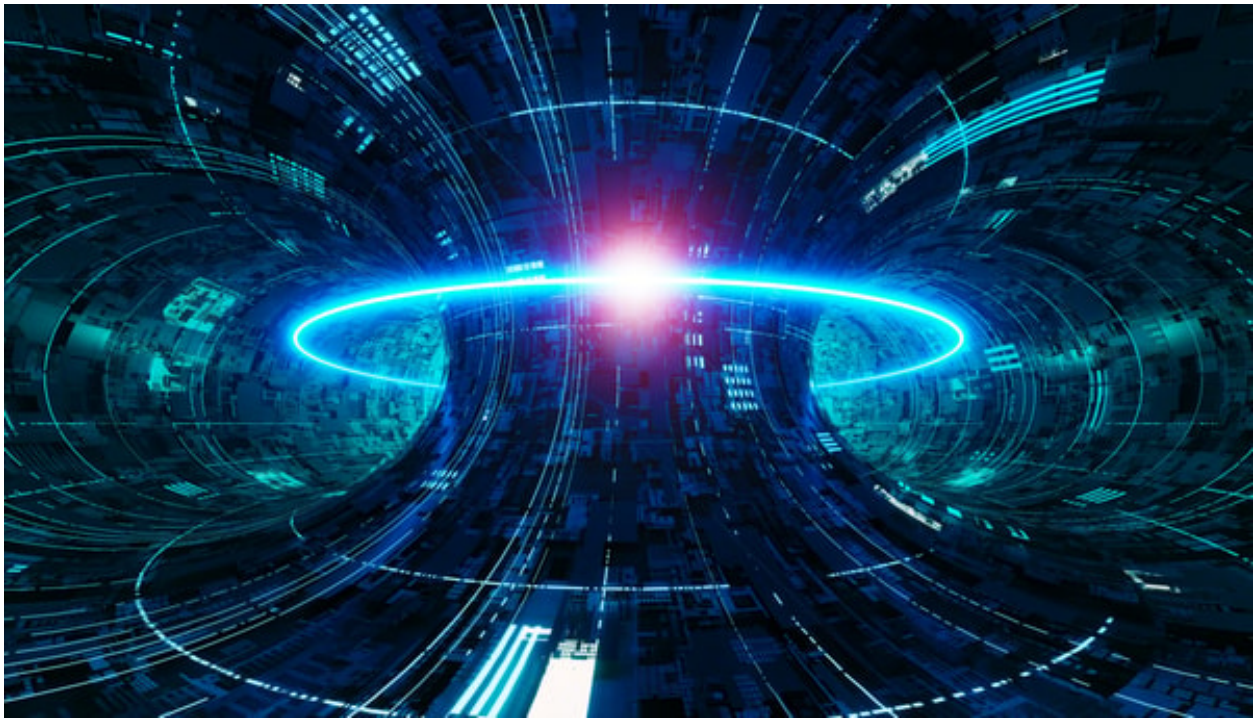
“They do need to make a quantum leap in technology…they need to design [a] fusion power plant that puts out positive energy…they’re not quite there yet for a sustained reaction, but they are on the doorstep – Lawrence Livermore National Laboratory (LLNL) demonstrated net-positive fusion energy from a Deuterium-Tritium fuel on December 5, 2022, and many times thereafter.”

This means the commercial development of helium-3 as a fusion fuel depends not only on expanding supply, but also on fusion technologies themselves reaching commercial operation.

Helium-3 also has applications in quantum computing, neutron detection, ultra-low-temperature cryogenics, and advanced nuclear research. For Warden, early demand for helium-3 supply will be concentrated in quantum computing, with fusion energy projected to drive long-term market growth.

“The business case as we’ve designed it doesn’t need fusion as a demand provider for helium-3 to close… [because with] the projected demand of only quantum, radiation protection, and medical diagnostics, our business case closes in three years from first production, and then after that, it runs profitably.”

In parallel, US natural resources company Interlune is targeting its first contracted deliveries of terrestrial helium-3 in 2028 to serve demand from the quantum computing industry. The company also plans to complete prospecting and demonstration missions, deliver first lunar helium-3 to Earth, and deploy a larger operational harvesting facility by the mid-2030s.



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Challenges of helium-3 supply

Significant investment would be required to harvest helium-3 from the Moon's surface, with technical challenges ranging from space travel and rocket launches to developing mining and processing equipment suitable for operation on the lunar surface.

The scale of infrastructure required for lunar extraction presents another major challenge.

"The probability of…successfully being able to go to the Moon and to start a mining operation, given the fact that you have to haul many, many thousands of tons of equipment up to the Moon, and then you have to bring back the material from the Moon, this is an absolute, very, very complex problem," Brook explained.

However, Warden argues that every step of the process has already been demonstrated either terrestrially or through previous lunar missions.

“We’ve already gone to the Moon, we’ve already collected helium-3, we’ve already brought it back in core samples…so it’s a tremendous engineering problem, but no quantum leap in technology [is] required,” he said.

Warden shared that while BMEC is involved with maturing space exploration technology that will optimize excavation of helium-3 from lunar regolith, it plans to outsource space exploration equipment such as rockets, rovers, and landers.

The largest challenge for BMEC will be helium-3 excavation from the Moon’s surface and robotically processing the gases and other solar volatiles associated with this process. “It’s a matter of engineering design to adapt them to the environment and do it robotically,” Warden noted.

> *“We’ve already gone to the Moon, we’ve already collected helium-3 ”*

Beyond the challenge of excavation, there are also considerable technical challenges associated with the separation of helium-3 from helium-4, Brook shared. “[Helium-3 is] mixed at a very attractive ratio compared to the ratio here on Earth [but] commercially viable technology to separate helium-3 from helium-4 doesn’t exist.”

The challenge, however, is not simply demonstrating isotope separation, but achieving sufficient recovery rates and economics for commercial-scale production.

In July, Interlune said it had produced 99% pure helium-3 by cryogenically distilling Grade A helium resources during a lab-scale demonstration at its Seattle facility. The company shared with gasworld that when deployed at scale, the technology could triple the existing domestic supply to serve the immediate needs of the quantum computing industry.

In a separate comment, Brook said that without Interlune providing meaningful details of its process, in all likelihood, the helium-3 recovery rate, processing, and equipment costs would make Interlune’s process “economically challenging.”

He estimates that the current global annual demand for helium-3 is less than five kilograms, given there are no operational commercial fusion reactors worldwide. An annual supply of five kilograms satisfies the current demand from the two main users of helium-3, neutron detectors and dilution refrigerators used for quantum computers.

“If you bring back 500kg of helium-3 from the Moon because you think it’s worth hundreds of millions of dollars…you will be very unhappy to learn that 500kg being sold into a market of just 5kg annual demand would result in a complete collapse of helium-3 pricing.”

For producers, the economics of lunar helium-3 therefore depend not only on solving the extraction problem, but on synchronizing new supply with the development of sufficiently large end markets.

“There are always naysayers for new things – flying, nuclear energy, television, the utility of the iPhone – and they always say the same thing: not possible, too expensive, no market. And they are proven wrong again and again.”

Future energy market

The use of helium-3 in fusion power rests on both the establishment of a viable helium-3 supply chain and the advancement of fusion power to commercial operation. In the near term, both remain constrained by significant economic and technical challenges.

In the nearer term, the commercial case for helium-3 may therefore depend more heavily on quantum computing, neutron detection and other specialist applications, while fusion remains a potentially much larger but longer-term market.

However, looking at long-term energy market maturation, Warden concluded, “Our funder is a major oil and gas company, and the then CEO of that company believed when they invested…this is the next real energy transition.

“We are not proposing to produce hundreds of kilograms in advance of the market. With our deep resource development experience, our approach is staged: characterize the resource, demonstrate the technology, secure customers and scale production in line with demand. Fusion represents the largest long-term opportunity – it is the next logical energy transition, but it is not required to establish the initial commercial market.”