

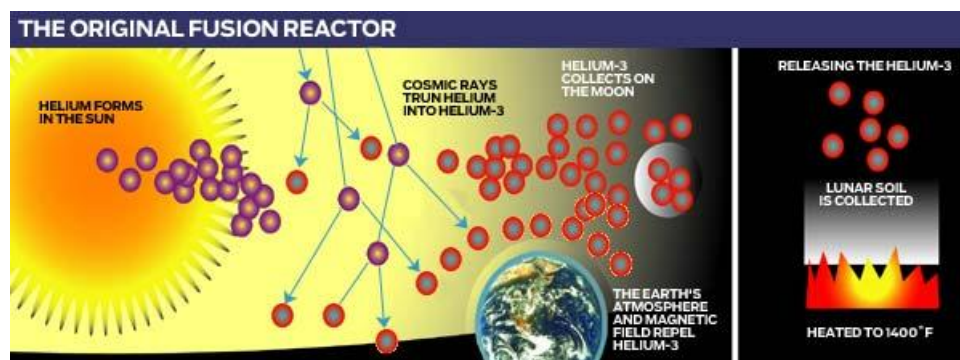
## Future of Lunar Exploration: Helium 3 Mining and Fusion

### Introduction

On January 14, 2004, President George W. Bush challenged NASA to "explore space and extend a human presence across our solar system." The sentiment was all well and good. Still open to debate, however, are the means and ends of such exploration. It is a debate that focuses on moving beyond low Earth orbit, returning to the Moon, establishing a permanent lunar base, and, eventually, planet-hopping manned missions to Mars, steps in human history analogized by Harrison Hagan "Jack" Schmitt, Apollo 17 astronaut, to mankind's departure from Africa 150,000 years ago. This brief paper discusses a prominent platform for returning to the Moon, specifically, lunar exploration with respect to mining Helium 3 from the lunar regolith<sup>1</sup> for use in terrestrial fusion reactors. It will outline the Helium 3 fusion process, the benefits/ caveats of Helium 3, and the future of lunar exploration.

Helium 3 is a Helium isotope, lighter than Helium 4 (common on Earth), continually ejected by the Sun from solar flares, and carried throughout the solar system through solar winds. Helium 3 is unable to breach Earth's magnetic field and atmosphere. As a result, the isotope exists only in minute quantities on Earth. However, the Moon has no such barriers, a fact which allowed the isotope to deposit and accumulate in the lunar regolith for billions of years. Helium 3 currently exists in ranges from 13 part per billion (found by Neil Armstrong during the Apollo 11 mission) to 20 and 30 parts per billion, and higher quantities (at latitudes above 70° due to cold trapping), with staggering economic potential.<sup>2</sup>

Pathway of Helium 3 from the Sun to lunar regolith extraction<sup>3</sup>



<sup>1</sup> Eric Chaisson and Steve McMillan, *Astronomy Today*, Seventh Ed., page 197 (Pearson Education, Inc., 2011) (Regolith "covers the lunar landscape to an average depth of about 20 m. This microscopic dust has a typical particle size of about 0.01 mm. In consistency, it is rather like talcum powder or ready-mix dry mortar.")

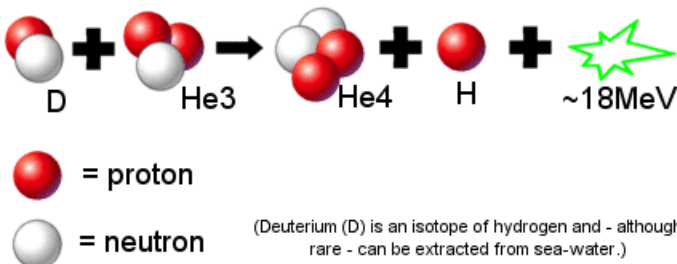
<sup>2</sup> See Harrison Schmitt, *Lunar Helium-3 Fusion Resource Distribution*, adapted from *Return to the Moon*, Copernicus-Praxis, New York (2006), at <http://www.lpi.usra.edu/decadal/leag/DecadalHelium3.pdf> ("Twenty parts per billion may not seem like much; however, the value of helium-3 relative to the probable energy equivalent value of coal in 2010-2020, estimated conservatively at \$2.50 per million BTU (0.25 x 106kcal) will be almost \$1400 per gram (\$40,000 per ounce)! This compares with about \$28 per gram (\$800 per ounce) for gold at the beginning of 2009. At \$1400 per gram, one hundred kilograms (220 pounds) of helium-3 would be worth about \$140 million.")

<sup>3</sup> Diagram available through Stefano Coledan, *Mining the Moon*, *Popular Mechanics*, December 7, 2004, at <http://www.popularmechanics.com/science/space/moon-mars/1283056>

### Helium 3 Fusion Process and Technology

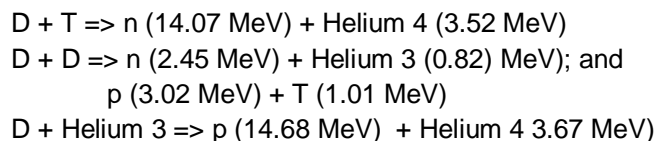
Nuclear fusion currently exists in a deuterium-tritium atom combination. This pairing presents significant downsides in conjunction with current technology. Specifically, the pair releases approximately eighty percent of the energy output in the form radioactive, and dangerous, neutrons. This high level of waste production makes the deuterium - tritium combination useful for research, but useless for commercial dissemination. On the other hand, a Helium 3 - deuterium atom fusion combination produces a single nuclear proton and neutron, from 'side reactions' of two deuterium atoms,<sup>4</sup> or about one percent of the deuterium tritium combination's waste.<sup>5</sup>

Helium 3 – deuterium fusion diagram:<sup>6</sup>



The University of Wisconsin-Madison's Fusion Technology Institute ("TCI") developed technology needed to pair deuterium with Helium3, trigger and then sustain a fusion reaction. The result is a "high-energy proton (positively charged He hydrogen ion) and an alpha particle (4He ion) for a total kinetic energy of 18.4 MeV."<sup>7</sup>

Comparison of inputs and outputs for fusion combinations, in mega electron volts (MeV):<sup>8</sup>



Benefits include the theoretical ease of containment, the ability to harness the reaction's significant output, and the healthy lunar supply – justifying 1) use of Helium 3 as fusion fuel; and 2) missions to the Moon to obtain it.

It is possible to contain the reaction's output with inertial electrostatic confinement (IEC) fusion technology, currently developed through TCI,<sup>9</sup> in lieu of more complex magnetic fields.<sup>10</sup> It is also possible to convert

<sup>4</sup> Harrison Schmitt, Lunar Helium-3 Fusion Resource Distribution, adapted from Adapted from Return to the Moon, Copernicus-Praxis, New York (2006), at <http://www.lpi.usra.edu/decadal/leag/DecadalHelium3.pdf>

<sup>5</sup> Julie Wakefield, Moon's Helium 3 could Power Earth, space.com, June 30, 2000, at <http://www.helium3.ru/articles/28.pdf>

<sup>6</sup> Diagram from Lunar Helium 3, Spacetime, at <http://www.kilnet.freemove.co.uk/moonhe3.htm>

<sup>7</sup> See Harrison Schmitt, Lunar Helium-3 Fusion Resource Distribution, adapted from Adapted from Return to the Moon, Copernicus-Praxis, New York (2006), at <http://www.lpi.usra.edu/decadal/leag/DecadalHelium3.pdf>

<sup>8</sup> Santarius, J.F., Kulcinski, G.L., and Miley, G.H., A Strategy for D-3He Fusion Development, Fusion Technology Institute, University of Wisconsin, June 2006, at <http://fti.neep.wisc.edu/pdf/fdm1291.pdf>

<sup>9</sup> Inertial Electrostatic Confinement Fusion, University of Wisconsin-Madison, <http://iec.neep.wisc.edu/>

<sup>10</sup> Alcator C-Mod, Plasma Science and Fusion Center, Massachusetts Institute of Technology, <http://www.psf.mit.edu/research/alcator/intro/info.html#fusion> (tokamak projects "use magnets to confine the plasma in a donut shape, called a torus.").

positively charged protons directly into electricity through currently available solid state conversion materials.<sup>11</sup> “Perhaps the most promising idea is to fuel [a helium-3] reactor solely with helium-3, which can directly yield an electric current--no generator required.”<sup>12</sup>

Any future energy program should safely provide for the needs for 10 billion people. To that end, Helium 3 meets energy output needs with lunar deposits that dwarf Earth’s own. Helium 3 “would have so much energy that it would require only 20 tons - less than one Shuttle load - to supply all the electricity used in the United States in a year.”<sup>13</sup> One hundred kilograms could power a 1000 megawatt electric plant for an entire year.<sup>14</sup> Helium 3 exists on the moon in estimated quantities of millions of tons. This supply can provide 10 times more energy than “all economically recoverable coal, oil, and natural gas on Earth.”<sup>15</sup> Meanwhile, current Helium 3 supplies on Earth are in the area of hundreds of kilograms – largely as a manufactured byproduct from nuclear weapon production.<sup>16</sup>

Helium 3 lunar regolith abundance and reserves at different landing sites:<sup>17</sup>

Category	3He probably reserve, tons	3He percentage
Category I	61491	2%
Category II	110796	4%
Category III	146480	6%
Category IV	2150391	87%

Station	3He abundance, ppb	Estimated regolith thickness, m	Region, Category
"Apollo-11"	15.1	4.7; 4.6; 4.4	Mare region, Category I
"Apollo-12"	7.1	3.7; 4.6; 5.3	Mare region, Category II
"Apollo-14"	5.7	8.1; 8.5	Mare region, Category III
"Apollo-15"	4.4	6.0; 4.4	Mare region, Category III
"Apollo-16"	1.4	10.1; 12.2	Highland region, Category IV
"Apollo-17"	8.0	7.0; 7-12; 8.5; 6-8	Mare region, Category II
"Luna-16"	7.9	4.0; 4.0; 1.0-5.0	Mare region, Category II
"Luna-20"	3.1	9.2; 0.4; 11.6	Highland region, Category IV
"Luna-24"	3.4	2.0; 2.0-3.0; 3.9	Mare area, Category IV

<sup>11</sup> Stefano Coledan, Mining the Moon, Popular Mechanics, December 7, 2004, at <http://www.popularmechanics.com/science/space/moon-mars/1283056>

<sup>12</sup> Stefano Coledan, Mining the Moon, Popular Mechanics, December 7, 2004, at <http://www.popularmechanics.com/science/space/moon-mars/1283056>

<sup>13</sup> NASA, Energy from the Moon, at <http://ares.jsc.nasa.gov/humanexplore/exploration/exlibrary/docs/isru/06energy.htm>

<sup>14</sup> See Harrison Schmitt, Lunar Helium-3 Fusion Resource Distribution, adapted from Adapted from Return to the Moon, Copernicus-Praxis, New York (2006), at <http://www.lpi.usra.edu/decadal/leag/DecadalHelium3.pdf> (An amount of “[o]ne hundred kilograms constitutes more than enough fuel to potentially power a 1000 megawatt electric plant for a year when fused with deuterium, the terrestrially abundant heavy isotope of hydrogen.”)

<sup>15</sup> Kulcinski, G.L., Using Lunar Helium 3 to Generate Nuclear Power Without Production of Nuclear Waste, Fusion Technology Institute, University of Wisconsin-Madison, Presented at the 20<sup>th</sup> International Space Development Conference, Albuquerque, New Mexico, May 24-28, 2001, at [http://fti.neep.wisc.edu/presentations/glk\\_isdc.pdf](http://fti.neep.wisc.edu/presentations/glk_isdc.pdf).

<sup>16</sup> Julie Wakefield, Moon’s Helium 3 could Power Earth, space.com, June 30, 2000, at <http://www.helium3.ru/articles/28.pdf>

<sup>17</sup> Abdrakhimov, A. M., Galimov, E. M., Vernadsky, V.I., The Estimation of Helium-3 Probable Reserves in Lunar Regolith, Lunar and Planetary Science, XXXVIII, (2007), at <http://www.lpi.usra.edu/meetings/lpsc2007/pdf/2175.pdf>

Furthermore, astronauts can supply future missions with Helium 3 mining by-products: water, hydrogen, nitrogen carbon (by way of methane).

Ancillary scientific activities would necessarily follow, similar to the technological Renaissance that accompanied the Apollo missions, including a means to develop new businesses and programs to further not only Helium 3 mining, but additional “lunar and planetary exploration, astronomical observatories, national defense, and long-term, on-call protection from the impacts of asteroids and comets.”<sup>18</sup> The program would also presumably support technologies in “physiological space adaptation, life support, energy supply, and international competition.”<sup>19</sup>

But the caveats are substantial. There are barriers with respect to funding development, whether through government funds or private entities, barriers with respect to developing and transporting materials for a lunar base and mining equipment (likely through a new Saturn V heavy lift rocket?), and then terrestrial limits to the fusion reactor technology.

Concerning the latter, Helium 3 fusion reactors are still in the ‘proof-of-concept’ stage, meaning that such reactors are still in early developmental stages, and decades away from widespread deployment by government or private agencies. Furthermore, despite the relatively vast quantities, “Helium 3 comprises only 1 part in 2-3000 of the total helium, and since the total helium level is only 10 to 200 [parts per million], tens of millions of kilograms of regolith must be mined to obtain one kilogram of [Helium 3].”<sup>20</sup> A million tons of lunar regolith heated to 800 degrees Celsius (or 1,470 degrees Fahrenheit) is needed to obtain 70 tons of processed Helium 3.<sup>21</sup>

#### Regolith Mining Facilitation – Future of Earth’s Energy Supply

The debate around mining Helium 3 is phrased in terms of whether Helium 3 can compete with available alternatives,<sup>22</sup> notably, fossil fuel production. But centering the discussion on available alternatives is based on purely late 20th century perspectives on an energy source’s supply, needs and impact. Advocacy for Helium 3 mining requires a realization that all widely disseminated sources of electricity currently in use (e.g. fossil fuels, nuclear power) outlived or will soon outlive their useful lives; and then identify a viable long-term backup.

So the question is not *whether* helium 3 can outperform fossil fuels with respect to mining **costs** (probably not in the near term as with any new technology), **safety** (the consensus appears to be that there is no comparison - Helium 3 presents a far superior alternative to any currently used method as far as radioactive waste production and environmental impact), **delivery** (percent of power generated viable for actual delivery is exceedingly high), and **supply** (fossil fuel production will eventually reach the tipping point once mankind consumes over 50% of available fuel on Earth, all within a span of merely 100-200 years - with consumption

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<sup>18</sup> Stefano Coledan, Mining the Moon, Popular Mechanics, December 7, 2004, at <http://www.popularmechanics.com/science/space/moon-mars/1283056>

<sup>19</sup> Harrison Schmitt, Lunar Helium-3 Fusion Resource Distribution, adapted from Adapted from Return to the Moon, Copernicus-Praxis, New York (2006), at <http://www.lpi.usra.edu/decadal/leag/DecadalHelium3.pdf>

<sup>20</sup> NASA, Energy from the Moon, at <http://ares.jsc.nasa.gov/humanexplore/exploration/exlibrary/docs/isru/06energy.htm>

<sup>21</sup> Julie Wakefield, Moon’s Helium 3 could Power Earth, space.com, June 30, 2000, at <http://www.helium3.ru/articles/28.pdf>

<sup>22</sup> See Harrison Schmitt, Lunar Helium-3 Fusion Resource Distribution, adapted from Adapted from Return to the Moon, Copernicus-Praxis, New York (2006), at <http://www.lpi.usra.edu/decadal/leag/DecadalHelium3.pdf> (the debate “must be evaluated in the context of probable global demand for energy and reasonably competitive alternatives for meeting that demand.”).

rates still increasing, and mankind poised to consume 100% of available fossil fuels within a few generations; the very idea is mind-blowing), but rather, *when* will mankind make the transition?

If that ‘when’ is in the near future, then are we assured that the scientific, economic and legal framework is present to promote development between nations? This question is one of facilitation, distinct from whether we can (the possibility is apparently within reach, in a matter of decades), or whether we should (against the deleterious aspects of fossil fuels, the answer must be yes), but focusing on whether or not we will.<sup>23</sup>

Facilitation requires cooperation and implementation of the United Nation’s Moon and Outer Space Treaties.<sup>24</sup> Harrison Schmitt has reservations. "The mandate of an international regime would complicate private commercial efforts," Schmitt wrote. "The Moon Treaty is not needed to further the development and use of lunar resources for the benefit of humankind -- including the extraction of lunar Helium 3 for terrestrial fusion power."<sup>25</sup> With competing interests by both Chinese and Russian agencies,<sup>26</sup> a clear and cooperative framework for research, mining and reactor development will help to avoid duplicative competition, expenses and risks.

“Liberty to innovate, change direction, and make suggestions for improvement, coupled with operational discipline, permeated the day-to-day activities at all implementation levels of Apollo.”<sup>27</sup> Lunar mining for Helium 3 should balance government funded exploration with private expedition, and recreate the innovative environment that contributed to the Apollo missions.

“All civilizations become either space-faring or extinct.” – Carl Sagan

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<sup>23</sup> It is telling that sustainable and renewable resources, such as dams, wind and solar power, are not even part of the conversation; as though we have given up on these *renewable* resources in their infancy.

<sup>24</sup> Richard B. Bilder, A Legal Regime for the Mining of Helium-3 on the Moon: US Policy Options, Fordham International Law Journal, Vol. 33, No. 2 (January 2010).

<sup>25</sup> See John Lasker, Race to the Moon for Nuclear Fuel, Wired, December 15, 2006, <http://www.wired.com/science/space/news/2006/12/72276?currentPage=all>

<sup>26</sup> John Lasker, Race to the Moon for Nuclear Fuel, Wired, December 15, 2006, <http://www.wired.com/science/space/news/2006/12/72276?currentPage=all> (“‘We will provide the most reliable report on helium-3 to mankind,’ Ouyang Ziyuan, the chief scientist of China’s lunar program, told a Chinese newspaper . ‘Whoever first conquers the moon will benefit first.’”)

Russian space geologist Erik Galimov told the Russian *Izvestia* newspaper that NASA’s plan to colonize the moon will ‘enable the U.S. to establish its control of the global energy market 20 years from now and put the rest of the world on its knees as hydrocarbons run out.’”)

<sup>27</sup> Harrison Schmitt, Lunar Helium-3 Fusion Resource Distribution, adapted from Adapted from Return to the Moon, Copernicus-Praxis, New York (2006), at <http://www.lpi.usra.edu/decadal/leag/DecadalHelium3.pdf>