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Defining the Helium-3 Industry for Private Sector

Current and Projected Resources,

Supply/Demand, Processing and Transportation of the

Critical Mineral Isotope ^{3}He

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PART I

Statement of Purpose

The purpose of this research is to provide a baseline for development of private industry centered on the stable, non-radioactive helium isotope helium-3 (^{3}He). Understanding helium's most abundant isotope, ^{4}He, is central to proposed commercial development of naturally occurring ^{3}He resources. The author previously conducted an executive analysis of the ^{4}He market in a privately circulated report entitled *Helium, ABC's (2013)*, and detailed analysis of that time-frame can be found by accessing Selling the Nation's Helium Reserve by the Committee on Understanding the Impact of Selling the Helium Reserve (2010) at www.nap.edu.

This paper assumes a basic understanding of the above resources and moves forward to assess only the most current developments in the ^{4}He market, expanding on the concepts of the NAP report by providing a primer on the helium refinery process, resources for refinery design and construction, and equipment resources for containment and mobilization of the product. This report's focus on ^{4}He is complimentary to the market study of ^{3}He, which evaluates the isotope's uses, man-made and natural occurrence, refinery method, and market conditions.

It is noteworthy that available literature concerning the considerations for future supplies of ^{3}He are by-and-large populist in nature, extolling the benefits of limitless energy by mining ^{3}He on the moon. For this reason, a market study would not be complete without exploring the credible available science, economics and impacts of international treaties on mining lunar ^{3}He as a viable competitive resource. While an investigative analysis of lunar ^{3}He could fill its own report, the topic's relevance to the market study receives examination in Part II of this study.

Introduction

Helium-3, which is commonly denoted as He3, or scientifically and hereafter as ^{3}He, is a rare, stable isotope of the Helium (^{4}He) atom. It is used in US missile guidance systems, oil and gas logging tools, cryogenic applications requiring temperatures near Absolute 0,[1] advanced MRI in hydrogen-depleted biosystems, US Department of Defense and Department of Homeland Security special nuclear materials (SNM) detection devices, and nuclear fusion tests for the production of clean, abundant electricity.

Marketable stockpiles of Helium-3 have been generated as tritium ^{3}H, (Hydrogen-3), in the world's nuclear arsenals decays into ^{3}He. Once every ten years, the ^{3}He is removed from the war-heads, and the tritium is processed and restored to maintain operational integrity. Industrial and experimental applications have been supplied ^{3}He by nuclear states solely as a waste-product of their national defense maintenance programs. Controlled pricing of the monopolized commodity has established a market which has decreased stockpiles, creating supply-shortages, terminated imports and sales, and exponential increases in the value of ^{3}He.

Now listed as a critical material by the United States Congress, alternate sources are being scrutinized to supplement the supply deficiency. Among the considerations are: tritium breeding and stockpile for natural decay into ^{3}He; final phase cryogenic (re)-distillation of crude helium in natural gas processing facilities; and deployment of personnel and mining equipment to process regolith on the surface of Earth's moon.

Of these potential competitive sources: (1) contrary to populist statements, extra-terrestrial exploration and exploitation of ^{3}He is not feasible as a potential competitive supply

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[1] 0 Kelvin = -273.15° Celsius = -459.67° Fahrenheit

channel. An analysis of the technological, logistic, financial and legal framework is provided in PART II of this report. (2) Tritium breeding as a competitive supply is undesirable because of the 12.5 year half-life of tritium decay and the irremediable burden of radioactive waste created during the process;[2] and (3) time-line, economics, and feasibility of ^{3}He extraction from ^{4}He production merits discussion of the process of cryogenic distillation for refinement of ^{3}He from the natural gas stream, including resources for joint-venture and contract design/build refinery capacity, and containment and transportation vessels for market deliverability.

Comparison of ^{4}He and ^{3}He

Uses of ^{4}He

To draw a comparison between ^{4}He and ^{3}He, both are non-renewable resources, and being lighter than air, every molecule now produced will eventually be lost to outer space as it escapes the atmosphere (Spisak 1). Of helium's industrial uses, there is no known substitute for its largest, cooling superconducting magnets which produce immense heat in magnetic resonance imaging (MRI) machines. Because it has the lowest boiling and melting point of any gas (King), is the only suitable element to keep the superconducting coil cooled to -452 F. (Magill). Because it is inflammable, helium's most important use during World War II was as a lifting gas for lighter than air aircraft. While its application in this field has declined, it is still used in military and scientific applications as a lifting gas. NASA and DOD use helium to purge rocket fuel. Because it's liquefaction temperature is near 4k, helium is ideal for purging cold fluids from

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[2] The benefit of a non-radioactive ^{3}He/^{3}He nuclear fusion reactions would be offset by creating radioactive waste to breed a non-radioactive fuel.
Besides this paradox, the world's current fleet of nuclear reactors and associated spent nuclear fuel pools are considered one of the greatest current threats to the human species in *A Theory for Human Extinction: Mass Coronal Ejection and Hemispherical Nuclear Meltdown. The Hidden Costs of Alternative Energy Series, Paper 1 (2015).* Copies are available from the author by request.

critical systems. Furthermore, its small atomic radius and high dispersion make it ideal for detecting leaks in vacuum and sensitive systems. Its inert and nonreactive properties also make it ideal in the creation of artificial atmospheres to grow crystals, process metals, and manufacture fiber optics. Helium is also used in breathing mixtures, and to create a stable atmosphere for some welding applications (King).

Uses of ^{3}He

Several of ^{3}He's uses include missile guidance systems, well logging and cryogenic applications. Despite its value in critical national defense systems, the United States Department of Defense has no special stockpile of ^{3}He (Kouzes 7). Its characteristic property for neutron-absorption makes ^{3}He useful for well logging for the oil and gas industry (Morgan & Shea 1) and its low boiling-point makes it useful in cryogenic applications where it is combined with ^{4}He to create temperatures a few-thousandths of a degree above absolute 0 (Morgan & Shea 2).

Magnetic Resonance Imaging

Another significant use of ^{3}He involves recent advances in Magnetic Resonance Imaging in hydrogen-depleted biosystems (Morgan & Shea 1). Traditional MRI machinery utilize the abundance of water in tissue to utilize magnetic reactions with the protons in the hydrogen nuclei as a signal source for imaging soft-tissue. In applications where there are deficient hydrogen protons, such as poorly ventilated areas of the lungs, hyperpolarized ^{3}He can be used to fill the lungs, gaining 10^6 times the polarization of hydrogen. Thus, breathing ^{3}He for MRI gives a clear visual of poorly-ventilated and damaged areas of the lungs (Ebert et al).

Radiation Portal Monitors

Another major, critical need for ^{3}He is in national and international security. Because ^{3}He is a stable, non-radioactive isotope, that absorbs neutrons, it is used in neutron detection devices by United States Border Patrol and Homeland Security forces to detect radioactive materials (Morgan & Shea 1). As ^{3}He absorbs neutrons from a radioactive source, its two protons and one neutron produce charged tritium and a proton in the form of a charge cloud that can be detected electronically (Cartwright). Radiation portal monitor systems (RPMs) based on this principle are manufactured in large part by LND and GE Reuter Stokes. Ratheon ASP, has also designed an RPM system and the Department of Energy has deployed RPMs manufactured by TSA Systems, Inc., "to detect illicit transport of special nuclear material (SNM) and other radioactive materials" (Kouzes 6). The Radiation Portal Monitor Project (RPMP) has deployed over 1,100 systems each using over 40 liters of ^{3}He. Replacement materials for the RPMs do not yield high efficiency results, making ^{3}He the ideal material for neutron-detection, however all of the companies listed above are low on ^{3}He supplies and face diminishing future supplies for the manufacture of RPM systems critical for national security (Kouzes 6).

Nuclear Fusion Experiments

Experiments in nuclear fusion provide another market for the rare commodity. Unlike the uses listed above, which have been scientifically-tested and proven as industrial uses with historic and quantifiable demand; the topic of nuclear fusion is often reported with minimal scientific investigation and euphoric claims about clean, safe and often 'unlimited' energy. The time-line for sustainable commercial power from this industry is a constantly moving target. A review of the credible literature on the technological advances required to attain sustainable, commercial nuclear fusion reveals a fifty-year pattern of timelines which seems to reset on the copyright date for each report that is written. Despite slow advances and the technological challenges of a sustained fusion-reaction with a net energy gain, vast international resources have been deployed for its development, and the scientific community's need for ^{3}He in third-generation nuclear fusion experiments are a market-reality.

First Generation Nuclear Fusion

There are three generations of nuclear fusion being pursued by the international community. First generation nuclear fusion utilizes two hydrogen isotopes-deuterium and tritium-to produce heat energy that can be utilized to turn traditional turbines. The first generation reactions have a number of drawbacks. (1) The tritium fuel is radioactive. (2) The process produces destructive, heat-intensive neutrons that cannot be contained on a sustained basis by materials currently or foreseeably available. When the elements are superheated to a plasma state, they give off neutrons that destroy the walls of the reactor vessels, necessitating frequent replacement of large structural components. (3) The damaged structural reactor walls are highly radioactive, because the tritium used in the plasma core is highly radioactive. This makes disposal of the wall tantamount to the disposal issues that plague all radioactive waste. Finally, (4) the process for first generation fusion allows for the production of weapons grade plutonium and uranium (Henley et al 3). The fusion reactor experiments at ITER (International Thermonuclear Experimental Reactor located in southern France), utilize first generation nuclear fusion technology (Williams 1).

Second Generation Nuclear Fusion

Second generation fusion reactors have been more promising, requiring the disposal of only low-level radioactive waste at the end of the plant's life cycle. Furthermore, Deutrium/^{3}He fusion produces "a high-energy proton (positively charged hydrogen ion) and an alpha particle (^{4}He ion)… Dealing with only charged particles (vs neutrons) as fusion fuels and products inherently simplifies engineering design and construction" (Henley et al 3) because the "fusion protons, as positively charged particles, can be converted directly into electricity… [and] conversion efficiencies of close to seventy percent may be possible" (Henley et al 4). The key to assessing a timeline of the viability of conversion efficiencies for second generation fusion reactors lies in the quote *may be possible*. The mathematics behind firing a shot at suspended particles to sustain reactions have consistently defied computer models.

Third Generation Nuclear Fusion

Third generation nuclear fusion utilizes ^{3}He/^{3}He as a fuel target. The only ^{3}He/^{3}He reactor in the world is located in the Fusion Technology Institute at the University of Wisconsin. The reactor is used to create deuterium/^{3}He reactions and ^{3}He/^{3}He reactions (Williams 2). The reactor utilizes inertial electrostatic confinement (IEC) of the plasma fuel, and its deuterium/^{3}He reactions produce only 2% of the radioactivity of first generation deuterium/tritium fusion reactions. Furthermore, ^{3}He/^{3}He fusion creates a ^{4}He nucleus and two protons which can be contained using electric and magnetic fields, and directed into wire for direct conversion into electricity. The absence of excess neutrons, and the absence of radioactivity eliminate the need for large containment vessels (Williams 3).

^{3}He fusion reactions have been attained by "Gerald Kulcinski's group at the Fusion Technology Institute of the University of Wisconsin-Madison… however, the reactor has not achieved energy balance or "break even"" (Lunarpedia.com). Notwithstanding a lack of energy balance, and the shifting timeline for development of commercial viability, third generation, ^{3}He nuclear fusion offers the most promise of all fusion prospects. Like second generation fusion, the positively charged particles can be converted directly to electricity. There is no radioactive waste associated with the reaction, as there is no tritium-breeding, and none of the fuel is radioactive.

Furthermore, the water requirements for cooling are less than first or second generation fusion, as the water that is used is not subjected to radioactivity (Henley, Mark W. et al 4).

^{4}He Market Update

“In a free market, supply follows demand. But in the helium market, regulations set price and production… Helium gas, essential for MRIs, rockets and space telescopes—is a limited resource” (Peek). “There is no substitute for helium in cryogenic applications if temperatures below -429 F are required” (USGS 73), yet Helium prices have been set arbitrarily. The sale price set to comply with the Helium Privatization Act of 1996 was determined only as a function of offsetting the $1billion debt incurred by the federal helium program; prices were determined by dividing the reserves by the debt.

Shifting from the WWI mandate to reserve all helium for the US Government for national security, the 1960’s ushered in a federal helium purchase and stockpile program, mostly for the space program. Loans on the stockpile were to be paid back by 1985, which was extended to 1995, then revised with the Helium Privatization Act of 1996, which mandated the sale of all but 600 MMCF to be kept as a permanent reserve on a straight-line drawdown by 2015. The price set for the drawdown of the Federal Helium Reserve was based on retiring the debt and interest incurred by the establishment of the reserve (Spisak 2). Prices have increased as BLM has tried to recapture operational costs as well, but helium price’s parity to actual market conditions do not exist. (Magill).

The current method of sale to federal helium users is the in-kind program, whereby federal users purchase refined helium from private industry, who is then bound to purchase the same amount of crude helium from the federal reserve (Spisak 4). Magill’s 2012 Popular mechanics article cites 75% of the world’s helium supply being provided by the US, with half of that, nearly

30% of world supply, coming from the Federal Helium Reserve. As of 2013, the Federal Helium Reserve provides 42% of domestic needs, and 35% of worldwide use (Spisak 1).

The USGS Mineral Commodity Summary reports ten US plants extracted helium and produced crude helium in 2014. Six plants along the federal helium pipeline produced Grade A helium. Two isolated US plants produced Grade A Helium (99.997% purity), one in Colorado, and one in Wyoming. Domestic consumption for 2014 was estimated at 1.2BCF. Prices for helium were $69MCF to government users, and $95MCF for nongovernment users. The average price of helium sold by the BLM in 2014 was $106/MCF (USGS 73). Estimated Grade A prices were $200MCF with some producers posting a surcharge over this amount. Tariffs on helium were at 3.7% added value. Privately owned companies purchased 693 MMCF of helium from the BLM. BLM took in 368MMCF for storage, and redelivered 1.5BCF+ (USGS 72-73).

New production came online in Wyoming in 2014, and enhanced production was expected from Colorado. With expansion of refining capacity completed in Algeria and Qatar, and seven international helium plants planned, USGS estimates that most of the world's supply will be from international facilities by the end of the decade (USGS 73). The BLM auction on August 26, 2015 set a reserve price of $100.00/MCF and sold 300 MMCF of its 1.2 BCF supply which amounts to 25% of its inventory. BLM projects to have 40% of its inventory sold off in 2016 (News Chanel 10).

The USGS projections for drawing down the Federal Helium Reserve and shifting supply to international facilities failed to account for construction delays, international instability and market disruptions. On March 18, 2016 Al Qaeda fired three rocket-propelled-grenades at the BP operated plant in Algiers. Future domestic production is being eyed by the industry at a premium because of the United States' political stability, and the import economics for US distribution and sales, including tariffs and shipping costs.

Projected supply shortages and price-spikes have encouraged Congress to revisit the Helium Privatization Act of 1996. In testimony before Congress in support of the Responsible Helium Administration and Stewardship Act, Spisak testifies that the mandated drawdown of the Federal Helium Reserve by 2015 poses a threat to science, industry and national security (p1). The Helium Stewardship Act was adopted in 2013 to end some shortcomings of the Helium Privatization Act.

The Helium Stewardship Act

The Helium Stewardship Act imposes two important revisions to the federal helium reserve. First, the Act revises the terms of the federal government exiting the helium business with an upward revision to maintenance of a stockpile to provide for the needs of federal users, from 600MMCF to 3BCF (Spisak 4). Secondly, Phase D of the Act, disposal of assets, pushes back the deadline for the drawdown of the federal helium reserve and the sale of its assets from the 2015 deadline, to a new deadline, mandated to be completed no later than September 30, 2021 (GAO).

Another major change brought about by the Responsible Stewardship Act is the provision of Subtitle C of Section 12 which amends all existing or after acquired federal oil and gas leases to grant the producer the first right of refusal to produce helium under the lease (114th Congress, 1st Session. S2012).

Finally, The Helium Stewardship Act of 2013 requires a study to determine the feasibility of constructing a plant for the purpose of separating ^{3}He (Spisak 5). Section 5 of the Helium Administration and Stewardship Act requires that the Secretary of the Interior with the

Department of Energy or it's designee conduct a feasibility study into separating ^{3}He from Helium at the Bush Dome Reservoir, or other refining facility connected to the federal pipeline. Included in the study are gas analysis, infrastructure studies, and a feasibility study, with a report to be issued no more than one year after the enactment of the Act. The mandated report is to include an assessment of global helium resources, along with ^{3}He content (US Congress Helium Stewardship Act).

As of the first quarter of 2016, it does not appear that this study has been conducted, nor has the Department of the Interior replied to inquiries regarding the report.

^{3}He Market: Stockpile Shortage, Supply and Demand

The current supply of ^{3}He is only produced from the radioactive decay of tritium in the artificial environments created by the military-industrial complex. In order to maintain the integrity of the tritium critical to the operation of nuclear warheads, the ^{3}He is removed by the National Nuclear Security Administration (NNSA) at the Savannah River Site in South Carolina. The tritium lost through radioactive decay is replaced for optimal function of the devices. The byproduct of decay, ^{3}He, has been publicly auctioned by the Department of Energy's National Isotope Development Center (NIDC) (Kouzes 2). Most of the supply has gone to Spectra Gasses (Linde Group), as they have the only facility in the United States licensed by the Nuclear Regulatory Commission to remove trace amounts of tritium from the ^{3}He supply. GE Reuter Stokes, Inc., is the other major purchaser of ^{3}He in the US (Morgan & Shea 2).

The decay of tritium by the U.S. nuclear weapons program currently generates approximately 8,000 liters of new ^{3}He/year. The tritium manufacture and maintenance for the weapons program has subsidized the production of ^{3}He. "According to one estimate, the unsubsidized cost of manufacturing tritium for the nuclear weapons program is between $84,000 and $130,000 per gram. This corresponds to between $11,000 and $18,000 per liter of eventual ^{3}He" (Morgan & Shea 9). The marginal price of ^{3}He, of around $100.00/liter which was fairly consistent through 2010, is a disunion between supply and demand. The price is far beneath the cost to process new supplies, which means that the demand has outstripped the supply (Morgan and Shea 2-3). From 2001 to 2010 the stockpile of ^{3}He had dwindled from 235,000 liters to 50,000 liters (Morgan and Shea 6), and in 2010, Russia, which had been a source for approximately 25,000 liters/year of imported ^{3}He, terminated exports (Morgan & Shea 15). The combined US needs for ^{3}He by the Department of Energy, Department of Homeland Security and Department of Defense are projected to be 85kL/year. "An estimate by GE Reuter Stokes projects total ^{3}He demand at 65kL/year, while total supply is 10-20kL/year" (Kouzes 7).

The supply shortage is visible in the price effects. Through 2008, the average market price for 80,000L of ^{3}He was $100.00/L, however in 2009, the DOE started rationing ^{3}He, and in 2010, 14,000L were sold at a price of $2,000/liter (Lunarpedia.com). In 2012 the United Kingdom saw price spikes to €1,600.00/liter (approximately $2,080.00 USD) (Cartwright), and the 114th United States Congress listed ^{3}He as a critical mineral. It was mandated that the USGS Mineral Commodity Summaries contain a comprehensive list of critical minerals entitled "Annual Critical Minerals Outlook", compiling price data for each critical mineral, expected usage for the preceding year and a comprehensive forecast of supply and use (US. 114th Congress, 1st Session. S2012).

The 114th Congress clarified that a critical mineral is meant to not include fuel minerals including oil, natural gas, or any other fossil fuels, or water, ice or snow and defined critical manufacturing to include the processing of minerals and the manufacture of equipment, components or other goods that utilize those minerals for energy technology defense, agriculture, consumer electronics, or health care related applications; or any other use of value added critical mineral use undertaken within the United States (US. 114th Congress, 1st Session. S2012).

The testimony of Dr. Scott Fish, chief scientist for the Army gives rise to the idea that an additional market could develop for the critical mineral ^{3}He:

> "The Army does not presume that all production of defense-critical chemical or material must be domestic, but there have to be adequate controls in place on both production and supply to ensure that requirements are met… relying on a sole source for a critical material must be paired with a program to stockpile sufficient reserves to cover an interim supply shortage" (Katt 9 & 66).

As of the publication of this study, the requirement for publication of a Critical Minerals Outlook does not appear to have been met, however, in 2014 the NDIC website reported supply sufficient to meet demand by making critical distributions to US Agencies through an allocation process. Only 4,000 liters were made available for public auction in 2014. Bidders were limited to an initial allocation of 400 liters each. The minimum bid price was $2,750.00/liter, plus containment ($325.00 for size 5 & $375.00 for size 30), plus shipping. Minimum bid size lots were 25 liters (DOE Helium 3 Sales Solicitation 2014).

2014's auction price of $2,750.00/liter marks the last available price data as supply shortages forced the Department of Energy to declare that there would be no public auction of ^{3}He in 2015, and only 10,000 liters would be available to the United States Government through interagency allocation. Pairing the market's ability to absorb 80,000 liters of ^{3}He before the supply-shortage with the last available market price of $2,750.00/liter, it is a reasonable assumption that the current market demand would absorb an additional 70,000 liters of ^{3}He annually. Assuming the supply-shortage has not pushed prices higher than the 2015 sales price of $2,750.00/liter, it is reasonable to assume an unserved annual market $192,850,000.00, plus containment and shipping costs. Dr. Gerald Kulcinski from the Fusion Institute at the University of Wisconsin, Madison expects ^{3}He to hit $30,000.00/gram in the near future.

Conversion Rates/Quick Reference

	^{3}He	^{4}He
Mass-Atomic	3 atomic mas units	4 atomic mass units
Mass-Molar	3 grams	4 grams
Liters/mole[3]	22.41 liters	22.41 liters
Liters/cubic foot	28.32 liters	28.32 liters
Boiling point (Wikipedia)	3.2 Kelvin[4]	4.2 Kelvin[5]
Price/liter	$2,750.00/L	
Price/gram	$20,533.33/g	
Price/cubic foot	$77,800.00/CF	
Price/thousand cubic foot	$77,800,000.00/MCF	

Alternatives Considered to Supplement ^{3}He Supply Shortage

Mining Lunar ^{3}He

Because of the vast amount of mis-information available about the potential of mining Lunar ^{3}He, an analysis of the implications of such an endeavor are included hereunder in PART II.

Tritium Breeding in Nuclear Reactors

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[3] Standard Temperature Pressure (STP) 0°C 1atm

[4] Boiling point ^{3}He 3.2K = -269.95°C = -453.91°F

[5] Boiling point ^{4}He 4.2K = -268.95°C = -452.11°F

The artificial market price set by NDIC has drawn down the US stockpile of ^{3}He, forcing Congress to look at the option of breeding a stockpile of tritium in nuclear reactors for the specific purpose of decay into a ^{3}He supply. Current methods for the production of tritium for decay into ^{3}He are not economical. Estimated costs to make 1 gram of tritium are 20-100 times greater than the value of the resulting ^{3}He (Kouzes 1). Considering the half-life of tritium, the dwindling supply of ^{3}He cannot support world-wide needs. To counteract this shortage, the DOE has tried irradiation of lithium-6 (^{6}Li) at the Watts Bar Nuclear Generating System, however, this tritium supply has not added to the stockpile (Kouzes 1). Even if tritium production is increased, only 4.4% decays into ^{3}He3 year-because of its 12.3-year half-life. It would take decades of additional tritium production for the supply to increase significantly. Furthermore, technical problems have plagued the Watts Bar and Sequoyah reactors, limiting the amount of tritium produced. It is believed that Watts Bar Nuclear Generating System may not be capable of producing enough tritium for US nuclear defense needs (Morgan & Shea 13).

Other considerations for the production of Tritium for decay into ^{3}He are the CANDU heavy water nuclear reactors in Canada. While Ontario Power Generation maintains a stockpile of tritium, as of 2009, it had no plans to harvest the ^{3}He. At $10,000,000.00 (USD) capitol required to extract the He3 the company did not find it economical or a high priority, however their stockpile of 15kg of tritium has already produced approximately 80kL of ^{3}He, and decay rates were calculated to add several kL/year. The 2009 economics broke down to $125.00/L, as 2009 rates for ^{3}He varied from $88.00-$300.00/L (Kouzes 2). With the improved market conditions from supply unavailability, bringing the CANDU reactor stockpiles to market would fill market needs for one year, and stabilize at a few thousand liters/year of actual supply thereafter. If the ^{3}He supply is brought into the market, it is expected that the world supply will experience a short-term flood of product, however, it is the author's opinion that scarcity of the commodity will keep the price from experiencing a downward shock. Supply stabilization at several thousand additional liters/year from Canada's CANDU reactors is not expected to significantly affect world supply or market prices.

Production from Oil and Gas Reservoirs

^{4}He is produced from the decay of radioactive substances such as uranium and thorium. The occurrence of its natural isotope, ^{3}He is very rare on earth (Lunarpedia.com). There is very little of either elemental isotope in the Earth's atmosphere, because it is lighter than air, and continues to rise until it escapes the atmosphere. ^{4}He is generally generated on granitoid rocks in the earth's crust which contain uranium and thorium. As these elements decay, ^{4}He is released. In order to find a helium field, three conditions must exist. The radioactive decay of deep sources, fracturing or faulting which allows for the vertical migration of the helium into a reservoir, and an impermeable seal of halite or anhydrite above a zone with reservoir characteristics. Shales plugged with abundant organic material can also form an imperfect trap (King).

In Spisak's testimony to Congress, he references 0.5% - 1.5% ^{4}He in the natural gas stream produced along the federal helium pipeline in Kansas, Texas, and Oklahoma, noting ^{4}He: hydrocarbon gas ratios as some of the richest on earth (1). Magill's *Popular Mechanics* article reports 1.9% helium concentrations along the federal helium pipeline in the Hugoton field and Texas panhandle as "very high concentration." While 0.3% concentration of ^{4}He is sufficient for commercialization from the hydrocarbon stream, the highest concentrations of ^{4}He on earth were produced from the Pinta Dome Field in Navajo County, Arizona, averaging 8.0% of the gas stream.

In nature, ^{3}He is found as a natural isotope within helium reservoirs as a decay-anomaly from source thorium and uranium. Wittenberg calculates concentrations of ^{3}He within crustal oil and gas reservoirs to be 0.2ppm of the ^{4}He stream (4-5). The economics of refining the negligible concentrations of ^{3}He from the ^{4}He production stream will depend on the cost per throughput to strip ^{3}He from the ^{4}He, the percent concentration of ^{3}He, and the percent concentration of ^{4}He.

According to Magill, ^{3}He is generated in the earth's mantle. According to Wittenberg, it is primordial, trapped in the Earth during the process of the Earth's formation. Wittenberg reports the highest concentrations of ^{3}He on Earth being found in magma-vented gasses from sea-floor spreading, 14ppm and Hawaiian volcanos, 30ppm (4-5). Like Helium, ^{3}He will escape into the earth's atmosphere if not trapped by an impermeable seal. The author theorizes that oil and gas fields capped with impermeable seals that communicate to the magma-series through deep faults, fissures, breccia pipes, plutons, and granite intrusives will hold anomalously high concentrations of ^{3}He, however, it is not believed that the higher concentrations are necessary to make extraction of ^{3}He from the helium stream profitable.

Extraction from the natural gas stream is the most economical method of producing helium. (Spisak 1). Because helium exists in the natural gas supply, the most cost-effective commercial supply of ^{3}He is through extraction from the natural gas stream because most of the energy needed to cool the ^{3}He product has already been applied to the helium supply in the gas stream. The additional energy required to further cool the helium to drop the ^{3}He out of the stream is expected to add a cost of \$34/liter-\$300/liter, depending on the efficiency of the heat exchange equipment (Morgan and Shea 11-12). Volumetric production calculations show encouraging economics for ^{3}He produced at 0.2ppm of the ^{4}He stream. 146 gas wells producing a total volume of 250MCFD at 6.0%^{4}He at 0.2ppm^{4}He at an 80%NRI and \$2,750.00/liter calculate

$49,802,702.40 in five years. Processing ^{3}He from the helium stream is the only economically viable option currently available to increase supply.

Processing ^{4}He and ^{3}He from the Gas Stream[6]

The extraction process for natural gas is called fractional distillation, and helium separation is referred to as cryogenic distillation or nitrogen rejection, as the purpose of cryogenic distillation is to remove impurities from the hydrocarbon gasses, to increase BTU. Impurities such as water, carbon dioxide, nitrogen, and neon are removed by fractional distillation, and helium is purified through cryogenic distillation.

The first step in distillation is the pretreatment process, in which natural gas is sprayed with monoethanolamine at 800 psi, to carry the carbon dioxide out of the stream. A molecular sieve then pulls the water from the stream, which is flushed from the system. Next, a rechargeable, activated carbon collects heavy hydrocarbons, allowing the gas comprised of mostly methane and nitrogen to move into the fractional distillation process.

The methane and nitrogen are warmed, and then passes through an expansion valve which cools the mixture as the pressure drops to 145-360 psi. The methane begins to liquefy at this temperature variation. The fluid/gas mixture passes into the fractionating column where methane continues to liquefy as it loses heat, and the gaseous mixture, rises to the top of the column. The liquid methane then passes through another expansion valve dropping the pressure to about 22psi, which removes most of the rest of the nitrogen, which is either processed or vented into the atmosphere. The methane is then pumped out, warmed and evaporated. The gasses captured from the top of the first stage fractionating column are cooled in a condenser

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[6] Abstracted from *How Helium is made-material, history, processing, components, product, history.*

which allows the nitrogen to rise, while the remaining mixture is crude helium consisting of 50-70% helium.

To further purify the crude helium, it is cooled to -315 F, which allows much of the remaining nitrogen and methane to condense into a liquid for removal, with the helium stream consisting of about 90% purity. Oxygen is then pumped into the mixture and warmed over a catalyst, which captures the hydrogen as it forms water vapor. Subsequent cooling allows the water vapor to be drained, before the gas enters into a pressure swing adsorption (PSA) unit. As the gas passes through the particular pores in several vessels in series, the remaining gasses are trapped, and can be purged. Repeating the process allows the helium content to move to 99.99%. The final step for purity levels of 99.9999% or better is to pass the helium over activated carbon in a cryogenic adsorber at -423 F. It is then passed through heat exchangers and expanders which further cools it to -452, which liquefies the product.

After this process, the ^{3}He is one degree from liquefaction. Most of the energy required to separate out the ^{3}He has already been provided. It is here that a final-leg distillation unit should be added onto ^{4}He refinery capacity to capture the critical isotope.

Distribution Vessels for He

Large scale transportation of helium is done in triple walled ISO (International Organization for Standardization) liquid helium containers, tankers generally 1.5MMCF or 1.1MMCF capacity and are generally shipped internationally through Newark, NJ, or Long Beach, CA. The ISOs can hold helium 30-45 days without significant loss of helium content. Smaller, and secondary distributions are made by steel cylinders, (10-300 cubic foot gaseous helium), tube trailers (30,000-180,000 cubic foot gaseous helium), and Dewars (50-500 liters liquid helium) (NAP Selling the Nations).

"Gaseous helium is distributed in forged steel or aluminum alloy cylinders at pressures in the range from 900-6000 psi. Bulk quantities of liquid helium are distributed in insulated containers with capacities of up to about 14,800 gallons (5,600 liters)". Vessels are generally of two types, a double walled container, with a vacuum chamber in between to isolate the helium from warming, or, in the case of long distance transport, a liquid nitrogen filled chamber, which is vented as it warms, to protect the inner helium chamber (How Helium is Made*)*.

NDIC distributes ^{3}He in Size 6 (capable of holding 25-180 STP liters) or Size 30 (capable of holding 200-800 STP liters) compressed gas cylinders at a standard temperature of 273 degrees kelvin (0 Celsius) at 1 atmosphere (14.7 psi), with 580 brass valves (DOE Helium 3 Sales Solicitation 2014).

Cryotherm manufactures and sells a number of vessels for the transportation and sale of helium and liquid helium, and secondary equipment dealers can be found online.

Infrastructure Resources for ^{3}He Refinery

The best resource for helium refinery is probably IACX Energy, which has deployed scalable nitrogen rejection and helium separation equipment. Based in Dallas, Texas, the company offers leasing, and joint ventures on gas treating and helium recovery units and infrastructure projects. They are also in the market to acquire helium reserves: 972-960-3210. http://iacx.com/about-iacx/

With commercial quantities as low as 0.5%, IACX Energy currently operate gas separation and helium extraction in Barton, Rush, Ellsworth, and Rice Counties in Kansas on their Otis Project. They also operate 0.7% - 2.0% concentration extraction from Hodgeman and Pawnee counties in Kansas from their Hodgeman Project and they operate separation in Ford County Kansas. They have entered into an agreement to set two units for nitrogen rejection and helium extraction on the Badger Ash Project in western Colorado. They operate Helium Reserve #2 on the Harley Dome Project in eastern Utah (with 8% He concentrations); they operate wells and processing equipment on the Woodside Dome Project with concentrations of 0.7-1.5% ^{4}He (also located in Utah); and they have installed two HRUs (Helium Refining Units) with a combined gas capacity of 4MMCFGD for the DBK Project which produces 3%-5% helium mixed with nitrogen in Apache County, Arizona. For most of these projects, they offer a fee on the helium produced and provide marketing services. http://iacx.com/helium -projects/.

CB&I is another source for helium refinery capacity, as they provide full design, fabrication and installation services for helium recovery units, and they advertise modular units which can be installed quickly with state of the art pressure swing adsorption technologies. For information on plant fabrication, see www.cbi.com/technologies/gas-processing-technoloty/modular-psa-gas-recovery.

Likewise PPE (Plant Process Equipment, Inc., (Engineering 281-333-7700; Manufacturing 281-333-7850; Fax 281-333-7701) specializes in the design and construction of gas stream processing equipment including helium separation http:www.plant-process.com/gas_processing/default.html.,

Air Liquide Global is one of the major helium players in the world with all phases of helium separation and marketing built into their company http://www.engineering-solutions.airliquide.com.

Additionally, the author's personal relationship with Cheryl Taskinen, PE and head of the Structural Division of Professional Engineering Consultants, PA, headquartered, in Topeka, Kanas, has evolved interest from Westley G. Briston, PE, SE, Principle, Energy and Structural division, who assures his firm has the experience and breadth of talent to engineer helium refining facilities. Professional Engineering Consultants, 303 South Topeka, Wichita, Kansas 67202, 316-262-2691

PART II

Lunar ^{3} He

A natural source of ^{3}He that has captured the imagination and efforts of the press, scientists, businessmen and sovereign states is our solar system's Sun. Mass coronal ejections have carried ^{3}He on solar winds to the earth's moon. Because the moon has no atmosphere to deflect the radiation, ^{3}He has been deposited in the rocky debris layer (lunar regolith) over billions of years. Through extrapolation of Apollo 11 samples, it is estimated that the regolith on Marre Tranquillitatis contains 5,500 tons of He-3, dispersed over 53,000 square miles. Mark W. Henley et al theorize theorizes the volume of ^{3}He on Mare Tranquillitatis would supply one hundred, 1,000MW ^{3}He fusion power plants for 50 years. Additional supplies inferred on the lunar poles are estimated to contain three times that amount, and significant deposits are inferred in areas of deep shadow in clathrates and non-lunar fullerenes (4, 6).

The scale of international cooperation and scientific operations undertaken to realize nuclear fusion, and to define the existence of significant deposits of lunar ^{3}He make the prospect of mining the moon seem credible. Though the US does not hold an official position on the mining of ^{3}He, it intends to return astronauts to the moon by 2020, with a permanent base being staffed by 2024. Likewise, Russian rocket corporation *Energia* has stated it will have a lunar base by 2015-2020 for the purposes of extracting ^{3}He. China, India, Japan, and Germany have all stated intentions of mining ^{3}He on the moon for use in fusion reactors on earth (Wiliams 1).

Engineers analyzed lunar samples returned from the moon to realize that they contained significant amounts of ^{3}He, which could be useful for third-generation electrical generation in fusion power plants, because its byproducts can be converted directly into electricity, with an estimated conversion factor of 70% efficiency, and there is no radioactive waste. “Although quantities sufficient for research exist, no commercial supplies of helium-3 are present on earth. If they were, we probably would be using them to produce electricity today”. The more we learn about building fusion reactors, the more desirable a helium-3 fueled reactor becomes.” Unlike deutreum-deutreum reactions, which require high pressures and powerful magnets that cannot contain the reactions for days on end, helium-3 can be confined with electrostatic confinement, greatly simplifying reactor design (Popular Mechanics).

Harrison H. Schmidt, who came from flagstaff’s USGS astrology office, and retrieved 224 lbs of lunar samples during his moon walk in 1972, is chairman of Albuquerquie-based Interlunej-Intermars Initiative, and an avid proponent of mining the moon estimates that “digging a patch of lunar surface roughly three-quarters of a square mile to a depth of 9 ft should yield about 220 lbs of helium-3- enough to power a city the size of Dallas or Detroit for a year. (popularmechanics). The spectroscopic properties of lunar samples were used to calibrate the tools on India’s Chandarayaan 1 Lunar Orbiter, and NASA’s M-3 hyperspectral scanner. The Chandrayaan 1 Lunar Orbiter mission has provided the most comprehensive map of the moons topography, mineralization, radioactive, and hydrodynamic environment ever recorded (NASA).

Technological Basis for the Presumption of Lunar ^{3}He Resources

Chandrayaan 1 Lunar Orbiter

At an estimated cost of $83million USD, the Indian Space Research Organization launched a 523kg cube named Chandrayaan (Moon Craft) 1 Lunar Orbiter from the Satish Dhawan Space center in Sriharikota on October 2, 2008. After obtaining terrestrial orbit, bipropellant propulsion, star sensors, accelerometers, and inertial equipment helped place the vehicle into a circular lunar polar orbit on November 14, 2008 (NASA). The craft carried 12 tools to demonstrate India's space technology, and to map the moon (Aanadurai et al 2). Two of the tools, were built by guest countries, and inhabited the satellite, (1), NASAS's Moon Minerology Mapper (M-3), a hyperspectral scanner designed to determine the mineral composition of the moon, and (2), Bulgarian built RADOM-7, a radiation dose meter intended to decipher surface radiation. Other mapping tools included (1) a 5 meter resolution Terrain Mapping Camera (TMC), the Hyperspectral Imager, focused in 15 nm intervals across the 400-900 nm bands with a resolution of 80 meters (HySI), (3) the Lunar Laser Ranging Instrument, designed to take precise elevations on the surface (LLRI), (4) and an X ray fluorescence spectrometer designed in three parts (a) a 10 Km resolution imaging X-ray spectrometer designed to map Si, Al, Mg, CA, Fe and Ti, (CIXS), (b) a 20 Km resolution, high energy X-ray/gamma ray spectrometer, designed to detect radiological anomalies, specifically the presence of U, Th, ^{201}Pb, and ^{22}Rn, (HEX), and (c) the Solar X-ray monitor, designed to calculate solar flux to smooth the readings of the CIXS and the HEX tools. (5) The Sub-ke V Atom Reflecting Analyzer was designed atoms thrown from the surface (SARA), and (6) the near infra-red spectrometer was also designed to detect mineralization (SIR-2). The Miniature Synthetic Aperture Radar was installed to detect water and ice in the polar regions (Mini-SAR) (NASA), and (7) a lunar probe was launched to the surface once the satellite reached its orbit. (*Chandrayaan 1 Lunar Orbiter*. NASA and NSSDC).

Moon Minerology Mapper (M-3)

The moon minerology mapper is a hyperspectral tool designed to cover wavelengths from 430 to 3000 nm, with a 10 nm sampling, consisting of 260 bands to detect the minerology of the moon, based on assumptions of known and possible lunar materials. It was launched on the

Indian Space Resource Organization's Chandaryaan-1 on October 2nd, 2008, and lost communication on August 29th 2009. (Aanadurai et al 1).

The M3 has 70 meter spatial resolution for mapping the surface of the moon (Aanadurai et al 1), and one of the tool's targeted objectives was to "identify and map areas with diverse 'feedstock' for future utilization. The lunar samples returned from the Reflectance Experiment Laboratory (RELAB), provided the basis, or ground truth, for the spectral wavelength selection of the M3, and surface temperatures of over 300K were accounted for in selection of the reflectance saturation (Aanadurai et al 2). The data was calibrated in two modes, target mode, which utilizes the full spatial and spectral imaging, and global mode, which was designed to offer a lower resolution, with quick sampling (86 channels, 140 meters) (Aanadurai et al 2, 27). An on-orbit spectral calibration was confirmed by pitching the craft to direct the field of view towards the earth, sampling the western Pacific region of the earth, sampling atmosphere, ocean land, and vegetation. Known absorption bands stored in MODTRAN, were compared with spectral data from M-3, and correlated precisely (Aandurai et al 26-27). The Data was transmitted in Consultative Committee for Space Data Systems (CCSDS) format and returned to the Instrument Ground Data Subsystem on earth (IGDS), who delivers processed and calibrated data sets to the NASA Planetary Data System (PDS) (Aanadurai et al 2).

Interpretation and Implication of Space-Law on Mining Lunar ^{3}He

Within the framework of the International Treaties and UN Resolutions governing space, there are major risks to business operations in outer space, including: the interpretation of property rights vs. communal rights in space; environmental protections of outer space and the possibility of scientific preserves or overall moratoriums on exploration; concerns of corporate espionage and protection of trade secrets; and international liabilities and restitution.

Treaties and UN Resolutions Governing Activities in Outer Space

The adoption by the UN General assembly of the *Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies*, laid a foundation for the treaties which have been entered into by a number of space-faring nations. Chief among these international agreements is (1) *The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies,* (1966). Other treaties entered into by the majority of the space-faring nations include: (2) *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, (1967),* (3) *Convention on International Liability for Damage Caused by Space Objects (1971)*, (4) *Convention on Registration of Objects Launched into Outer Space,* (5) *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies.* Additionally, the UN had drafted and adopted resolutions including (1) *Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space (1963),* (2) *Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting*, (1982) (3) *Principles Relating to Remote Sensing of the Earth from Outer Space (1986)*, (4) *Principles Relevant to the Use of Nuclear Power Sources in Outer Space (1992),* and (5) *Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries (1996)* (UN v-vi) (United Nations Treaties and Principles on Outer Space. United Nations, New York, NY 2002)

Property Rights and Mining Lunar ^{3}He

The Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space serves as a framework for the Treaty Governing the Activities of States in the Exploration of Outer Space and Celestial Bodies. Article I of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies sets forth some principles that contradict ownership of lunar resources by stating that the exploration "shall be carried out for the benefit and interest of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind", that they "shall be free for exploration and use by all States without any discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies…, freedom of scientific investigations…and States shall facilitate and encourage the international cooperation in such investigation" (UN 4).

Article II compounds the communal domain of all mankind by stating "Outer space, including the Moon and other celestial bodies is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means" (UN).

The provisions of Article I and II of the treaty seek to limit the authority that a nation-state can exert over outer space. The implication of this language presents the fundamental dilemma for private interests who wish to procure property rights in space, as it may be interpreted that such rights are illegal under the treaty because terrestrial common-law derives title to property as being vested by the authority and recognition of sovereign states (Dudley-Rowley, Marilyn and Thomas Gangle 2).

However, Article 12 sets forth specific property rights, maintaining that the vehicles and equipment and component parts registered within a nation shall be the property of and under the jurisdiction of the launching state and organization (33). Furthermore Articles 8-10 set forth that any state party may construct facilities, or land or maintain craft for the purposes of exploration, and shall exercise control over such properties whether on the surface or in the subsurface, as long as they safeguard the rights of other states to the full access and use of the moon, and they do not interfere with the activities of other state parties (UN).

While there is common agreement that the States must monitor the activities of their private interest groups, who do have the right to appropriate resources, because they are not specifically forbidden to do so by the treaty, large appropriations would be antithetical to the provisions of the treaty's free access to all nations. However, operating in an area for the extraction of resources, would not necessarily require large appropriations, and therefore, may not violate the law (Dudley-Rowley, Marilyn and Thomas Gangale 3).

While no State shall own the moon, article IV provides a specific ownership clause to materials collected on the moon for scientific purposes. The language may be interpreted to place business interests at risk by restricting activity to scientific investigation:

> State Parties shall have the right to collect on and remove from the Moon samples of its mineral and other substances. Such samples shall remain at the disposal of those State Parties which caused them to be collected and may be used by them for scientific purposes. State Parties shall have regard to the desirability of making a portion of such samples available to other interested State Parties and international scientific community for scientific investigation. Parties may in the course of scientific investigations also use mineral and other substances of the Moon in quantities appropriate for the support of their missions (UN 29). United Nations Treaties and Principles on Outer Space. United Nations, New York, NY 2002

This language could also be interpreted as making primary property rights unnecessary, because history dictates a take-it, own-it precedent, in which lunar samples returned to the US and USSR under the ownership, control and jurisdiction of those nations was never contested. (Dudley-Rowley, Marilyn and Thomas Gangale 4). Because the states retain jurisdiction, control and property rights in and to their vessels and bases constructed, and maintain control of an area around their bases, 'functional property rights' could develop as a course of common law. (Dudley-Rowley, Marilyn and Thomas Gangale 5)

While Article 11 specifically prohibits the natural resources in situ from becoming the property of any state, governmental or non-governmental entity (UN) common practices make removal of resources a reality that reverts the property rights to those exercising control over the removed resources. In support of this, the treaty's proclamation of freedom in outer space, could be interpreted to include the freedom to extract resources. The wording of the treaty that no entity shall own the resources 'in place', would be interpreted such that ownership could transfer upon extraction" (Dudley-Rowley, Marilyn and Thomas Gangale 5).

This interpretation fits with the customs of the United Nations Convention on the Law of the Sea (UNCLOS), which states "Title to minerals shall pass upon recovery to the entity which recovered them" (Dudley-Rowley, Marilyn and Thomas Gangale 5). Because most of the treaty was derived from principles of maritime law, it is believed that this provision can be applied to outer space. Examples of functional property rights occur when private companies conduct activities on public lands, such as grazing rights and mineral leases. The private entities do not own the land, but still have the right to utilize it. A specific example is the production of petroleum in the maritime Exclusive Economic Zone by British Petroleum, Amoco, and Exxon-Mobile (Dudley-Rowley, Marilyn and Thomas Gangale 5).

While the interpretation and usage of functional property rights has the ability to develop by precident, there is another danger to the economic interests and property rights of an entity seeking to exploit extra-terrestrial minerals. Article 11 of the treaty leaves the future of ownership wide open to interpretation and the decisions of the international community in the enactment of its principles. Contentious to the property rights of mineral removal are the statements that "the Moon and its natural resources are the common heritage of all mankind" (UN 31) and that the parties to the agreement should undertake to "establish an international regime, including appropriate procedures, to govern the exploitation of the natural resources of the moon as such exploitation is about to become feasible" (32).

The questionable future of property rights is embodied in the statement that the international body maintain "an equitable sharing by all State Parties in the benefits derived from those resources, whereby the interests and needs of the developing countries, as well as the efforts of those countries which have contributed either directly or indirectly to the exploration of the moon, shall be given special consideration" (32). In its purest sense, this language could be enforced as profit sharing and collectivism.

Article IV of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies further defines the ambiguity of enforced collectivism versus ownership of lunar resources, by its provision that:

> "the exploration and use of the Moon shall be the province of all mankind, and shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development. Due regard shall be paid to the interests of present and future generations as well as the need to promote higher standards of living and conditions of economic and social progress and development in accordance with the Charter of the United Nations." And that "State parties shall be guided by the principle of cooperation and mutual assistance in all of their activities concerning the exploration and use of the Moon." (UN 28).

Environmental Protections in Outer Space

Another possible setback to industrial activities in outer space, including the mining of lunar ^{3}He are the environmental protections written into the treaties.

Article IX of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies addresses environmental concern, declaring states conduct exploration so as to "avoid their harmful contamination and also adverse changes in the environment of the earth resulting from the introduction of extraterrestrial matter" (UN 6).

Article 7 is the environmental clause, requiring that States notify the Secretary General of the UN of any radioactive materials to be placed on the moon, and to notify the Secretary General of any areas of particular scientific interest so that preserves can be made on the moon. It also requires that State Parties, "prevent the disruption of the existing balance of its [the moon's] environment, whether by producing adverse changes in that environment, by its harmful contamination through the introduction of extra-environmental matter or otherwise" (UN 30), and it provides that the environment of the earth not be harmed by the introduction of extraterrestrial matter or otherwise (UN 30).

These provisions bring up several key points that should be addressed. First, mining vast areas of lunar regolith for the production of ^{3}He could be considered disruptive to the balance of the moon. To date, there is not enough scientific investigation of outer-space to know whether those changes would be harmful to the moon's environment, the space environment, or the Earth's. Furthermore, it could be argued that the nascent nature of scientific investigations into the moon make all of its areas of particular scientific interest, and should be made into preserves.

Environmental Moratorium on Activities in Outer Space

Drawing on the unknowns of space, Race makes the point that the protection of the space environment and extraterrestrial bodies is confounding, because much of space is too harsh to support life. He makes the suggestion that COSPAR's idea of entering into a period of biological exploration, could be used as a stepping stone to limit commercial activities in space, much the way that the moratorium on mineral extraction in Antarctica has been implemented, a period of perhaps 50 years in which science can better learn the biological and environmental impacts to space systems so that a well-researched and well-understood environmental framework could be put in place before commercialization (150).

In support of Race's opinion, the section on Ultrahazardous Materials in Space has been abstracted from McGarigle to open the mind of the reader to the types of economic and scientific endeavors that are being considered in outer space, and the 'known' ultrahazardous nature of such operations; ultrahazardous being defined in this case as operations for which significant care may not be enough eliminate the risks for harm to the environment of space or the earth—and the consequences may be unforeseeable (McGarigle 110-111).

Ultrahazardous Materials in Outer Space

There are several reasons why China intends to have astronauts on the moon by 2025. First, there is a belief that solar arrays could be deployed on the moon to provide energy to the entire earth, with a longer equipment life-span because of the lack of atmospheric degradation to the solar panels. Secondly, rare materials like ^{3}He are believed to be in abundance to satisfy earthly energy needs for 10,000 years. Third, the atmospheric and temperature variations on the lunar surface provide unique manufacturing opportunities, and lunar elements such as titanium and uranium could be mined, returned to earth or utilized in a lunar manufacturing post for extraterrestrial missions (Shukman).

Energy plans such as harvesting solar power from satellites or celestial stations, could cause adverse radiation transference to receiving stations, damaging plant and/or animal life or heating the atmosphere on Earth (McGarrigle 107). Another energy source, nuclear power, or even the transference of spent fuel from the terrestrial environment is a simple shift of risk from the earth to outer space, which could be more hazardous than the production of nuclear power or storage of spent nuclear fuel on earth because of the greater dissemination of contamination in an accident because of the microgravity environment (McGarrigle 108).

Another possible use of space involves manufacturing of pharmaceuticals which has showed an 450% increase of production values through continuous flow electrophoresis, and crystal growth is advantageously affected in the vacuum of space. 500 other materials have been found to be advantageously manufactured in space, and over 250 companies have expressed serious interest in taking operations to outer space (McGarrigle 105).

Mining is another use of space that could have severe adverse impacts on the environment of space itself. One of the major reasons to consider mining is the cost-effectiveness of processing materials, and limitation of terrestrial removal of substances for space-borne operations and outposts (McGarigle 107).

Another major, ultrahazardous use of space being considered is the manufacture of genetically engineered organisms for the production of medicines. The unregulated nature of space make it look attractive to companies, however, the unplanned release of genetically modified bacteria has unknown risks to the space systems their release may encounter (McGarigle 109).

Another use for space laboratories is to isolate and experiment on extraterrestrial organisms, to conclude their level of virility or potential harm to mankind before entering them into the earth’s atmosphere. While careful construction of automated control measures can help to eliminate the risk of bringing extraterrestrial materials to earth, all of the uses presented above are defined as ultrahazardous, because significant care may not be enough to eliminate the risks for harm to the environment of space or the earth, and the consequences may be unforeseeable (McGarigle 110-111).

Furthermore, the 1981 Antaeus report, issued by NASA to address building a station to quarantine Martian materials, stated that there is little likelihood that life will be found, and that other purposes for an Orbiting Quarantine Facility should be considered. The most significant terrestrial contamination could be caused by a deorbit of the quarantine facility, were it to crash on earth. Another risk, is unintentional organic release, which could contaminate a celestial body. A compatibility between the released microbe and the celestial environment could irreparably change the environment. Likewise, a release of pathogens into space could disperse the pathogens until they are captured by an entity's gravity, including the Earths. A greater risk, contamination of personal within an Orbiting Quarantine Facility, which would result in disallowing their return to earth (McGarigle 111-114).

McGarigle recommends that international oversite be employed for ultrahazardous biological materials, noting that the International Council of Scientific Unions (ICSU) was responsible for extraterrestrial contamination, but that this was turned over to the Committee on Contamination by Extraterrestrial Exploration (CETEX), which was then turned over to group V within the Committee on Space Research (COSPAR). As the current regulatory body, McGarigle recommends that the advice of COSPAR be utilized for NASA to develop specific guidelines in adherence with that advice for projects with potential hazardous contamination issues in outer-space (136-137).

Corporate Espionage and Trade Secret Risks in Outer Space

> "State parties to the treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner. The moon and other celestial bodies shall be used by all State Parties to the Treaty exclusively for peaceful purposes. The establishment of military bases, installations and fortifications, the testing of any type of weapon and the conduct of military maneuvers on celestial bodies shall be forbidden. The use of military personnel for scientific research or for any other peaceful purposes shall not be prohibited. The use of any equipment or

> facility necessary for peaceful exploration of the Moon and other celestial bodies shall also not be prohibited (UN 4).

Article V regards astronauts as envoys to humanity, and requires states to aid astronauts in peril, and return astronauts landing in foreign states be returned to their state of origin (UN 5). The agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects launched into Outers Space, further expands on the sovereign control over astronauts and space objects, requiring that astronauts who land under distress, emergency, or unintentionally in a nation state other than their state of origin, or on the high seas, shall be rendered what assistance the states to the treaty are capable of rendering, and shall be returned to their state of origin. The same rule applies for objects or parts of objects to be returned to their country of origin (UN 9-10).

Furthermore, as with the registration of space vehicles, all stations are to be registered with the UN, and all personnel on the moon shall be regarded with the diplomatic status afforded to Astronauts, with state parties "offer[ing] shelter in their stations, installations, vehicles and other facilities to [persons] in distress on the moon" (UN 30-31).

The fact that many astronauts come from the military of their home nation-states, and the fact that diplomatic treatment is to be afforded to all astronauts, opens up any facility, whether owned by a nation state, or private entity, to any person who claims a state of distress. This could open up competitively sensitive processes and corporate trade secrets for inspection by foreign nation states and competitive interests. Furthermore, the communal provision in the treaty of states sets forth provisions that operations be "carried out for the benefit and interest of all countries, irrespective of their degree of economic or scientific development." This could be interpreted to open proprietary processes and corporate trade secrets to the inspection of all nations.

Article XII of the treaty pushes the risk to proprietary processes one step further by adhering to its standard of equity by declaring "all stations, installations, equipment and space vehicles on the Moon and other celestial bodies shall be open to representatives of other state parties to the treaty on a basis of reciprocity (UN).

United Nations Regulation of Outer Space

Every space faring nation has their own system of enforcement of protocols for outer space, however, the United Nations maintains a registry of all extraterrestrial craft, stations, and it controls the main-stays of the international legal system for outer space.

With the spirit of cooperation echoed throughout the space treaty regime, Article X opens observational rights of launch and flight of space objects by requesting state parties. (UN Nations Treaties)

Article XI of the Nations Treaty requires member States to the treaty to inform the Secretary-General of the UN as to the nature, conduct, locations, and results of any space related vessels and activities and the Convention on registration of Objects Launched into Outer Space sets forth that all objects launched should be placed in a registry by the launching state, and that a registry shall also be maintained by the Secretary General of the UN (22). The registry is to include the name of the launching state or states, a registration number for the space object, the date and territory from which the object is launched, basic orbital parameters, and the general function of the object. Each state may decide to include and/or inform the Secretary General of the UN of additional information, but they are bound to the "greatest extent feasible and as soon as practicable [to notify the Secretary General of the UN of] space objects concerning which it has previously transmitted information, and which have been but no longer are in Earth orbit (UN 23-34).

Article V requires a State Party to inform the Secretary General of the UN of their activities planned for the exploration of space and the moon, including the time, location, orbital parameters, and requires scientific results be furnished upon the completion of the mission. Additional to the interesting provision that scientific discoveries must be shared, it also requires that any phenomena which could endanger human life be reported, as well as the discovery of extraterrestrial life.

Paragraph 2 of Article V is noteworthy because it was written to keep competing interests from intersecting in space. It can be interpreted as a race-to-space clause however. The race to space provision stays a state that learns that another state has the same basic mission location planned shall notify the other party of its timing and plans (UN 29). This could easily create a contest of filing plans for missions to critical resources to procure a spot in line in the international community, even though the logistic feasibility and timeline for completion of the plans are outside the scope of the submission.

Ownership of Liability and Restitution in Outer Space

The Convention on International Liability for Damage Caused by Space Objects sets forth the terms and conditions and limits of liability from one state to another by damage caused by its craft, but sets forth very little in terms of enforcement. The States that are adversarial in a liability claim must only engage in consultations, and diplomatic negotiations, however, the plaintiff is not barred from bringing suit in the courts of the launching state (13-17).

Common Law System for Governance of Outer Space

Additional to United Nations oversight, Outer Space treaty has been supplemented with a needed common law regime (ROUSIS), Regency of United Societies in Space, which "is a common law government trust with the character of compliance to space treaty principles" (UN

6). The purpose of the common law system is to supplement the outer space treaty with a system of common law for torts, crimes, and all matters of issues not specifically addressed by the outer space treaty. “The ROUSIS convention was noticed to all UN offices, all UN delegations, and to all space agencies [and] No objections were received”. Because the United States sent a delegate to the convention, it is customary that its presence amounts to an acquiescence to the terms of the treaty (Dudley-Rowley, Marilyn and Thomas Gangale 6).

While ROUSIS could help the business interests of nation states, particularly those of the United States, by providing legal frameworks and interpretations aligned with UNICLOS, or otherwise favorable to common law exploration of mineral resources, rigid interpretation of business-prohibitive or communal language presented in the treaties could result in unilateral actions by nations.

Unilateral Actions

Dudley-Rowley et al presents two theories for the development of outer space: (1) a “Techno-economy,” which has been the focus of this report, a process by which which technologies are developed by industry in an organic way, providing long term profits over the life of the market demand for the technology; and (2) “technocracy” which is a forced development of technology to serve state interests. While a technocracy can develop technology in short time periods, (Dudley-Rowley, Marilyn and Thomas Gangale 2), it also can set a dangerous stage for imbalances of power among nations, who are forced to strike-first, before the balance of power can be shifted.

Because the basis for enforcement in the treaties is diplomacy, industrialists are already arguing nuances of property law that contradict the spirit of the treaties. While unilateral action based on false assumptions would violate the Law of Treaties, Article 31, paragraph 31, which reads that treaties should be interpreted in good-faith, within the intended meaning of their object and purpose (Dudley-Rowley, Marilyn and Thomas Gangale 4), there is very little that can be done. In fact, history is more favorable to such manuvers.

The United States Congress proposed and passed the "'Space Resource Exploration and Utilization Act of 2015,' H.R. 1508, as part of the broader SPACE Act of 2015," which provision seeks to unilaterally impose legal title over asteroids to those who first exploit them, as long as they conform with the provisions of the Outer Space Treaty by non-interference with the activities of other states. This follows the US custom of denying treaties it deems to communist in nature, such as the "Moon Treaty" proposed by the UN, but not ratified by the US for its insistence on an international committee of oversight, and the Law of the Sea Convention (Part IX), enacted by the UN in 1982, which the US saw as too collectivist.

US adherence to The Principles Relating to Remote Sensing of Earth from Outer Space demonstrates another example of interpretation in action. The principles have two important conventions. One, that the knowledge of any harmful natural disaster discovered be communicated immediately to the state in harm's way, and two, any state that is 'sensed' remotely be provided with the processed data of its own territory or jurisdiction promptly and under reasonable cost terms (UN 44-47). During the SIR Shuttle missions of the 1980's, which scanned the earth with ground penetrating radar, it was showed that subsurface features could be detected in the middle east, which could help identify mineral and oil and gas deposits. When the US finally released the GPR images to the nations that were sensed, they were low resolution images.

Another example can be seen beginning with the Bush administration's aggressive pursuit of Space Based Weapons systems such as kinetic kill vehicles (i.e. 'rods from God', a 20' long 1' diameter tungsten rod, traveling from orbit to smash terrestrial targets at 26,000'/second), space based lasers, and anti-satellite weapons (which have been operational in the US since the 1980's, and successfully tested by China in 2007), because even though the Nations Treaty does prohibit weapons of mass destruction, it does not specifically prohibit limited target systems (Englehart 133-136).

Unilateral actions of statesmanship are not limited to US operations. Their bearing on the risks of procurement of ^{3}He from lunar mining operations is open to interpretation. They depend upon a business's tolerance to playing by the rules or not playing buy the rules. While it is always best for a business to play by the rules, statesmanship is what it is. Perhaps the biggest deterrent from mining lunar ^{3}He is not the legal environment, but rather—the economics.

Economics of Mining Lunar ^{3}He

Popular media has circulated a lot of information about the great economic possibilities and unlimited power potential of mining ^{3}He on the moon for nuclear fusion.

A Popular Mechanics Article from 2004 claims 220 lbs of lunar ^{3}He is economically feasible to produce from 13-30 ppb ore because it would return a value of USD $141million on USD $15billion in start-up costs for "fusion development, rocket development and starting lunar operations". One can only assume that the USD $6billion of investment cited to develop a commercial, utility scale helium-3 reactor, with payback at 5 cents per kilowatt hour being obtained with five 1000 megawatt plants online is included in the $15billion number. It also estimates that the Saturn V rockets can be enhanced to a 100 ton payload capacity with an investment of $5 billion, which they calculate to $1,500/lb of payload delivery.

Citing 2006 prices, Mark W. Henley et al estimate 100 kg (220 lbs) of helium-3 would have a value of $140 million. They assume 220 pounds/year would require processing 1.6 sq miles to a depth of 3 meters. Estimating 8 personnel per miner/processor with two 10 hour shifts, and a 90% operational up time, they conclude a financial breakeven on a USD $2.5billion investment when 5 processors are in operation (Gillo 5-6).

While both articles seem to quote the same numbers for the rate of return on lunar ^{3}He, the credible source on the topic is COSPAR Scientific Assembly, whose study estimates that production of enough Helium-3 to provide for 10% of the worlds energy needs by 2040 would require between 1,700-2,000 of the University of Wisconsin's Mark III miners, 39 GW power, & 22 continuous-thrust vehicles to transfer material from the moon to the earth. The projected annual costs of such a large-scale operation are expected to be €7.7billion – €20.5billion, with an expected annual loss of €14.3billion – €0.8billion. "Although only a starting point for further investigations, this study shows that, despite popular claims, lunar Helium-3 is unsuitable to provide a significant percentage of the global energy demand for 2040" (Blange). COSPAR does not report the start-up costs and timeline to develop fusion, equip the industry with the spacecraft and mining equipment, nor do they look at the feasibility of housing 15,000 employees on the moon: The only economically feasible source of ^{3}He production is on here on Earth.

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