Lunar Commercialization: Helium-3 Extraction

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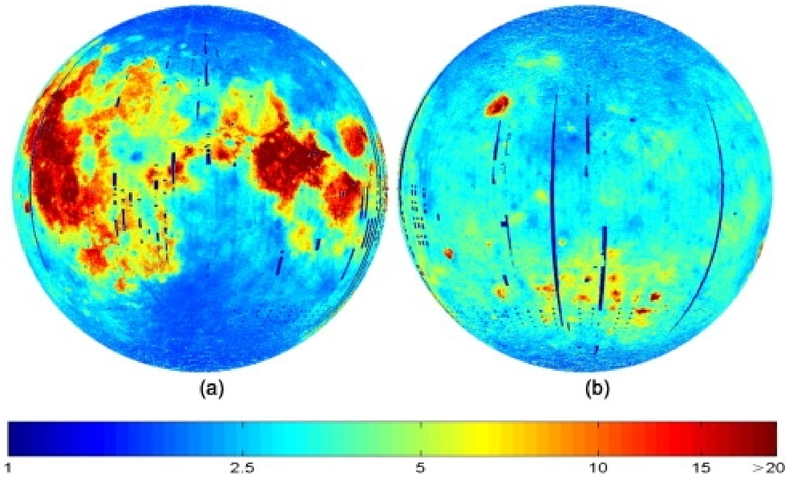
What Are We Trying to Do?

Lead the World to Mine He-3 from the Moon

- Lunar He-3 represents an immediate commercial opportunity Natural He-3 is very rare on Earth but abundant on the Moon

Need to study whether He-3 can be extracted from the Moon and delivered to terrestrial market at a reasonable price point



Map based on data from Chang'e-1

How Is It Done Today, and What Are the Limits of Current Practice?

- No He-3 extraction and transportation process currently available on the Moon
- He-3 accumulates within thermonuclear warheads and is extracted and stored in DOE stockpile, but supply has diminished
- US national stockpile of He-3 is dwindling, perhaps 20 years remaining, due to decommissioning of nuclear warheads
- Critical shortage of He-3 in USA, rationing introduced in 2010

What Is New in Our Approach and Why Do We Think This Will Be Successful?

- Lunar exploration is a new field and no one has extracted and transported He-3 (or any other commodity) from the Moon before
- First commercial commodity play off-Earth – sets precedent for many more commodities to be extracted
- He-3 represents the low hanging fruit of lunar resources extraction – existing robust commercial market is a solid foundation for the business case
- There is a surprising amount of misinformation about availability of He-3 even in NASA

Who Cares? If We are Successful, What Difference Will It Make?

- The current and future end-users will care
- Demand for He-3 would definitely expand if more supplies were available
- He-3 already has multiple commercial industrial uses:
  - Oil/gas well logging
  - Homeland security (neutron detectors)
  - Medical (MRI)
  - Superconductors (CERN)
- This will be a new value stream

Risks

- Mining vehicle technology development risk – unique design
- Market price uncertainty but we believe the demand is strong
- Substitutes for He-3 might become available, but unlikely
- A new terrestrial source of He-3 might emerge, but this is unlikely
- Improving efficiency of He-3 usage – some work emerging in this area

Economics of He-3

- He-3 market today is $192 Million/year, constrained by lack of supply
- He-3 rationing started in 2010:
  - Before 2010: 100,000 L/year @$200/L*
  - After 2010: 14,000 L/year @$2000/L*

*in DOE auction primary market (prices from Russia are much higher)

- The priority of auction of DOE is given to oil and gas industry
- Current DOE auction price:
  - $2K/L
  - $30K/gr
  - $1M/oz
  - $30M/kg (secondary market prices are rumored 5X higher)

How Much Will Lunar He-3 Extraction and Transportation Cost?

- Transport Costs:
  - Astrobotic charges $199.5M for 450 kg payload (Griffin/Viper)
  - Hence Lunar soft landing = $1.33M/kg
  - Sample return payload would be 1/3 => $199.5 M for 150 kg returned => Value = $4.5 Billion on Terrestrial spot market @ $30M/kg
  - Transport Cost to return 150 kg = $199.5MM. Revenues from 150 kg = $4.5B =>
  - **Revenue is 22.6x Transport Cost** (ignoring capital cost of developing miner and return vehicle, and assuming 100% payload fraction)
  - In todays market the transport cost is lost in the noise
- We can clearly return mass to Earth for less than $30M / kg, so this appears achievable and profitable
- Extraction – costs currently uncertain

Business Model -- Financing

- Develop Consortium of anchor tenants from cash rich users: oil/gas and medical imaging
  - Oil and Gas Sector: With lots of cash, biggest users of He-3
    - Schlumberger
    - Exxon Mobil
    - Chevron, etc
  - Medical Imaging: Highly motivated because they do not have access to DOE He-3
    - GE Healthcare
    - Phillips
    - Siemens
    - Fuji Films

How long will it take?

- Currently Estimate 5 years to develop mining vehicle (MV) and return vehicle (RV)
- In parallel – fundraising;
  - Need perhaps $50M to begin develop effort, perhaps $500M to complete development effort (including launch)
  - Funding rate needs to match dev burn rate -- $100M / year
- Once MV and RV are delivered to lunar surface it will take about one year to collect 1kg of He-3 and deliver back to Earth
  - RV can be delivered to Moon a few months after the MV

What are the mid-term and final "exams" to check for success?

- Preliminary Design Review (PDR) - Breadboard Testing
- Critical Design Review (CDR)
  - Fully Analyzed and modelled Design
  - Engineering Model demonstrated/tested
- Qualification Testing (Shake/bake, EM, burst pressure etc.)
- Flight Article Manufacture
- Acceptance Testing
- Integration and Launch
- On-surface lunar operations
- Product sales

Suggested Approach

- Develop an understanding of the capital cost
- Obtain $150K budget for Phase-A study to define capital costs of miner and return vehicle:
- Recovery vehicle:
  - Students in Netherlands built a Fotino LEO re-entry capsule for 2MEU
  - Miner: survey existing studies

Results of $150 K study

Primary Deliverable:

A Solid Fundraising Prospectus to shop around target end users

- Invite end-users to become investors
- Detailed description of budget and use of funds
- Detailed description of return on investment:
  - Financial profit
  - Increased supply of He3 for the investor/end-user
- Description of risk, rewards, timeframes

Thank you!

Questions?

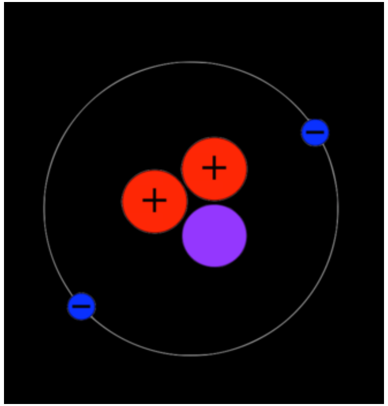
- We propose a simplified miner design compared to Wisconsin Uni, with no excavation required

- Mining process is:
  - Heat regolith to 500 C using microwaves or sunlight
  - Capture gases evolved
  - Compress gases and subject to fractional distillation to separate Helium from other constituents
  - Separate He3 isotope from He4 isotope

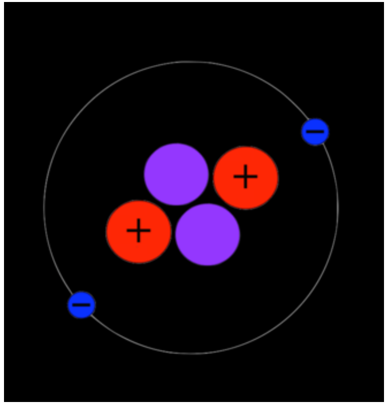
Selected Annual Miner Parameters	
He3 extraction (kg)	1
Mining time (hr): 90% of lunar days	3942
Irradiation depth (m)	0.1 m
Forward miner speed (m/hr)	23
Area irradiated (Km^{2})	0.45
Thermal process power (KW)	186.4
Power use (kWe)	5.3
Mass (kg)	150
Internal pressure (kPa)	15
Gas storage tank pressure (Mpa)	20
Dimensions (LxWxH) (m)	3.37 x 1.34 x 1.19

Helium-3 and Helium-4

- Helium-3 (He-3) is a light, stable isotope of helium with two protons and one neutron.
- He-3 is the only stable isotope of any element with more protons than neutrons.



- Helium-4 (He-4) is a stable isotope of the element helium.
- It is by far the more abundant of the two naturally occurring isotopes of helium, making up about 99% of the helium on Earth.



He-3 Synthesis

- Methods to synthesize He-3 on Earth are very capital intensive and slow to produce
- There is no known process to directly synthesize He-3
- Synthetic He-3 on Earth is entirely the result of Tritium decay, which has half-life of 12.32 years
- Tritium was used in thermo-nuclear warheads but its production on Earth has fallen off a cliff since the end of the cold war

$$^3_1\mathrm{H} \longrightarrow {}^3_2\,\mathrm{He} + e^- + \bar{\nu}_e$$