Lunar Helium-3 Value Chain: Investment and Funding*

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Abstract

Lunar helium-3 is considered one of the potential resources for utilization as fuel source for future earth-based nuclear fusion plants. With a potential start-up of a commercial fusion power plant by the year 2050, the author describes technology and commercial aspects for a lunar helium-3 mining operation that could fuel such a power plant. Barriers for development are inferred to exist largely in the fusion portion of the helium-3 value chain. Commercially a helium-3 operation would have to compete with other energy supply sources that might become available in the future and that could be developed in a stepwise function rather than in an all-encompassing effort. The author suggests that space technology RD&D and fusion research should be pursued separately, and should only form a symbiosis once a common fit due to separately achieved scientific/technical progress justify a joint commitment of financial resources. RD&D costs for these programs will be several hundred billion dollars, which will largely be provided by public investments. The private sector, however, is emerging in space technology and could play a significant role in such a value chain, as outlined in the suggested business model.

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Prepared by: Dieter Beike, PhD

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Vision

50 year budget NASA 1958 – 2008:

$471.53 Bn (nominal US$)

$790.0 US$ Bn (real terms adjusted for inflation)

$170 Bn (2005$) Apollo costs

Vision creates Facts

1865 1944 1957 1961 1969 2050 ?

Start of Mining of helum-3?

Neil Armstrong first human on lunar surface

Yuri Gagarin first human in space April 12, 1961

“Sputnik” October 4, 1957

First ballistic missile “V2” used in WWII reaching sub-orbital altitude

Jules Verne publishes “De la terre a la lune”

“From the Earth to the Moon”

(serialized in the ‘New York Weekly Magazine’ in 1867)

No Vision – But Facts

Year	Statement	Expert
~ 1870	"I have not the smallest molecule of faith in aerial navigation (flight) other than ballooning"	Lord Kelvin
~1880	"Fooling around with alternating currents is just a waste of time. Nobody will use it.	Thomas Edison
~1880	"X-rays are a hoax"	Lord Kelvin
~1930	"The energy produced by the breaking down of atoms is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine."	Ernest Rutherford
1939	"As far as sinking a ship with a bomb is concerned , it just can't be done"	Rear Admiral U.S.N. Clark Woodward
1945	"That is the biggest fool thing we have ever done….. The atomic bomb will never go off, and I speak as an expert in explosives"	Admiral William Leahy, U.S. N. to President Truman

See: "Augustine's Laws", Augustine, N.R. , 1983

Value

Btu Comparison:

Btu value of petroleum: 42,000 btu/kg

Btu value of helium-3 fused with deuterium: 5.6E+11/kg [1]

Btu ratio: 1:13,333,333

US Btu consumption (2007): 101,568 Trillion

Worldwide crude oil reserves: 1258 trillion bbl[2] = 7,422 quadrillion Btu

Mare Tranquillitatis – landing site of Apollo 11 & 17:

Possible helium-3 resources: 2,500 tons (E. Cameron [1]) = 1,400 quadrillion Btu

178,571 kg (~180 tons) of helium-3 fused w/deuterium could provide U.S. annual 2007 Btu volume

2,500 tons could provide the entire US Btu demand for 14 years

Possible total lunar resources of helium-3:

2,469,158 tons [3] = 1,400,000 quadrillion Btu

[1] Schmitt, H.: Return to the Moon, 2006 [2]BP Statistical Review 2009 [3]Slyuta et. al. 2007

Market

100 kg helium-3 fused w/deuterium could fuel
1000 MW power plant for 1 year [1]

Worldwide Nuclear fission power plants

in operation (March 2010):	437
under construction:	55
Total:	492

Mare Tranquillitatis
could fuel this entire fleet for 50 years
w/25,000 containers of 100 kg helium-3

For comparison: if terrestrial gas hydrates would be developed, then
max. 73 MM containers ($40*10^{17}$ scf)[2]
min. 1.6 MM containers ($0.9*10^{17}$)

[1] Schmitt, H.: Return to the Moon, 2006 [2] Koh, C. et. al. "Hydrates" JPT 12/2009

Lunar Helium-3 Project Chain

UPSTREAM – lunar surface
Development / Production / Gathering / Processing of Helium-3 and production of H20 , O2 and propellant (LOX, LH2)

<u>Surface Mining of regolith (per year)[1]</u>

Area: $2km^2$

depth: 3m

= mining & processing 10 MM tons

= 100 kg helium-3

<u>Byproducts:</u>

Extraction of H2O from regolith Plus (via electrolysis)

Production of gaseous H and O (for propellant use)

And breathing purposes

HIGHER RISK MANAGEMENT

MIDSTREAM
Gas Storage,Export, Sales into importing market

SHIPPING
Government (L1 – LEO)
Commercial (LEO - Earth)

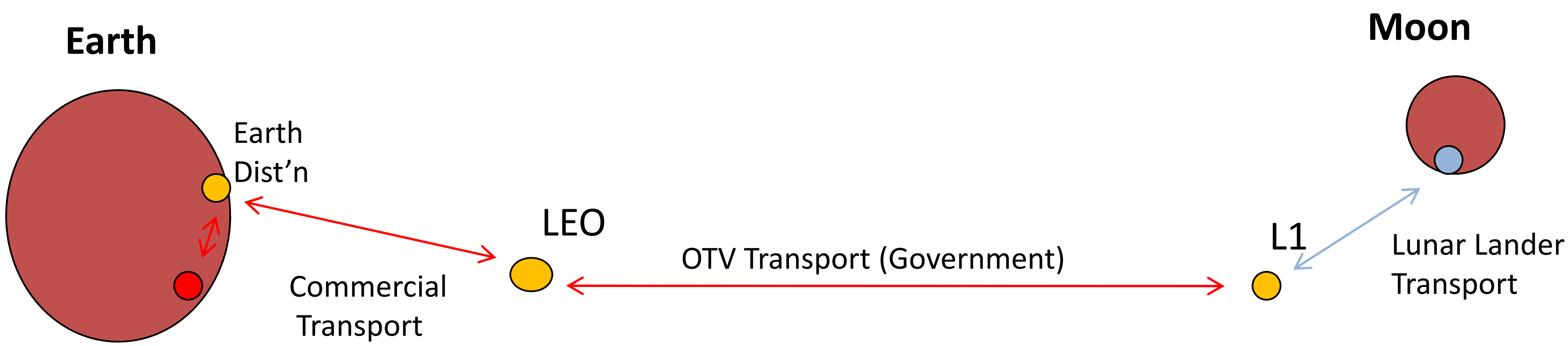
VALUE GROWTH

1000 MW Fusion Power plant

DOWNSTREAM
Fusion Power Plant capacity

[1] Schmitt, H.: Return to the Moon, 2006

Business Concept, Logistics, contracts, risk distribution and netback pricing of Helium-3 value chain



Future Fusion Power Co.

Owns all risk for Transportation from Sendout at L1 through Powerplant;
Pays fee for OTV and Commercial transport;
Sells Helium-3 competitively into power market

SPA

Space Transport & Logistics

Owns all risk at Logistics facilities L1, LEO, earth Distribution;
Sells helium-3 to 'Future Fusion Power Co.' and receives payment based on market value according to 'Sales & Purchasing Agreement'

GSA

Lunar Industrial Park And Helium-3 Mining Co.

Owns all risk to docking Station at L1;
Sells helium-3, propellant, H2O to 'Space Transport & Logistics' and receives Payment based on market value According to 'Gas Sales Agreement'

Investment ($US Bn)

TOTAL	**252.6**	
Space Delivery Infrastructure		**146.6**
Rocket development		
Crew Capsule		
Lunar surface system equipment development		
Lunar lander		
Advanced capabilities technology developments		
Program Integration, Operations, Management		
Reserves		
Lunar Industrial Park		**62.6**
Lunar Outpost		
Regolith mining, processing, refining		
Oxygen, Propellant & helium-3 liquefaction plant		
Transportation & Storage Logistics		**4.4**
L1 Storage & Propellant Production		
LEO Storage & Propellant Production		
OTV		
Power plant		**39.0**
ITER R&DD facility		
DEMO Plant		
Commercial Plant		

Cost Risk

Year	Study	Cost Growth Risk Factor	Value for lunar mining project ($Bn)
2010	Lunar mining study base figure		252.6
2004	Congressional Budget Office Study establishes Cost Growth Risk factor (based on 72 NASA projects)	45%	366.27
2002	Worldwide transportation infrastructure study of 258 projects resulted in 9 of 10 projects had cost overruns between 50 – 100%)	75%	442.05
2009	NASA Cost Symposium (example Apollo project): 1961 NASA estimate: $7 Bn but NASA director Jim Webb submitted a $20 Bn budget – resulting in real costs of $25.4 Bn (1973)	263%	664.34
2009	National Ignition Facility (Lawrence Livermore fusion research facility (1994 original cost estimate: $1.2 bn – real cost 2009: $3.5)	292%	737.59

Schedule & Funding Fusion development

	2010 - 2015	2016 - 2020	2021 – 2025	2026 – 2030	2031 - 2035	2036 – 2040	2041 – 2045	2046 – 2050

Phase 1: Fusion Research Reactor ITER

Reactor Construction — Low / High Duty D-T Ops. Check — 2^{nd} D -T Operations Phase

Materials Testing Facility Construction — Material Testing Phase

Phase 2: Fusion Demonstration Plant

Concept Design — Eng'g. Design — Construction Phase 1, Installation & Testing — Operation Phase 1 — Operation Phase 2

Adv. Material design, construction, testing for "blanket" that surrounds magnetically confined plasma

Phase 3: Comm. Power Plant

Concept Design — Eng. Design

2041 - 2045:

Earliest possibility for commercial funding of Generation IV-type nuclear fusion power plants

Schedule & Funding Space technology development [1]

	2010 - 2015	2016 - 2020	2021 – 2025	2026 – 2030	2031 - 2035	2036 – 2040	2041 – 2045	2046 – 2050

Phase 1: Comm. Crew Transport to Low Earth Orbit (LEO)

Phase 2: Dev. of Space Logistics Enablers

- Propellant storage & Transport, in-space Refueling, in-space re-startable engines
- Heavy Lift Rocket Dev.

Phase 3: Space Operations beyond LEO

- Lunar fly-by, Earth-Moon L1 test, Near Earth Object Visits
- Lunar Landings & Surface system Langrange Points Utilization tests
- Adv. Systems For human habitat

Phase 4:Lunar Mining Tests

2011
Some companies already are being funded for LEO operations

2046:
Earliest possibility for commercial funding for lunar mining

[1] modified after "Flexible Path Method" as suggested in Blue Ribbon report to President Obama October 2009

Complexities for Funding

Technical and scientific challenges

1. Conquering high energy physics
2. Developing a space transportation delivery system
3. Developing robotics for lunar operations

Commercial challenges

1. Cost competitive with alternative investments
2. Deliver on schedule relative to the other components of the value chain
3. Perform on quality, environmental impact and safety standards

Legal Challenges

1. Jurisdiction on the moon
2. Ownership rights

Geopolitical Challenges

1. Global cooperation, views and preferences

Management Challenges

1. Several industry sectors need to be coordinated
2. JV Alignment issues of partners

Financing of project

1. Risk Allocation and neutralization
2. Risk/Rewards relationship

Summary

	2010 - 2015	2016 - 2020	2021 – 2025	2026 – 2030	2031 - 2035	2036 – 2040	2041 – 2045	2046 – 2050

Technology Commercialization

Fusion and space technology should be developed separately

2020 timeframe possible for commercial operations to LEO

If both technologies operationally succeed (individually) then 2036 – 2040 timeframe will tell if symbiosis of both for lunar mining is possible

Private funding for commercial space technology is increasing

Barriers

Complexity of integrated project development requires sophisticated management skillset

High risk of cost overruns and project delays exists

Geopolitical solutions need to be found for conflicting value objectives

Legal regulations required to clarify mineral ownership issues

Funding for large scale commercial fusion power plants limited to public sector