**FUTURE EARTH-MOON TRANSPORT METHODOLOGY WITH REUSABLE SPACECRAFTS USING LUNAR MATERIAL AS ITS FUEL.** Berkay Kars[1,2], [1]California State University Northridge, 18111 Nordhoff St, Northridge, CA 91330 USA, [2]Zarha Design & Visualization LLC, 1500 N. Harbor Blvd. E3 Santa Ana, CA 92703 USA (design@berkaykars.com).

**Introduction:** Current methodologies for transporting payloads to and from the lunar surface has been largely unchanged since the Apollo era. All the necessary propellants, engines and landers are being launched along with the payload which reduces the total payload capacity and limits the range of operations significantly. Also, future possibility of extracting and processing lunar soil into consumable liquid products such as H2O, LOX, LH2 as well as Si, Al and Ca oxides in powder form [1] will eventually enable new markets and technological breakthroughs like orbital refueling capabilities for satellites which will permeate the presence of humans in cislunar space. Producing and using these In-Situ products within the low gravity environment of the Moon offers more sustainable and economical transportation systems for the future colonization efforts.

**Moon as a refueling station:** Although Moon being the closest planetary body to the planet Earth, it is still a challenging and expensive task to send humans and cargo to the surface of the Moon safely. Besides its apparent complexity and risks, main challenge of reaching the moon is the Earth strong gravity, which is also known as the "Gravity Well" (Fig. 1). For Earth, the escape velocity is about 11.2 km/s [2]. For any rocket launched to reach Earth Orbit or any injection trajectories, majority of the fuel is used to produce enough energy escape the Earth's gravitaional pull. In contrast, the Moon's escape velocity is about 2.38 km/s [2] which makes it much easier to navigate around and leave the Moon.

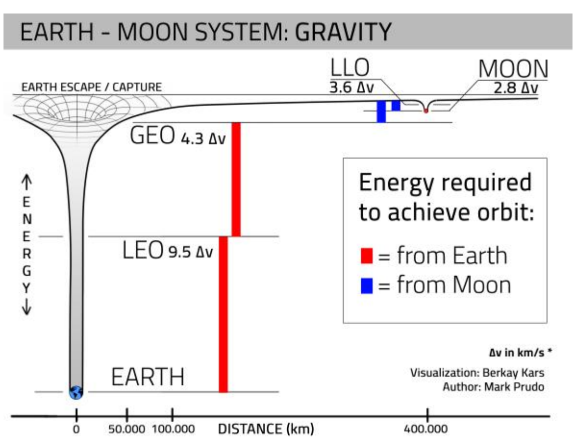



*Fig. 1: Energy requirements to leave Earth vs. Moon*

Recently discovered high quantities of hydrated volatiles in the Permanently Shadow Regions (PSR) of the lunar poles [2] has enabled the possibility of using the lunar ice as a raw material for future operations. Through electrolysis, harvested and sublimed water ice can be further separated into LOX and LH2 to be used in life support systems by astronauts, and more importantly, as rocket fuel for the future lunar landers as well as spacecraft orbiting the Moon or the Earth. Because of its low gravity, these liquids can be carried anywhere within the solar system with relatively low delta-v (Fig. 1, Δv values).

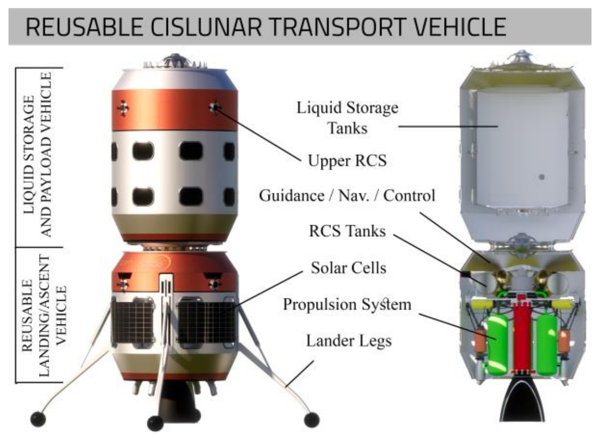



*Fig. 2: Reusable Cislunar Transport Vehicle*

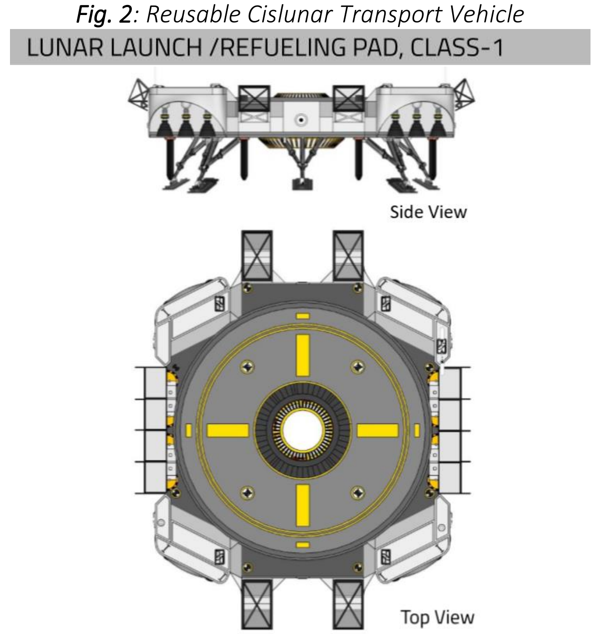
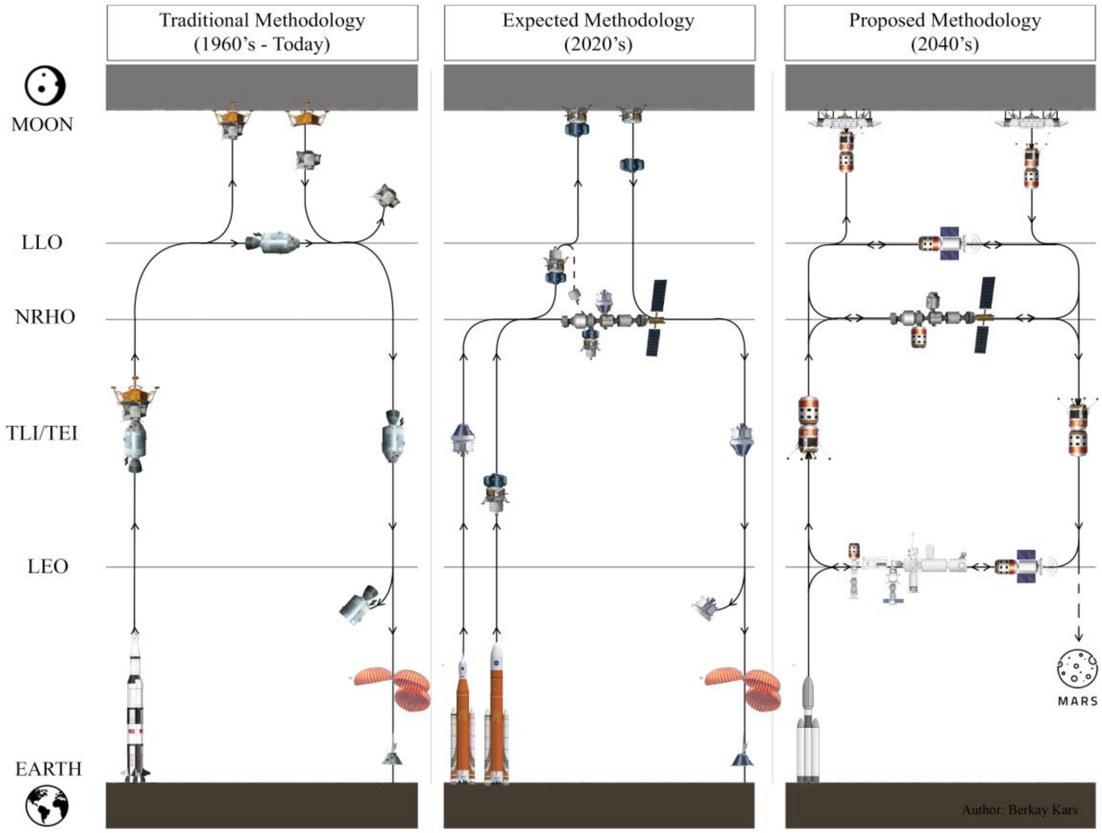



*Fig. 3: Lunar Launch / Refueling Pad, Class-1*

***Fig. 4**: Earth – Moon transportation methodologies comparison*




**Operations Brief:** Instead of the traditional expendable rockets which are currently being used, a reusable spacecraft designed specifically to operate in the vacuum of cislunar space between Earth orbits and the Moon is proposed (fig. 2). Launched from Earth with a heavy launch vehicle, these spacecrafts can navigate between orbits of the Earth and Moon systems multiple times with its integrated hybrid rocket motor. Having an hybrid rocket motor over liquid rocket engine offers more long term use, minimizes the need for propellant pressurization or coolants and reduces the parts/complexity significantly. Besides orbital transportation capabilities, the lander can perform precision landings on the lunar surface to deliver solid/liquid payloads brought from Earth.

Once on the lunar surface, the transport vehicle is refueled with the liquid oxidizers and solid fuel grains through 3D additive printing using processed materials from the lunar soil. In addition, upper payload vehicle (fig. 2) is also filled with additional liquids to be distributed along the cislunar orbits. Fully refueled transport vehicle can now continue its operations through cislunar space to refuel orbiting stations, satellites and deliver payloads to and from the lunar surface repeatedly. Upon the spacecrafts return to LEO, the spacecraft can be refueled again in orbit with liquids launched from Earth, if deemed economically feasible. This would create a closed-loop system where the transport vehicle can conduct constant Earth-Moon transportation operations for extensive amounts of time, until the end of its service.

**Assumptions/Prerequisites:** This transportation methodology will only be feasible if;

- **Economics:** Market for orbital refueling and cislunar payload delivery will grow [3].
- **Robotic refueling in microgravity**: Phase 2 of the Robotic Refueling Mission (RRM) by NASA has been successful and Phase 3 is currently being planned [3].
- **Lunar mining / processing / refueling / launch facilitlies**: Considerable amount of equipment must be put in place on the Lunar surface and/or orbits that would enable the processing and storing the lunar soil into consumable goods. Class-1 type infrastructure (preintegrated) [4] is recommenned when possible (Fig. 3).

**References:** [1] McKay D.S. et al. (1991) The lunar regolith. In Lunar Sourcebook, pp. 285-356. Cambridge University Press, 736 pp. [2] Benaroya H. (2018) REACH – Reviews in Human Space Exploration, pp. 14, DOI: 10.1016/j.reach.2018.08.002. [3] Ricks W. et al. (2006) American Institute of Aeronautics and Astronautics, DOI: 10.2514/6.2006-7026. [4] Thangavelu M. (2014) Space Architecture: The New Frontier for Design Research, pp. 20-29, doi.org/10.1002/ad.1828