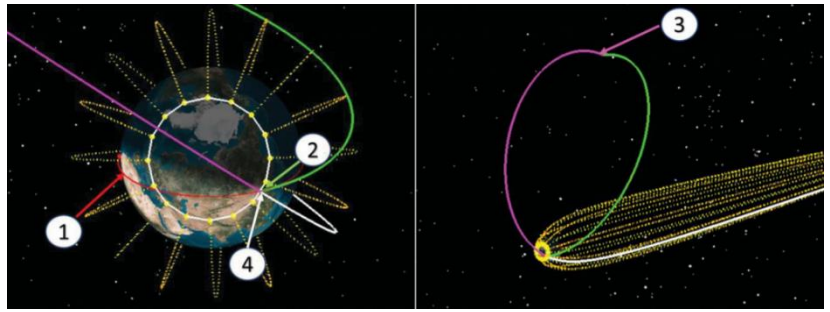
Independent Perspectives on Cislunar Depotization

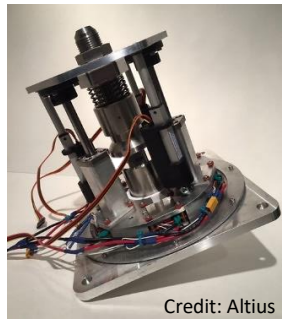
Jonathan Goff
jgoff@gravitics.com
801-362-2310

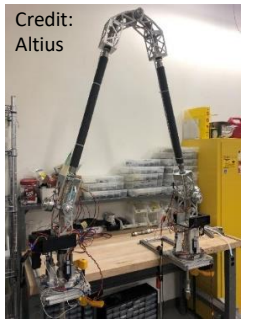
Background and Caveat

- Working on depot related advocacy, technology development, business planning, and policy for over 16yrs
- **Technical Papers:** Started coauthoring technical papers on the topic in 2009, including papers on near-term depot design, the orbital dynamics of using depots for cislunar and interplanetary missions, and the utility of depots for enabling high performance dedicated interplanetary smallsat missions
- **Advocacy/Policy:** Provided feedback to the Obama transition team on the importance of depots for beyond-LEO exploration and supported a member of the Augustine Committee on analyzing depot-enabled beyond-LEO architectures.
- **Depot Technology Development:** At **Altius Space Machines** (former startup), we focused on developing technologies needed for affordable multi-user depots, including low-impact cryo fluid transfer technologies, technologies for long-duration cryogenic upper stages, and depot-enabling RPO and magnetic soft-docking capabilities.
- **Depot Facilityt Development:** At **Gravitics** (current startup) we'relooking at depots as a potential application for our StarMax space station facilities

Caveat: These perspectives are my ***individual perspective***, based on work at multiple companies that are still actively involved in the depot development space, and ***do not necessarily reflect the official opinions of my current (Gravitics) or former (Altius/Voyager) companies***.




Credit: Altius



Credit: Altius

Credit: Gravitics

Depots Throughout Cislunar Space are Key Enabling Infrastructure

- They enable beyond LEO travel to *take advantage of advances in launch costs* to orbit (RLVs, unconventional launch, SEP/NEP space tugs, etc).
- They help *drive down the cost of beyond LEO transportation* and *enable fully-reusable in-space transportation* architectures to evolve over time.
- They can *enable rapid affordable dedicated delivery of small and medium spacecraft* to beyond LEO destinations including cislunar and interplanetary.
- They can *provide additional launch demand for valuable launch capabilities* including RLVs and dedicated Smallsat launchers.
- They can *enable **much** more ambitious missions* than would be possible without using depots, both by enabling launchers to participate in bigger missions than they could easily support otherwise with *less complexity or risk than multi-launch docked modular missions*, enabling much *higher delta-V missions*, and enabling *fully-reusable in-space transportation* architectures (including fully reusable landers).
- When coupled with advanced technologies like propellantless lunar launch (e.g. sling tethers or mass drivers), and aerobraking/aerocapture, *can unlock the potential of lunar ISRU* to further drive down the cost of transportation in the Cislunar system
- *Simplify international cooperation* on beyond-LEO space projects and missions

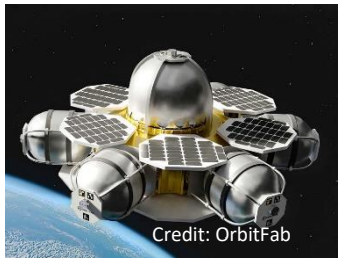
Depot Value and Utility

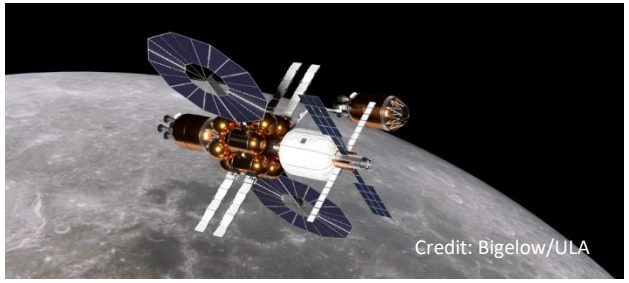
I like to think of value and utility in terms of this quote (my emphasis added):

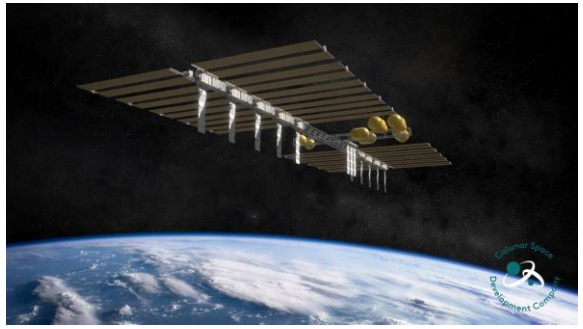
"If we are serious about this, then our objective must be more than a disconnected series of missions, each conducted at huge expense and risk, and none *building a lasting infrastructure to reduce the expense and risk of future operations*. If we are serious, we will build capability, not just on the ground but in space. And *our objective must be to make the use of space for human purposes a routine function*." – *John Marburger, 2008 Goddard Symposium*

Depots are useful and valuable precisely because they help *lower the expense and risk of future missions*, and help *make the use of cislunar space for human purposes a more routine function*.

Four Most Valuable Near/Medium-term Cislunar Depot Locations/Types



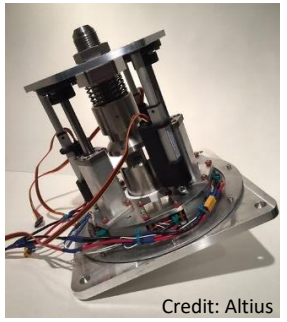


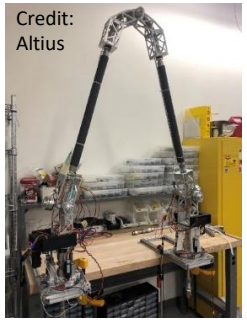


- GEO Satellite refueling depot
  - Storable prop for refueling satellites in the GEO belt
  - Lowest hanging fruit technologically and commercially
- LEO Multi-user depots
  - Critical for rapid, affordable beyond LEO smallsat missions for DoD (tactically responsive space), NASA (interplanetary smallsats), and commercial users (MEO constellations, small GEO, and GEO ISAM payloads)
  - Enables lower-cost reusable tankers for lunar-vicinity depots
  - Enables affordable, reusable, beyond-LEO human transportation
- Lunar High-Orbit lander refueling depots
  - Due to Artemis/Gateway architecture, an NRHO depot is probably the right initial place for supporting reusable lunar lander missions
- Lunar Low-Orbit lander/ISRU aggregation depots (longer-term)
  - Could initially be temporary tankers in LLO operating out of the NRHO depot
  - Enhance payload capacity of reusable lunar landers and can provide enhanced abort options if necessary
  - More optimal refueling location for reusable lunar landers
  - May provide transit point for future fully-reusable cis-lunar human transportation
  - Can support future Lunar ISRU operations, including supporting “catcher” tugs for lunar propellantless launch systems

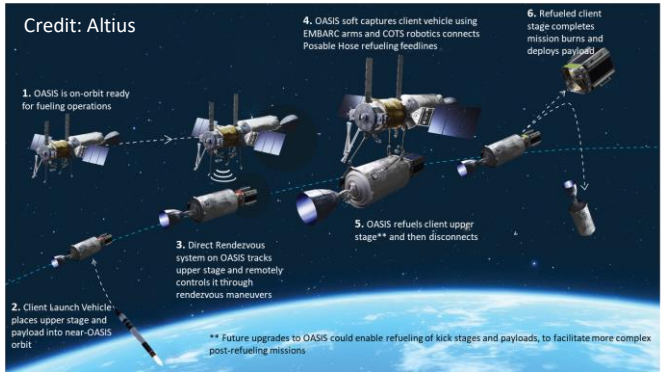
Desired Depot Technical Advances

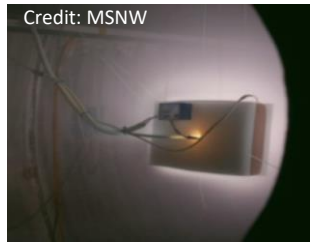
- Many depot-needed technologies currently being funded under NASA Tipping Point demonstrations
  - Cryogenic fluid management/mass gauging
  - Insulation/cooling for low/zero-boiloff operations
- Other technologies still need further development
- Low-Impact Standardized Multi-User Cryogenic Transfer
  - My former startup Altius has been developing a technology to reuse pre-existing T-0 umbilicals with light modifications as refueling ports for in-space refueling
  - Could still use some standardization – may be possible to make some standards (like gas nozzle and fueling funnel standards) that leave some design details flexible while enabling intercompatibility
- Tugless Low-Impact Direct Rendezvous
  - Altius has also been developing robotics and RPO tech that can enable depots or other facilities to detect and guide a lightly-modified upper stage through maneuvers that bring it close enough for magnetic, boom-assisted capture and soft-dock
- Longer-term depot-complementing technologies
  - Lunar ISRU
  - Lunar propellantless launch (e.g. sling tethers, mass drivers, railguns, etc.)
  - Magnetoshell Aerocapture (for lowering the return-trip dV of reusable cislunar vehicles)


Credit: Altius


Credit: Altius

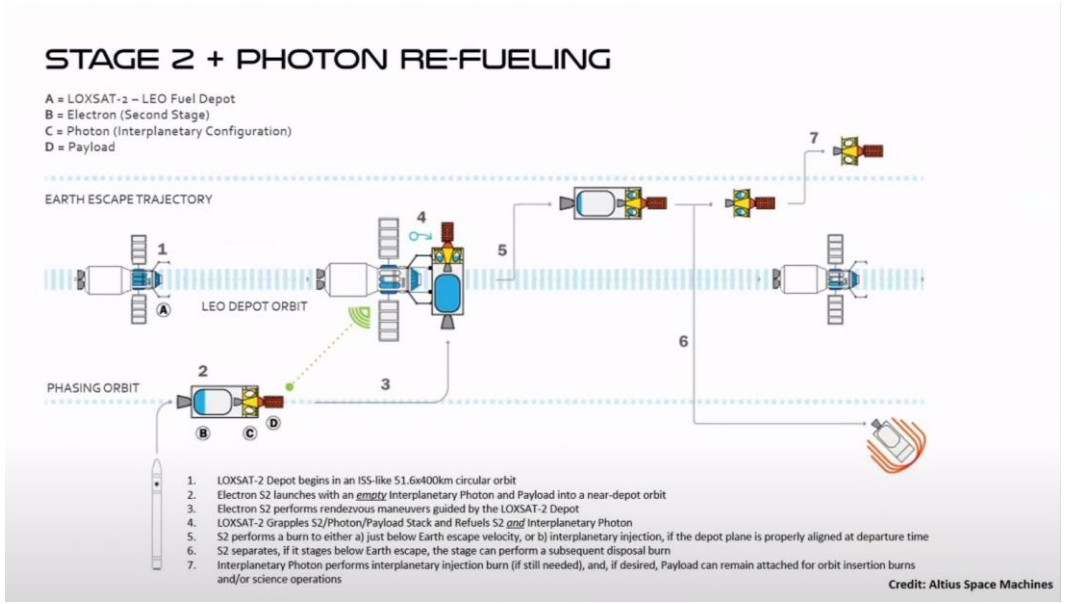
Credit: Altius

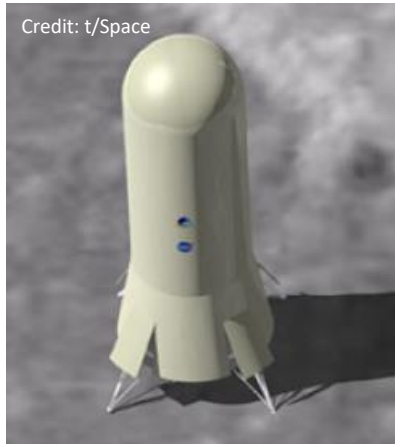



Credit: MSNW

Desired Depot-Enabled Application Advances

- LEO refueling of smallsat launcher upper stages/kick stages for rapid, beyond LEO dedicated smallsat launch
- Reusable lunar landers
- Reusable Cislunar human transports





Credit: ULA

Greatest Challenges

- Financial
  - Raising the money for large capital projects
  - Driven by market risks – people aren't using depots yet, so can we convince funders that there is enough demand?
- Technology
  - Many depot-technologies need to be flight demonstrated
  - Some technology pieces for affordable multi-user depots are also missing:
    - Affordable depot arrival/departure RPO and robotics
    - Standardized cryogenic propellant transfer solutions
- Political Opposition
  - Historically most opposition was coming from supporters of shuttle-derived HLVs
  - Opposition seems to be decreasing both due to SLS finally nearing first flight, and the budgetary impracticality of doing Artemis missions without commercial launch and depots for the landers
  - DoD and NASA non-human spaceflight applications are also becoming more open to depots in a world of increasingly capable beyond-LEO smallsat missions