Reliable Regolith Handling: A Modular, Low-Power Conveying System for Handling Abrasive Materials in Space and Lunar Environments

Süleyman SALİHLER
ssalihler@polimak.com

LSIC ISRU Focus Group Monthly Meeting
June 21, 2023

About

Who
Polimak is an engineering and fabrication company that specializes in bulk solids handling technologies for various industries.

What
Main product lines are bulk solid conveying, storage, loading, discharging dosing, dust collection systems.

How
- Designing and engineering bulk material handling systems.
- Manufacturing systems and components.
- Developing software for industrial automation systems in the bulk solids handling industry.

With
Over 100 employees

Where
Turkey, USA, Germany, England, Scotland

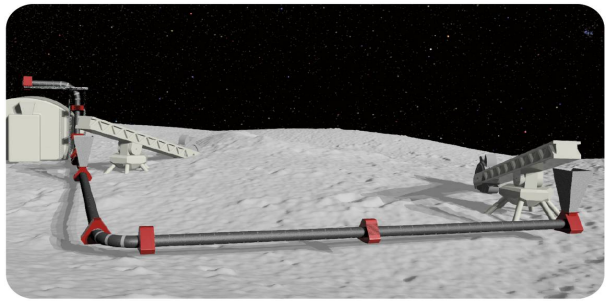
Terrestial: polimak.com **Celestial:** polimak.space

Our Aim In Space Tech

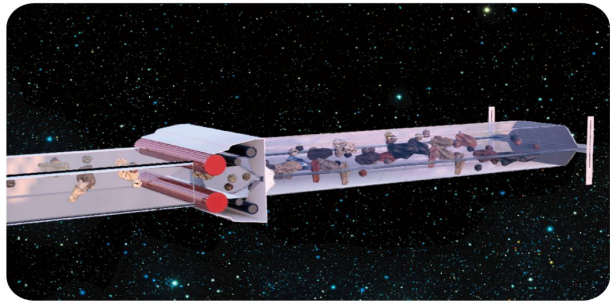
Utilizing our extensive terrestrial expertise in processing, conveying, and storing bulk solids, we aim to contribute to space tech, enhancing resource extraction from celestial bodies.

Key technologies for Lunar, Martian, asteroid, and zero-gravity environments:

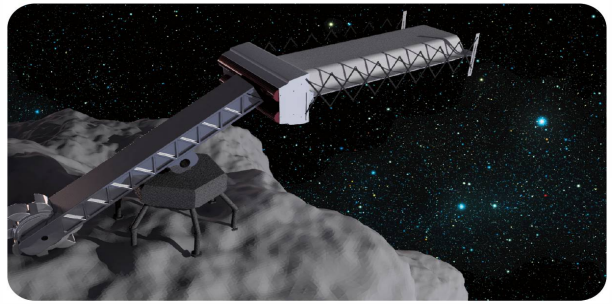
Interconnected conveying systems for extraction, processing, and transport units.



Advanced storage and transportation systems for space resources.

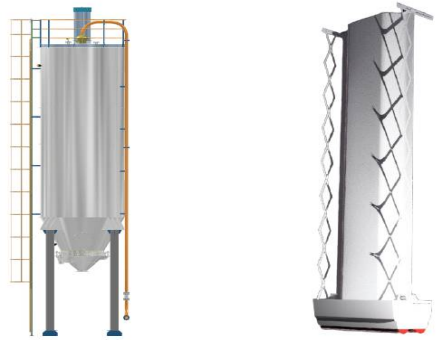


Systems enhancing logistics for more efficient space operations.



HOW TO TRANSPORT REGOLITH ON MOON?

HOW TO FILL A SILO ON SPACE?



EARTH VS SPACE

Challenges in Regolith Handling and Logistics

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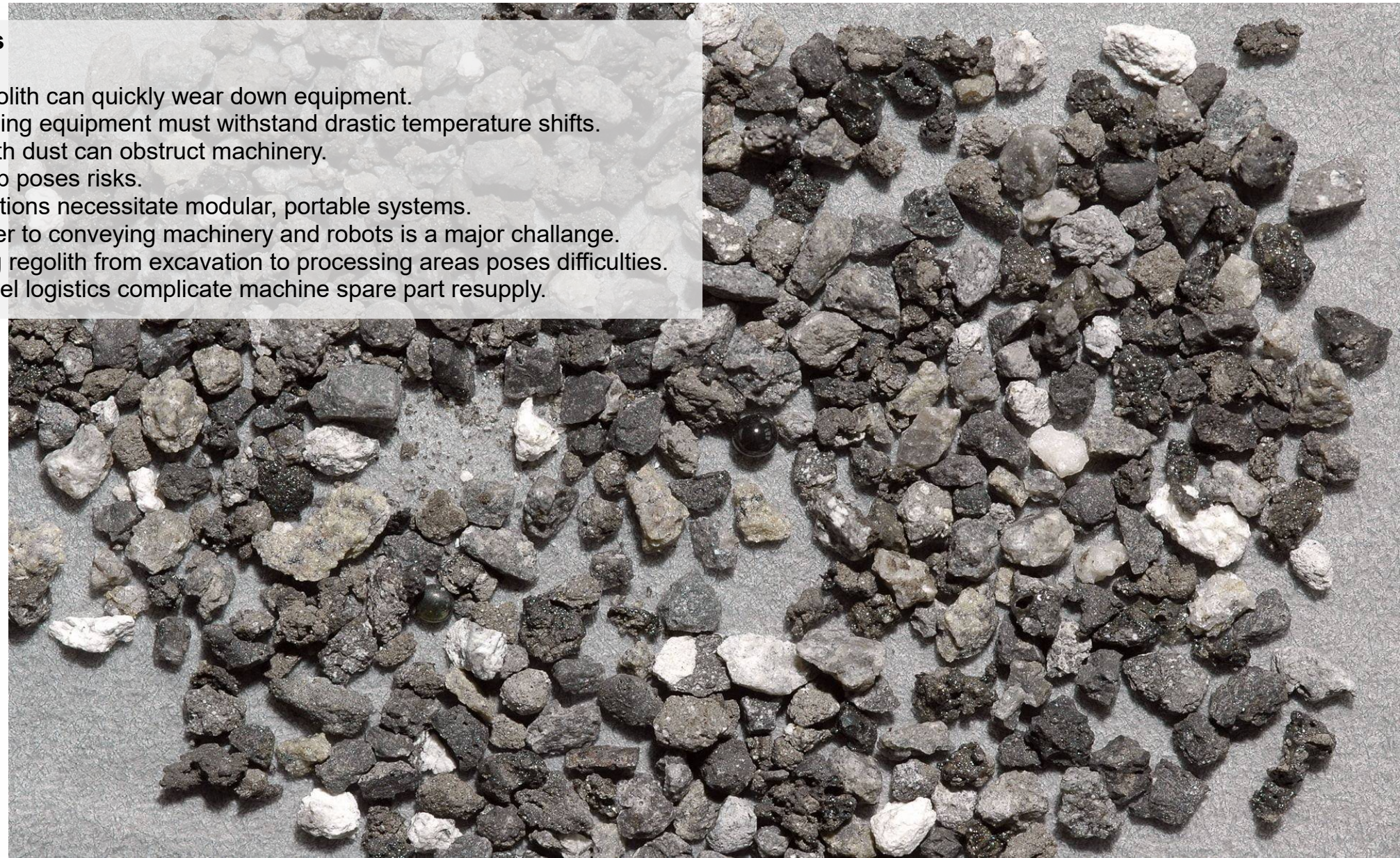
Regolith Handling Challenges

Abrasive Nature: Abrasive regolith can quickly wear down equipment.
Temperature Extremes: Handling equipment must withstand drastic temperature shifts.
Dust Emission: Sticking regolith dust can obstruct machinery.
Static Electricity: Static buildup poses risks.
Site Changes: Frequent relocations necessitate modular, portable systems.
Power Supply: Supplying power to conveying machinery and robots is a major challange.
Conveying Routes: Conveying regolith from excavation to processing areas poses difficulties.
Spare Part Supply: Space travel logistics complicate machine spare part resupply.



Common Conveying Systems for Regolith Transport

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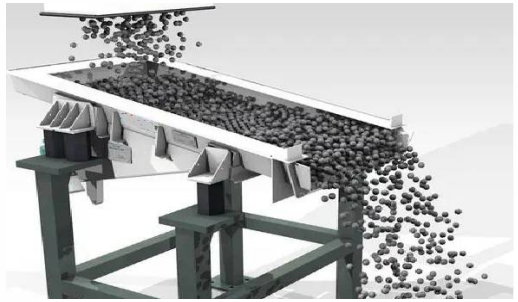
Auger/Screw Conveyor

Belt Conveyor

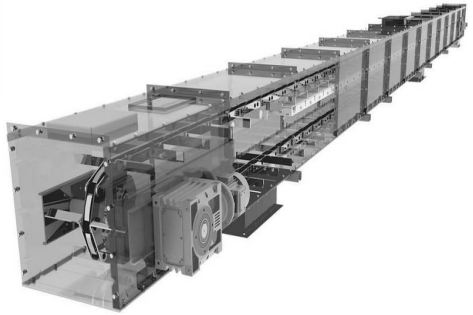
Pipe Conveyor

Vibrating Feeder



Bucket Elevator

Chain Conveyor



Pneumatic Transport

Utilizing Robotic Rovers for Regolith Transportation

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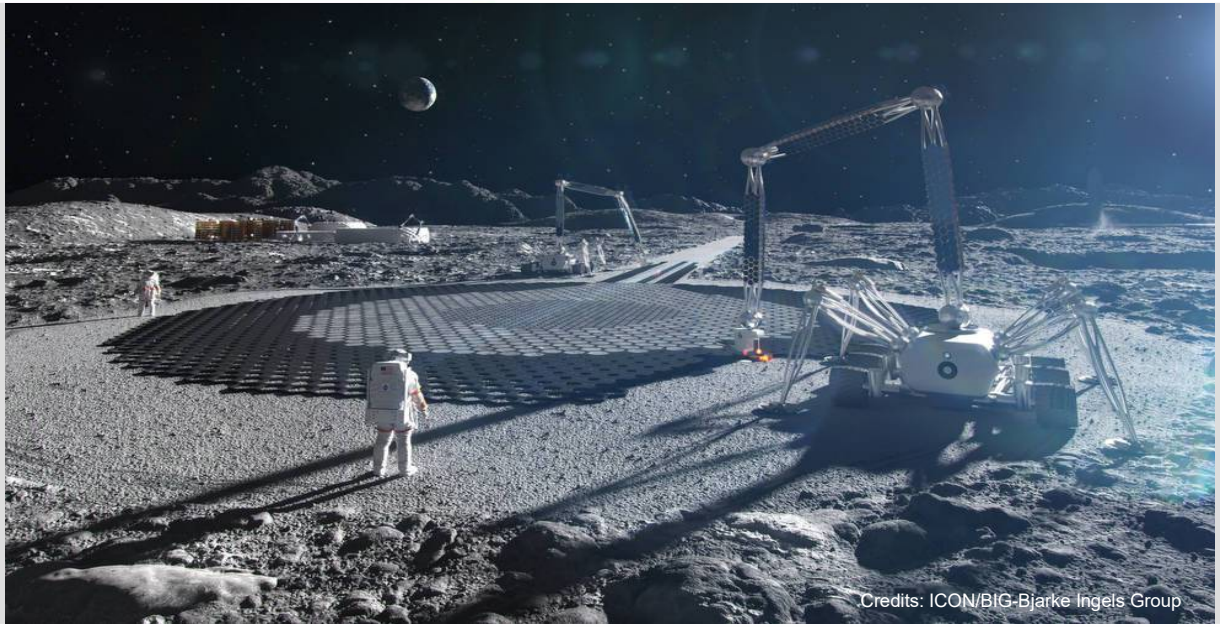
Advantages of Robotic Rovers

Autonomous Operation
Precise navigation in difficult terrains
Deploying multiple rovers can enhance operational scale.
Flexible navigation paths for relocation of excavation sites

Disadvantages of Robotic Rovers

Limited speed limits efficiency in transportation tasks.
Open top body could cause dust spreading during transport
Reliability issues due to harsh environments
Maintenance challenges
For large-scale operations, more rovers or trips are needed.

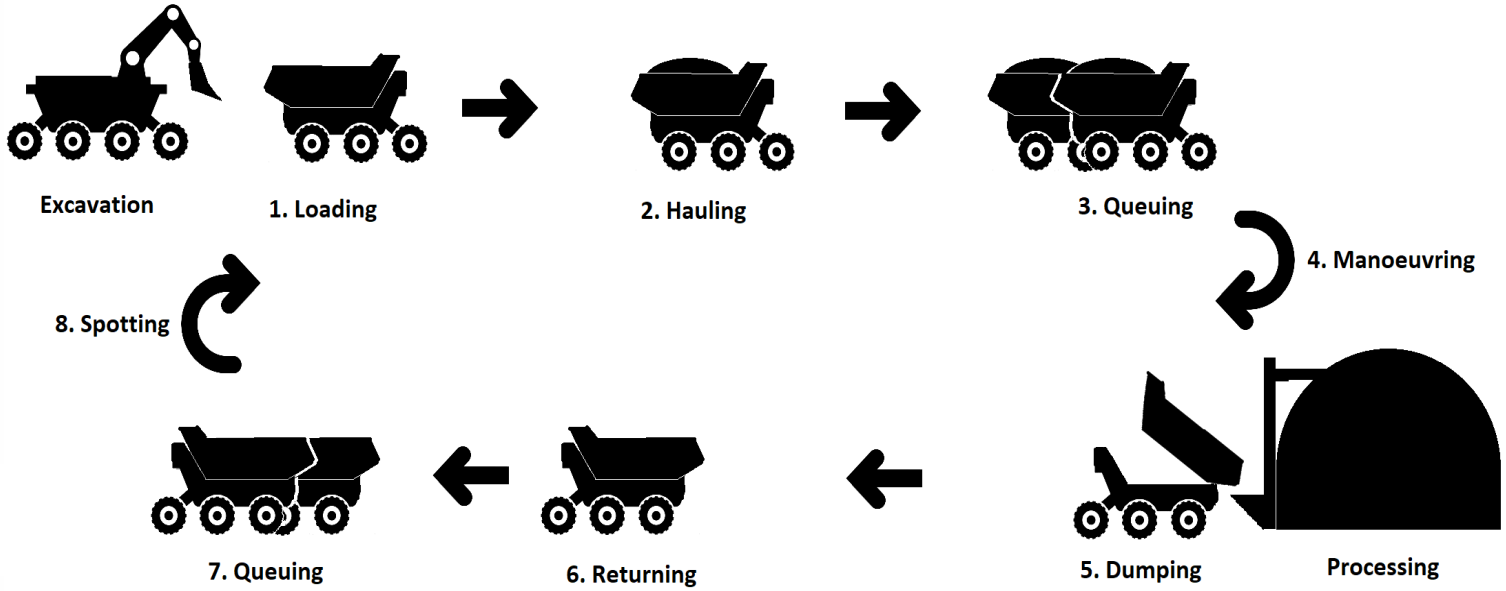


Robotic Rover Economics

Time Consumption
50%: Empty, traveling back from the processing area to the excavation site for reloading.
5-10%: Loading and unloading activities
5-30% : Charging or battery replacement
20-40%: Payload transport

Energy Consumption
75% : For moving robotic rover itself
25% : For moving payload

* values are estimated



Modular Drum Conveyor

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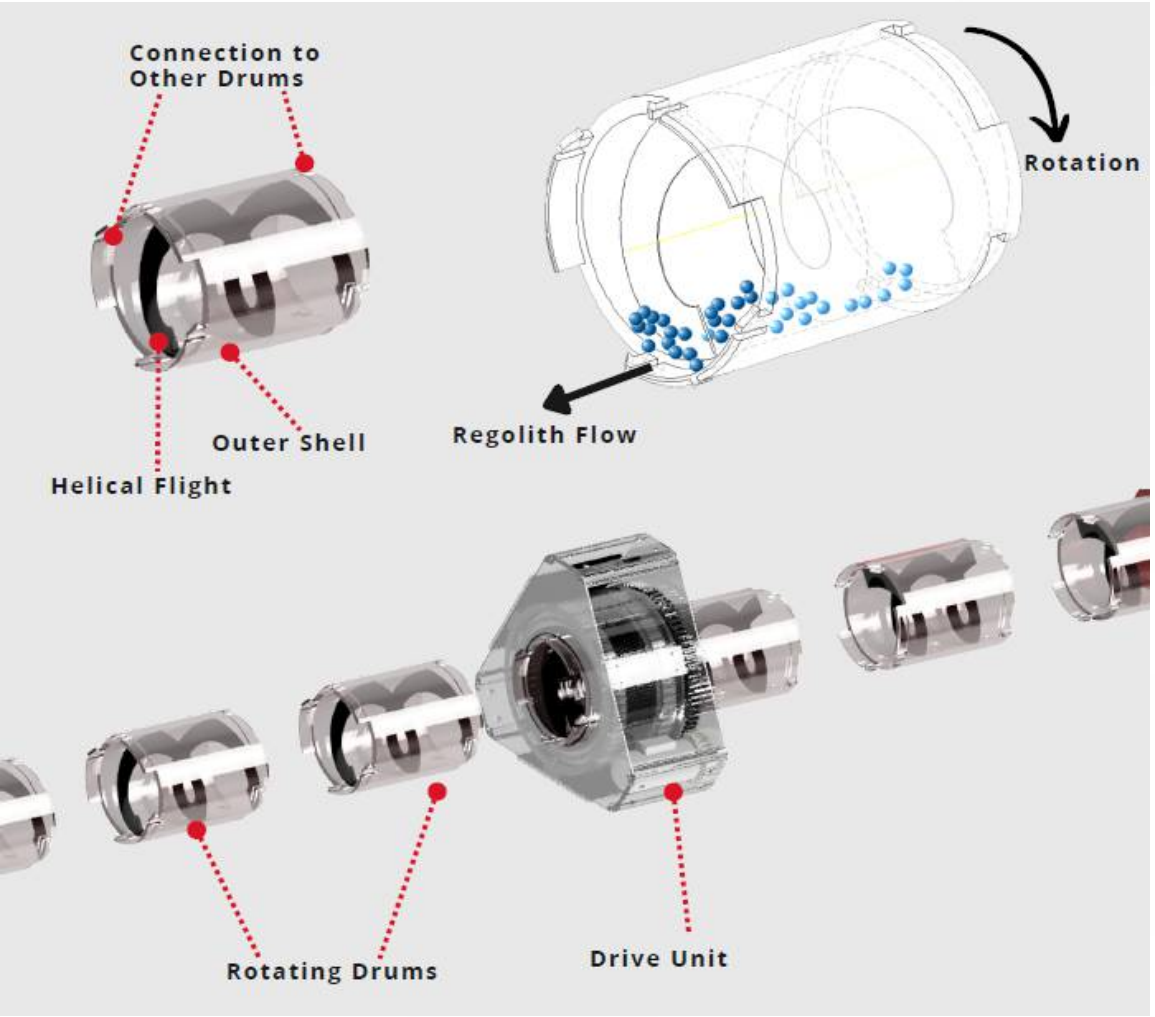
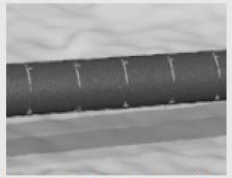
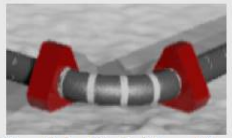
The conveyor system uses connectable, rotating drums with inner helical flights to transport bulk materials along a flexible path while they rotate.

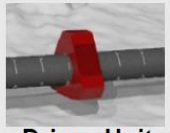
PATENT PENDING

With its modular, building blocks like design, the conveying system is easily adaptable to process needs, making it perfect for wide range of regolith conveying applications.

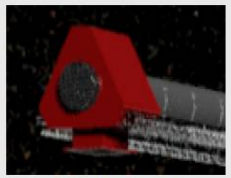



Linear Rotating Drum


Flexible Rotating Drum


Drive Unit

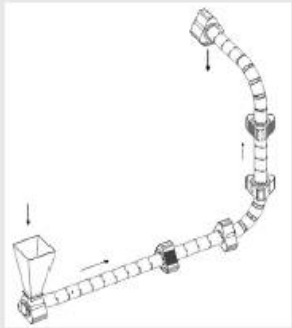

Inlet Unit

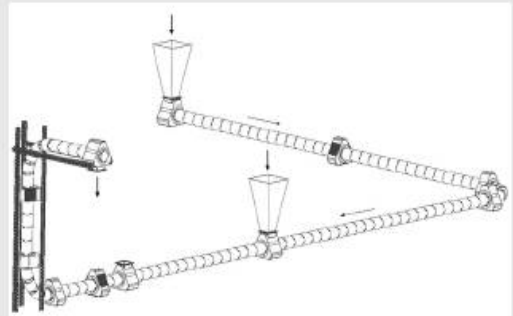

Outlet Unit

SMART ASSEMBLY

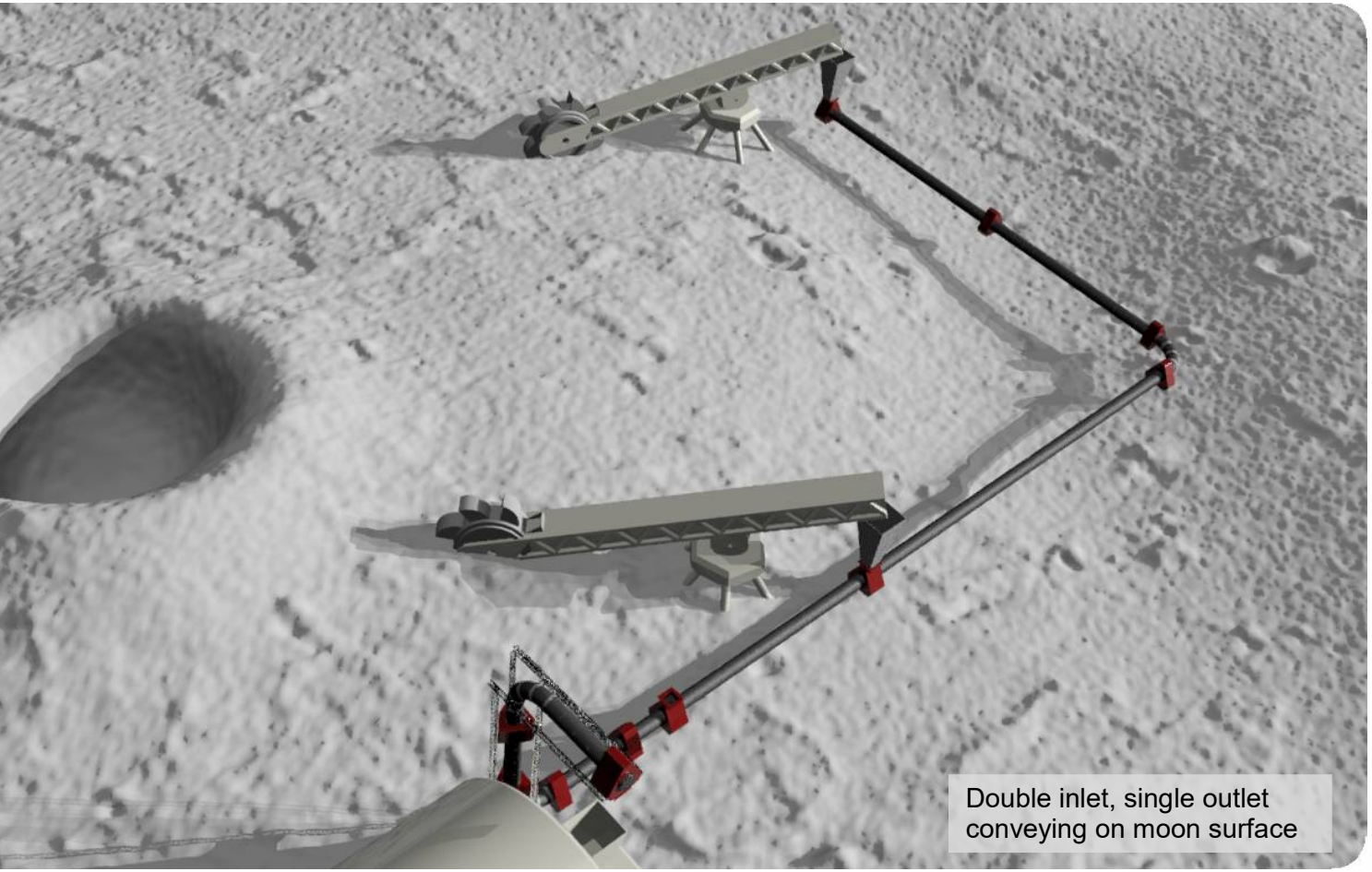
INFINITE CONFIGURATIONS


Inclined conveying
1 inlet, 1 outlet

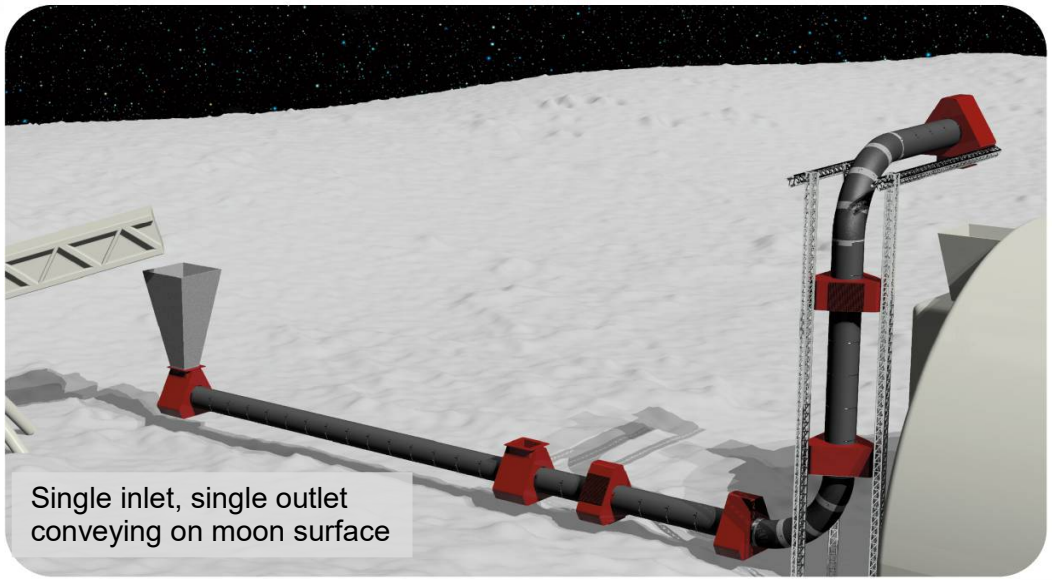

Horizontal & vertical conveying
1 inlet, 1 outlet


Horizontal conveying with bend, vertical conveying
2 inlets, 1 outlet

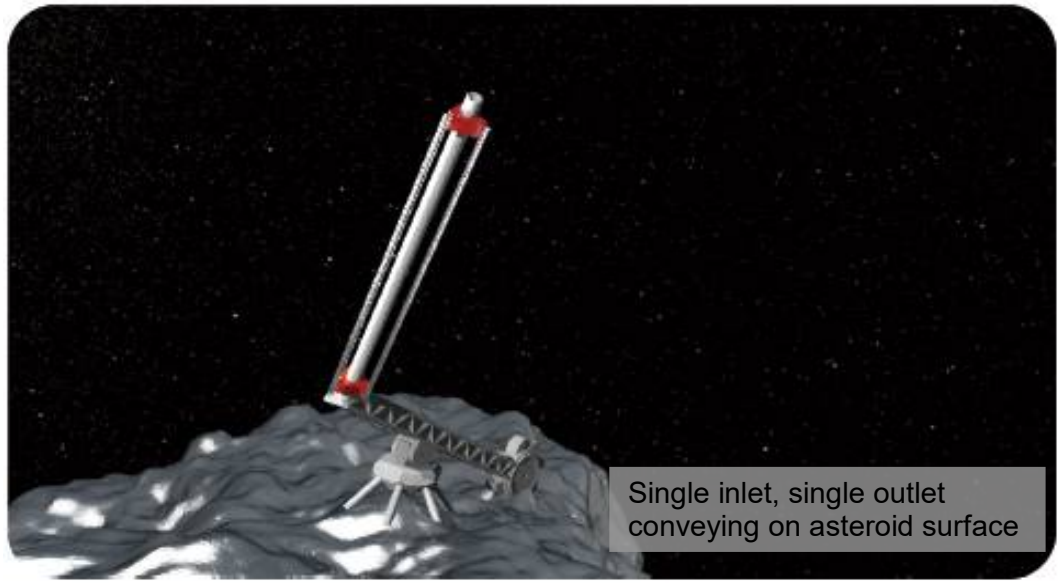
Modular Drum Conveyor



Double inlet, single outlet conveying on moon surface



Single inlet, single outlet conveying on moon surface



Single inlet, single outlet conveying on asteroid surface

KEY FEATURES

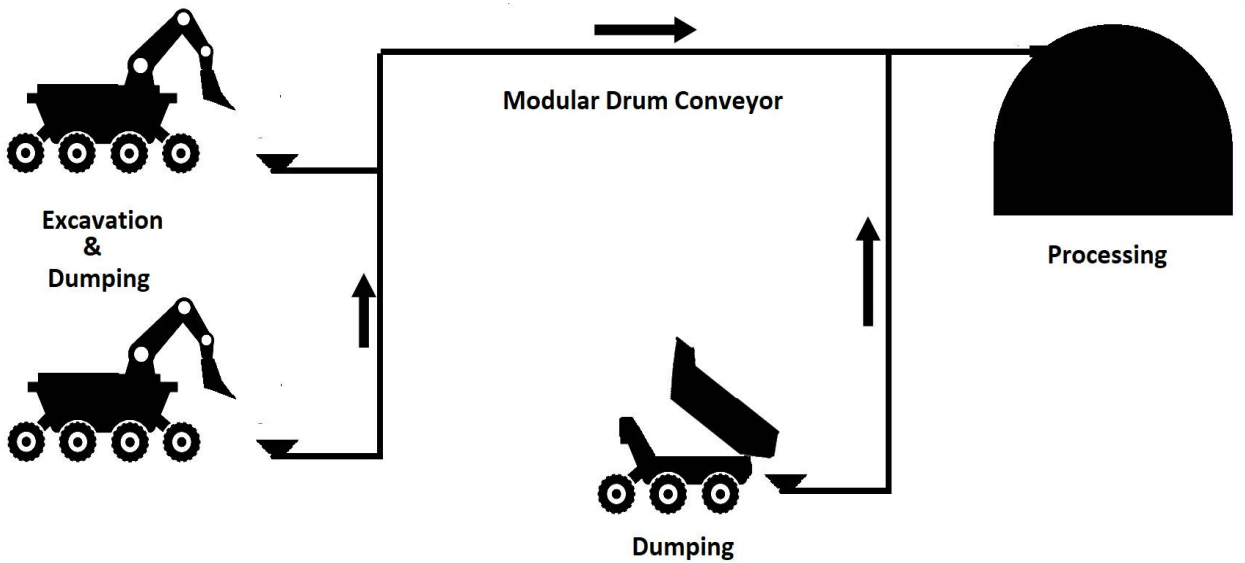
- Modular design allows limitless configurations and simple assembly.
- 50% of the parts can be made from extraterrestrial materials.
- Reduces abrasion via rolling regolith particles instead of sliding.
- Fully-contained system prevents dust emission and component contact.
- Suitable for low or zero gravity.

Comparison With Other Systems

Challenge	Modular Drum Conveyor	Auger	Robot Trucks	Belt Conveyor	Pipe Conveyor	Vibrating Feeder	Bucket Elevator	Chain Conveyor	Pneumatic Transport
Low Gravity	●●●	●●●	●●●	●●○	●●●	●●○	●●○	●●●	●●●
Zero Gravity	●●●	●●●	○○○	○○○	●○○	○○○	○○○	○○○	●●●
Vertical Conveying	●●●	●●●	○○○	○○○	○○○	●●●	●●●	●○○	●●●
Changing Route Direction	●●●	●●○	●●●	●●○	●●●	●●○	○○○	●○○	●●●
Vacuum Environment	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●○○*
Extreme Temperatures	●●○	●●○	●●○	●○○	●○○	●●○	●●○	●●○	●●○
Abrasion	●●●	○○○	●●●	●●○	●●○	●○○	●○○	○○○	○○○
Efficiency (kW/kg)	●●○	○○○	●○○	●○○	●○○	●●○	●○○	○○○	○○○
Launch Weight Limitations	●●○	●●○	●●○	○○○	○○○	●●○	○○○	○○○	●●○
Dust Containment	●●●	●●●	●○○	○○○	●●●	●●○	●○○	●●○	●●●
Static Electricity	●●○	●●○	●●○	○○○	○○○	●●○	●●○	●○○	●○○
Reliability	●●●	●○○	●●●	●○○	●○○	●●●	●○○	○○○	●●●
Reconfiguration for New Routes	●●●	●○○	●●●	●○○	○○○	●○○	○○○	○○○	●●○
InSitu Production of Parts	●●○	●○○	○○○	○○○	○○○	○○○	○○○	○○○	●○○
Multiple Inlets/Outlets	●●●	●●○	●●●	●○○	○○○	●○○	○○○	●○○	●●○

Improving Operational Efficiency

Modular drum conveyors are suitable for short to long distance conveying and gathering from multiple extraction sites, while robotic rovers excel at short-distance transportation. Integrating both systems presents an optimum mix of efficiency and flexibility.



*Closed-loop pneumatic conveying systems can operate in a vacuum environment.
PS: Table compares conveying systems for regolith handling. It gives a general overview and does not account for all possible technologies and variations. The suitability of each method may change with new developments.

Current & Future Work

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Current Work

- Technical designs of key components were completed.
- Patent application completed.
- Small scale prototypes produced.
- Preliminary tests were done.
- TRL 5 for terrestial applications is reached.
- Terrestial commercialization efforts started.
- Started preparing full scale prototype for field tests.

Future Work for Terrestial Applications

- Full scale prototype tests (within 2 months).
- Configuration management studies for different bulk materials, capacities and conveying routes (within 8 months).
- Design improvements (within 8 months).
- Real life testing in operational environments (within 8 months).
- Technical documentation and certification (within 12 months).
- Reaching TRL9 (within 12 months).

Future Work for Celestial Applications

- Procurement of space grade motor & gearbox (within 4 months).
- Testing with regolith simulants (within 8 months).
- Primary design improvements (within 12 months).
- Collaboration with space agencies, companies and institutes (within 12 months).
- 3D printing of parts with molten regolith (? depends on availability).
- Zero gravity testing (?).
- Testing on moon (?).
- Secondary design improvements after tests (?).

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Thank You

Questions ?

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Thank You

Questions ?

Lunar Surface Innovation
CONSORTIUM

What You Need to Know About Lunar Communications

June 2023

Sarah Withee and Danielle Mortensen
Extreme Access Focus Group
JHU Applied Physics Laboratory

Sarah.Withee@jhuapl.edu Danielle.Mortensen@jhuapl.edu

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Terrestrial vs Lunar Comms
Availability, Accessibility, and Duration

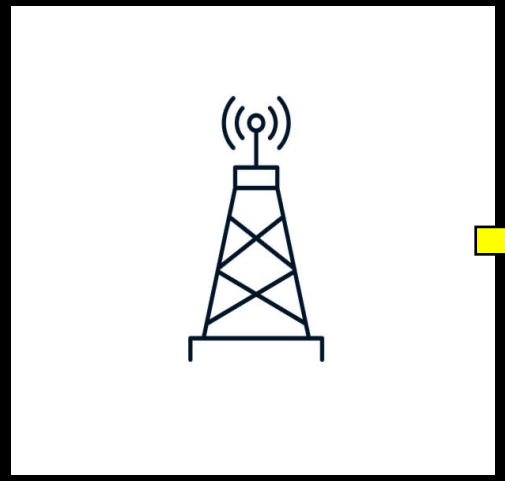
Terrestrial

Call anyone with a phone number, anywhere, at any time without reservations or blackouts and talk for however long you wish

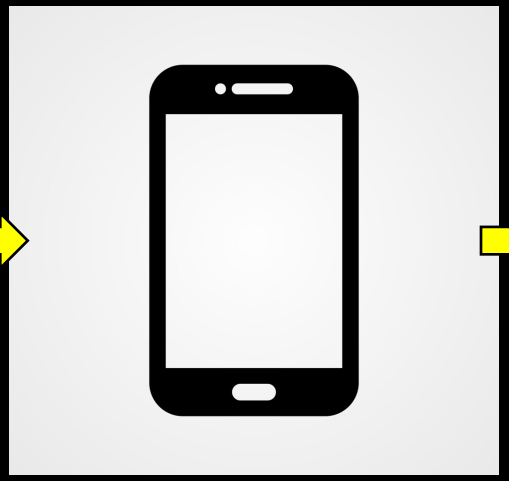
Lunar

Set up contact schedule with your provider, most likely for limited duration communications (minutes to hours at a time). At present, you can only contact your service provider. There is no network to connect you to other users.

Terrestrial Comms: Our Day-to-Day



Choose a cellphone provider

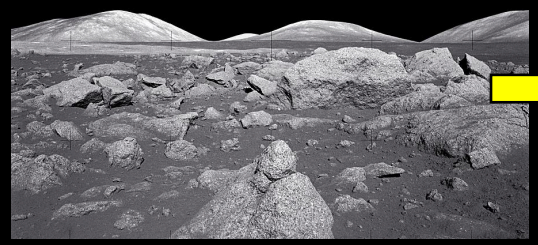


Choose pre-built hardware (iPhone, Android, etc) that works with the network

Sign contract with provider and pay fees

Call anyone with a phone number, anywhere, at any time without reservations or blackouts, even if they have a different service provider. Pay a flat rate for voice comms and a certain amount of data.

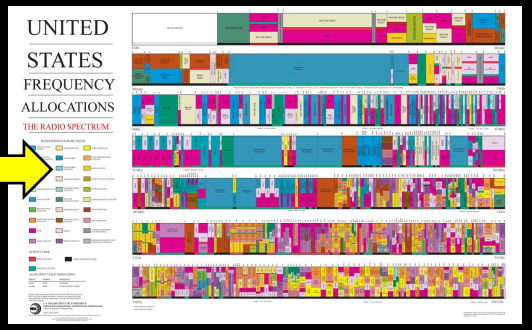
Lunar Comms: Current Process



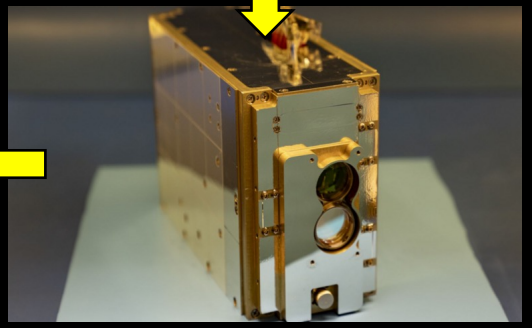
Analyze radio propagation characteristics and communications availability of your operating location

Select a ground station service provider

Select hardware: Radio, Antenna, Amplifier

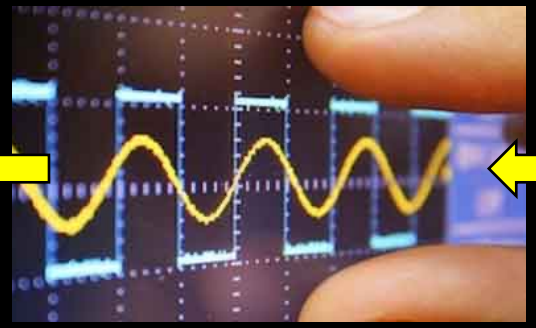


Develop link budget & Apply to spectrum licensing for transmit (1-2 yrs min.)



Integrate hardware

Sign contract with provider and pay fees



RF compatibility testing with your service provider

Launch & communicate with your provider during scheduled time periods (no 24/7 comms)

Blackouts of Comms Services at Various Locations on the Moon

South Pole Direct to Earth (DTE)

8-14 day comms blackouts depending on location at the Pole

South Pole relay

ESA Lunar Pathfinder best case 10 hours on 2 hours off for South Pole (starting in 2026)

Parsec
No blackouts as long as you have a view of the sky (starting in 2025, according to LSIC comms subgroup presentation 5-17-2023)

Far Side – no DTE, relay only

Availability and duration of relay services will depend on provider

In all locations, local topography will also affect comms availability

Factors Limiting Availability of Lunar Comms

Direct to Earth (DTE) Comms

- Location on the Moon
  - Do you have a view of Earth?
  - Does lunar topography permit communication (i.e. no mountain blocking your signal)?
- Is your Earth ground station in view?
  - Just because you can see the Earth doesn't mean you can see your ground station
- Is it your allotted time to communicate with your provider?
  - Ground station service providers generally utilize a time-division model for comms
- Radio frequency interference
  - We've seen this already at Mars, and that was with only ~13 missions operating

Relay Comms

- Are there relays that service your location on the Moon?
  - Initial services are focused on South Pole
- Is the relay satellite in view?
- Relay services will provide comms to multiple clients
  - This may limit time available to any one client for comms
- Radio frequency interference
  - We've seen this already at Mars, and that was with only ~13 missions operating

At present there is no "roaming" from one provider to another. This may change, but for now, your mission can only communicate with your comms provider and no one else.

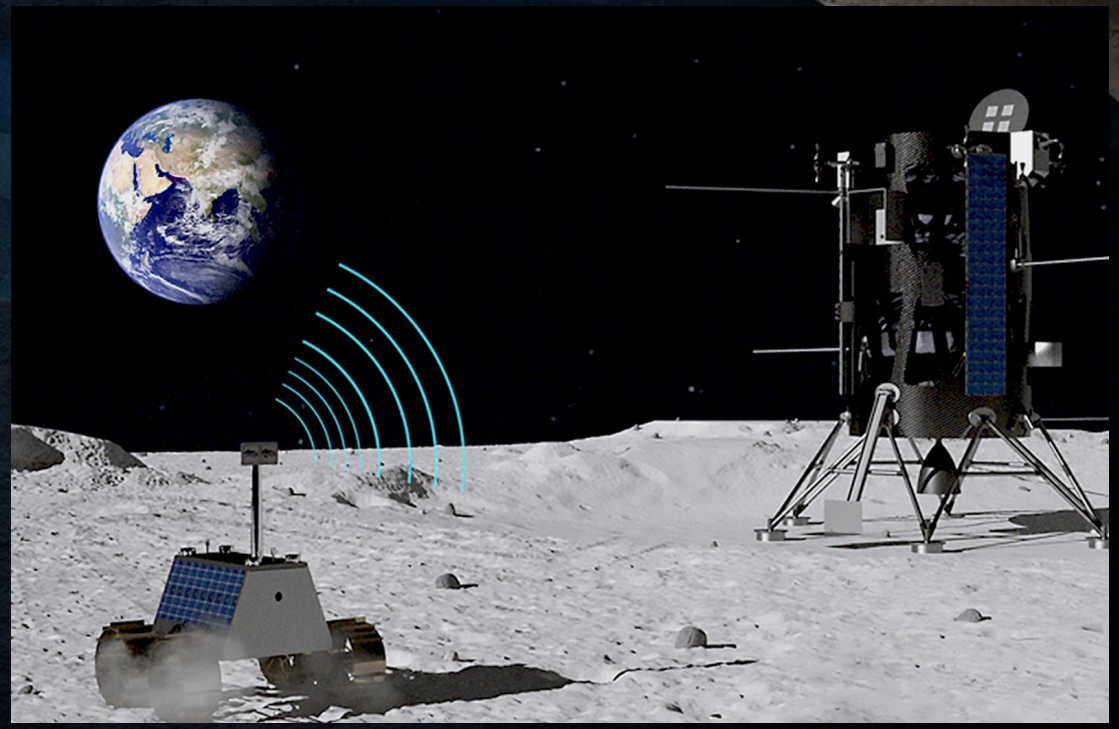
Delays

Delays will be part of the system, so plan for them!
Includes light time delays and travel time from ground stations to mission ops centers.

Earth-to-Moon
~2.6 seconds round trip light time

Surface-to-Surface Comms

- Currently limited to line of sight (~2 km or less depending on topography)
  - Due to lack of atmosphere for bouncing signal
- Network infrastructure is in very early stages of development
  - Tech demo from Nokia of LTE/4G tech happening in sometime in 2023
    - Mission will gather data needed on RF propagation and regolith properties to help validate models used to design cell networks



Implications for Mission Planning and CONOPS

- DTE comms blackout and lunar night do NOT always occur at the same time
  - If you are using DTE and you are solar powered/need light to operate, you may not be able to communicate during light periods
- Delays of 2.6 seconds are substantial for teleoperation
  - Delays of greater that 0.4 to 0.5 seconds significantly degrade the performance of human operators
  - Need to account for the performance hit due to time delay
- Rover missions will have different (and more complicated) comms issues than stationary installations
- Comms availability depends on your location and whether you are doing DTE or relay.

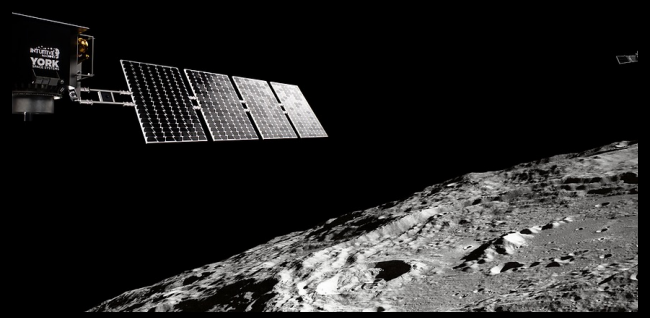
Questions to Ask Your Comms Service Provider

- Recommend reviewing the Lunar Pathfinder Services Guide to get an idea of what questions to ask:
  - https://www.sstl.co.uk/getmedia/ea388951-1330-4746-b641-72b7cd65f05a/Lunar-Pathfinder-Services-Service-Guide-V2-3.pdf
- What is your pricing model?
  - Per bit? Per minute? Something else?
- Do you provide…
  - A comms terminal? Or is the mission responsible for providing radio hardware?
  - Spectrum licensing? Or will the mission be responsible for filing the paperwork for a transmit license?

Upcoming Lunar Relays (Subject to Change)

Lunar Pathfinder (ESA)

- Anticipated in-orbit services by 2026
- ESA commercial relay satellite
- Transmission to Pathfinder over X-band
- Intended to support Lunar robotic missions
  - Moonlight is an SSTL follow-on intended for human missions



Khon2 (Intuitive Machines)

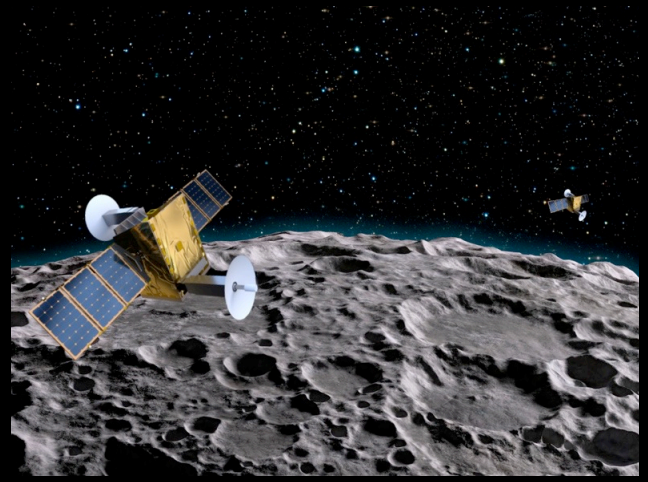
- Operations planned to start in ~2023
- Relay services for spacecraft in cislunar space and on the Lunar surface
- Plan to have 5 data relay satellites in a variety of orbits
- Khon satellites developed by York Space Systems, but owned and operated by IM

COMMSTAR-1 (CommStar Space)

- COMMSTAR-1 anticipated to arrive by 2023
- Optical and radio frequency relay services
- “For commercial and government users on and around the Moon”
- Working with industry to “permit ‘On-Net’ access to an **existing, privately-financed, multi-billion-dollar, diverse global infrastructure** – space, ground, fiber, cloud storage, hardware, and software”

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=IM-3-NOVA https://www.intuitivemachines.com/lunar-data-services
https://www.esa.int/ESA_Multimedia/Images/2021/09/Lunar_Pathfinder https://www.capacitymedia.com/article/29otc9t6wy04gbqwxwtts/news/commstar-to-deploy-data-relay-satellite-by-2023

Upcoming Lunar Relays (Subject to Change) Cont'd



Parsec (Lockheed Martin)

- Services missions on the Far Side and Lunar South Pole
- Two commsats in place by 2025
- Low and high data rate options
- Real time and store-and-forward options
- Also provides Doppler and two way ranging for positioning

Near Space Network

- Run by NASA, but NASA purchases services from commercial providers
- "The network will act as a one-stop-shop for mission teams, helping with planning and design, spectrum management, launch, operations in orbit, and more."

Lunar Gateway

- Supporting human crewed missions to lunar South Pole
- Can support up to 3 simultaneous lunar surface users

https://spacenews.com/lockheed-martin-subsidiary-to-offer-commercial-lunar-communications-and-navigation-services/
https://www.nasa.gov/feature/goddard/2023/nasa-seeks-commercial-near-space-network-services
https://ntrs.nasa.gov/api/citations/20210018935/downloads/GW_Comm_ICSSC_Paper.pdf

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