10-Year Lunar Architecture (LunA-10) Capability Study

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Briefing prepared for Space Resources Roundtable

June 4, 2024

LunA-10 consortium of industry, arranged by (initial) services

These groupings change across the program based on proposed technical areas/products

Market Analysis and Cislunar Logistics:

FIREFLY AEROSPACE

Power:

BLUE ORIGIN

HONEYBEE ROBOTICS

FIBERTEK, INC.

Mining & ISRU:

CISLUNAR INDUSTRIES

SIERRA SPACE

HELIOS

Communications, Position, Navigation, and Timing:

crescent

REDWIRE

Transit and Mobility:

NORTHROP GRUMMAN

SPACEX

Construction & Robotics:

GITAI

ICON

Initial study results for all performers at https://www.darpa.mil/program/ten-year-lunar-architecture-luna-10-capability-study

What direction is DARPA exploring?

Push from individual self-service to commercial multi-service

Push from government as a sole sponsor to commercial as a customer

For a given service or unit: what are the inputs/outputs/limitations?

What DARPA-hard technical challenges must be surmounted to create a sustainable lunar economy by 2035?

DARPA's hypothesis:
A lunar commercial infrastructure would catalyze economic activity, and thereby accelerate the US-led establishment of international norms.

The LunA-10 Analytical Framework

- This is *a* version of the Lunar Economy, not *the* Lunar Economy.
- Any lunar economy framework includes error bars
- LunA-10 aims to start the discussion: what is needed to enable a commercial lunar economy, and where do **you** fit in?

Framework

What does the Lunar Economy Look Like?

Value Chains

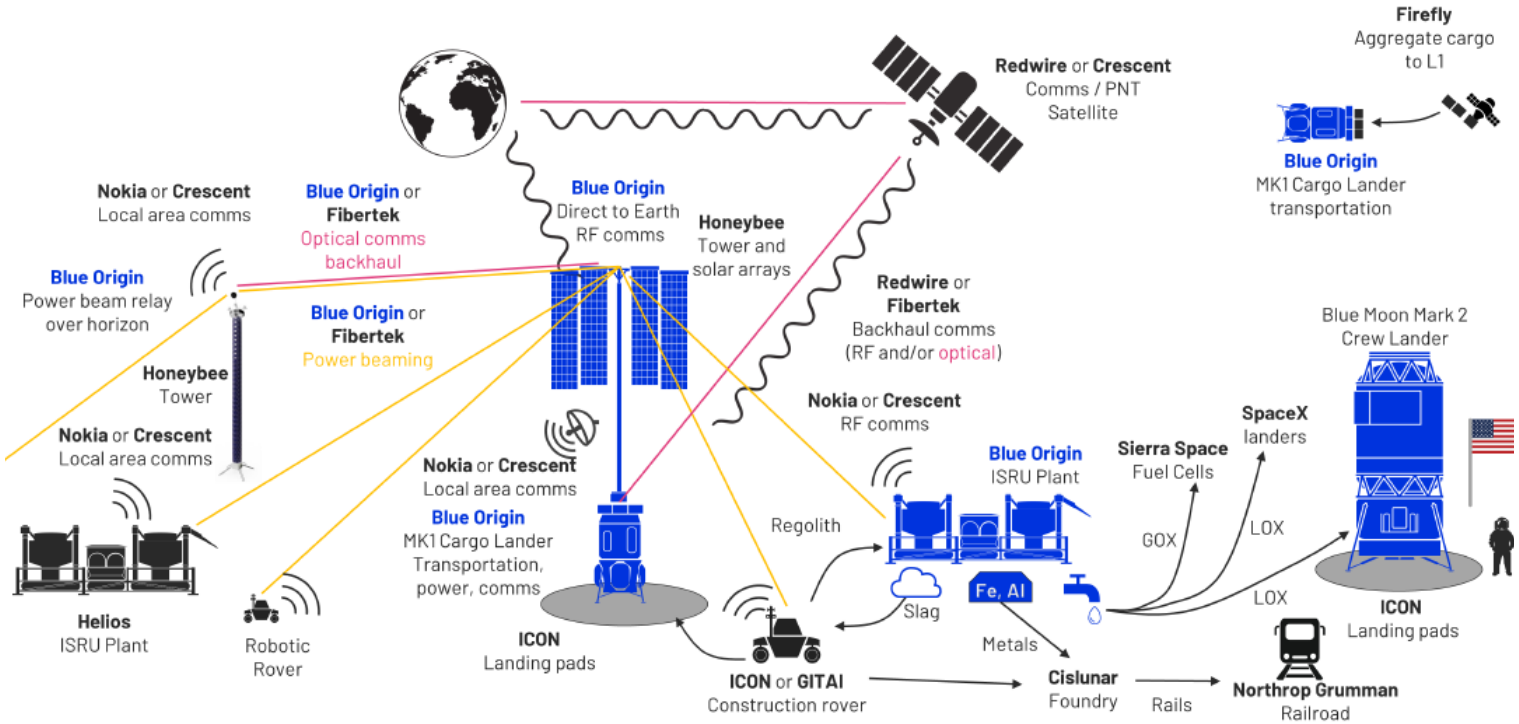
How do we get there?

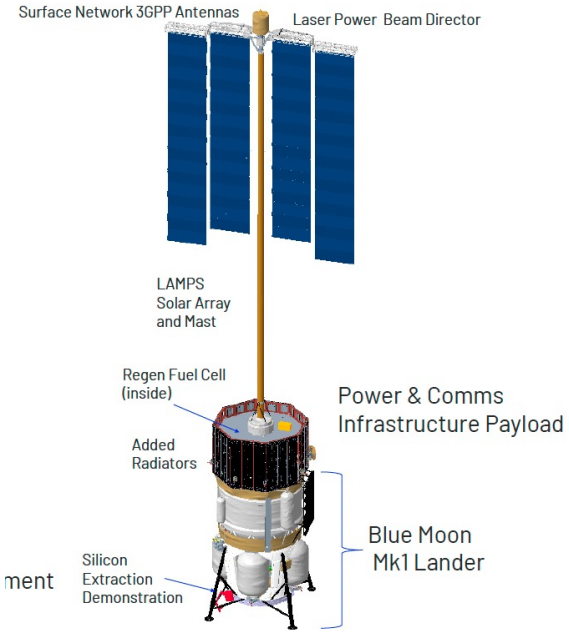
Blue Origin: lander, power, comms and ISRU

Three complementary, multi-service commercial systems:

1. Lander node as payload host and Infrastructure Platform
2. Laser-enabled Wireless power framework
3. ISRU for Construction, Mining and Energy

Features	Capability
Solar Array	> 10 kWe
Mast	20 m mast on ~10 m lander (total 30 m above surface)
3GPP Telecom Service	25 Mbps bps up to > 10 km range, max range ~100 km
Regen Fuel Cell Augmentation Kit	1.5 MWh, 7.8 kW_e over 192 hrs
Laser Power Transmitter	~1 kW_e delivered to 10+ km,
Silicon Extraction Experiment	Demonstrate production of silicon from regolith
Heat Rejection Augmentation Kit	Added Radiator area for payload power

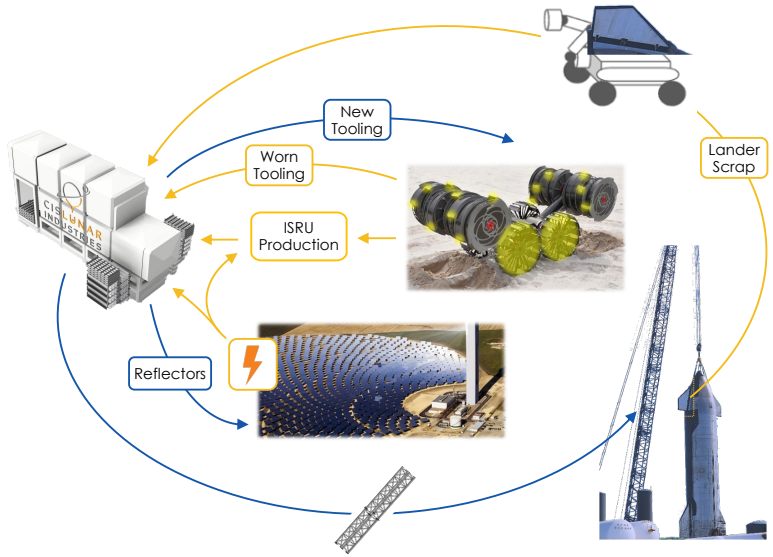


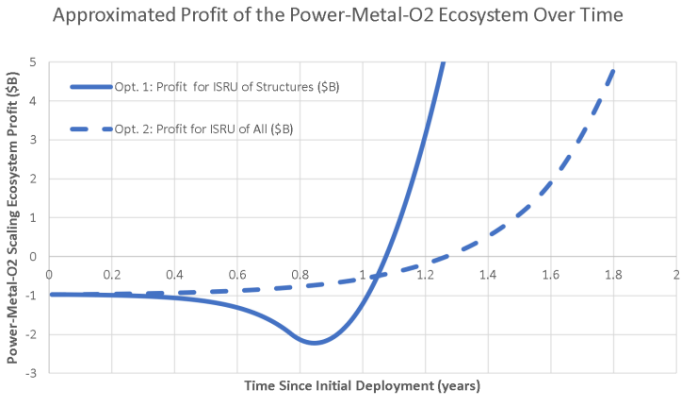


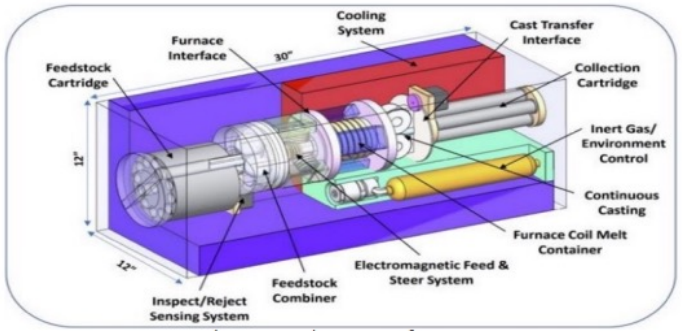
CisLunar Industries: metal extraction and recycling on the Moon

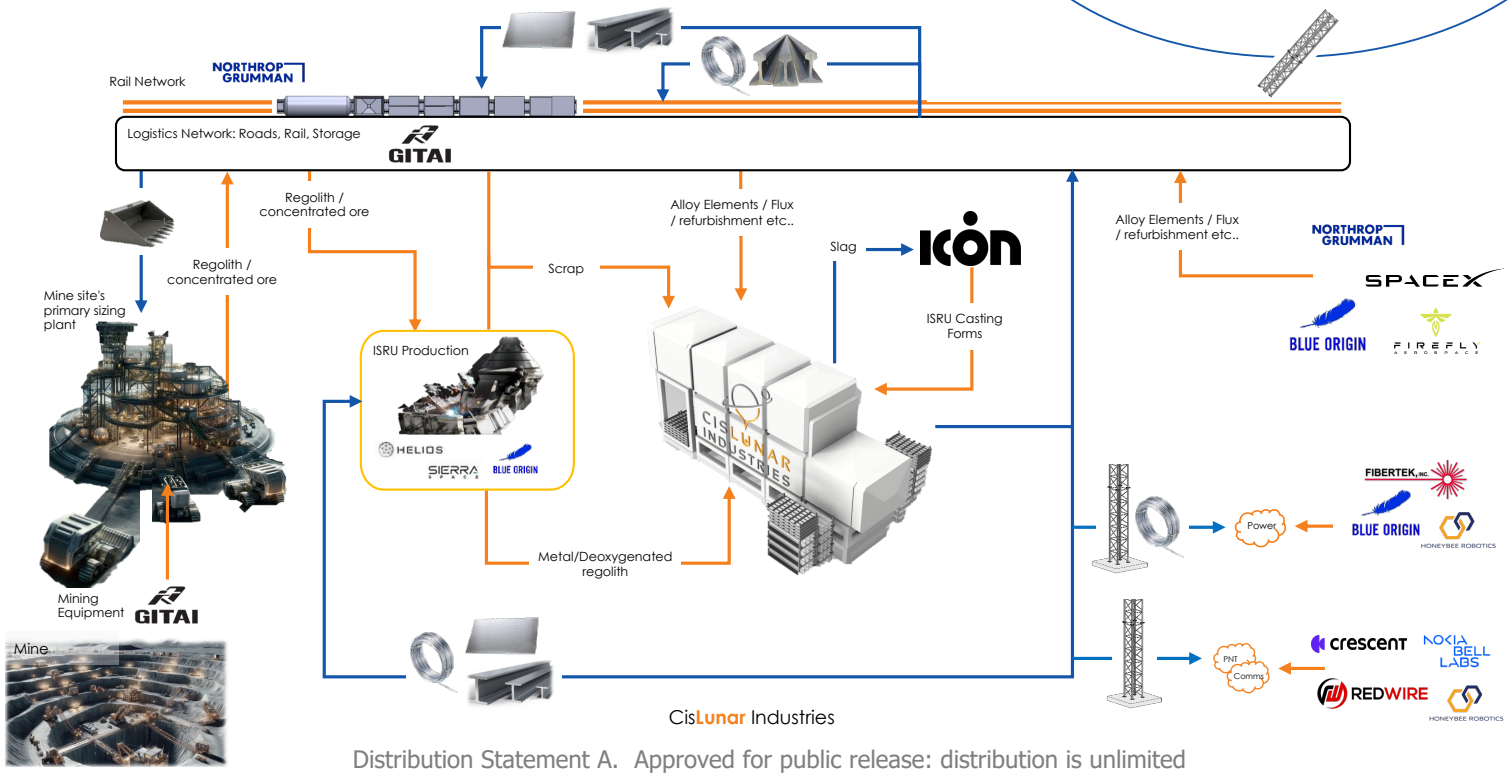
Building infrastructure and enabling sustainable mining operations:

- Inputs: ISRU metals (Al, Fe), scrap, slag, alloying elements
- Outputs: Ingots, beams, sheet metal, extruded wire and other metal-based products needed for the lunar economy







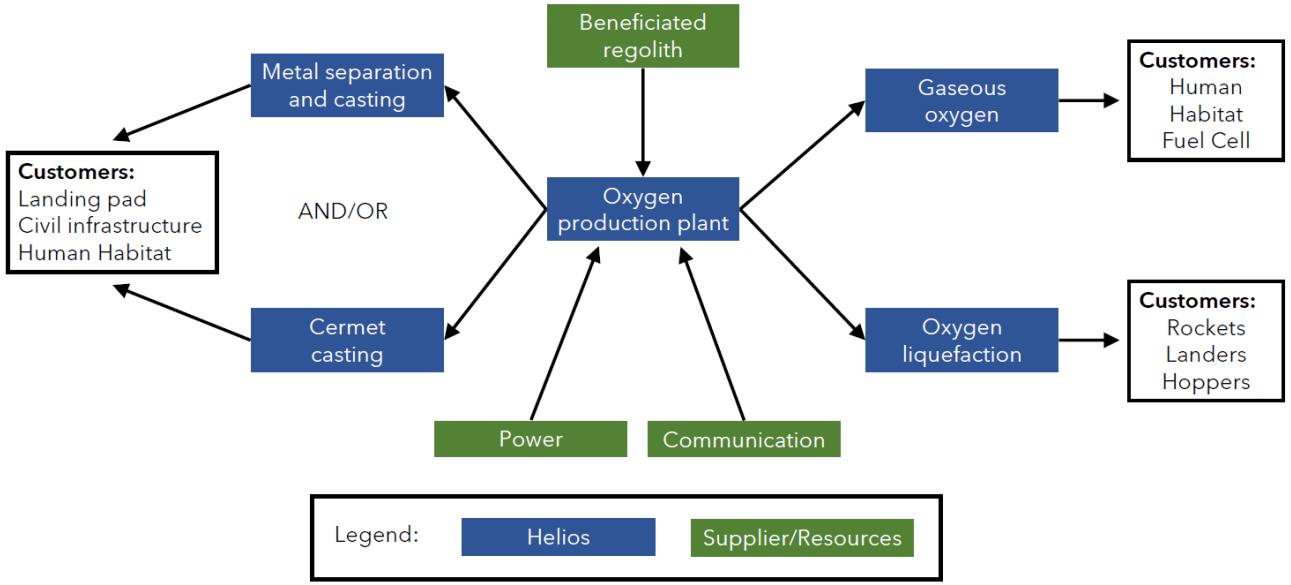


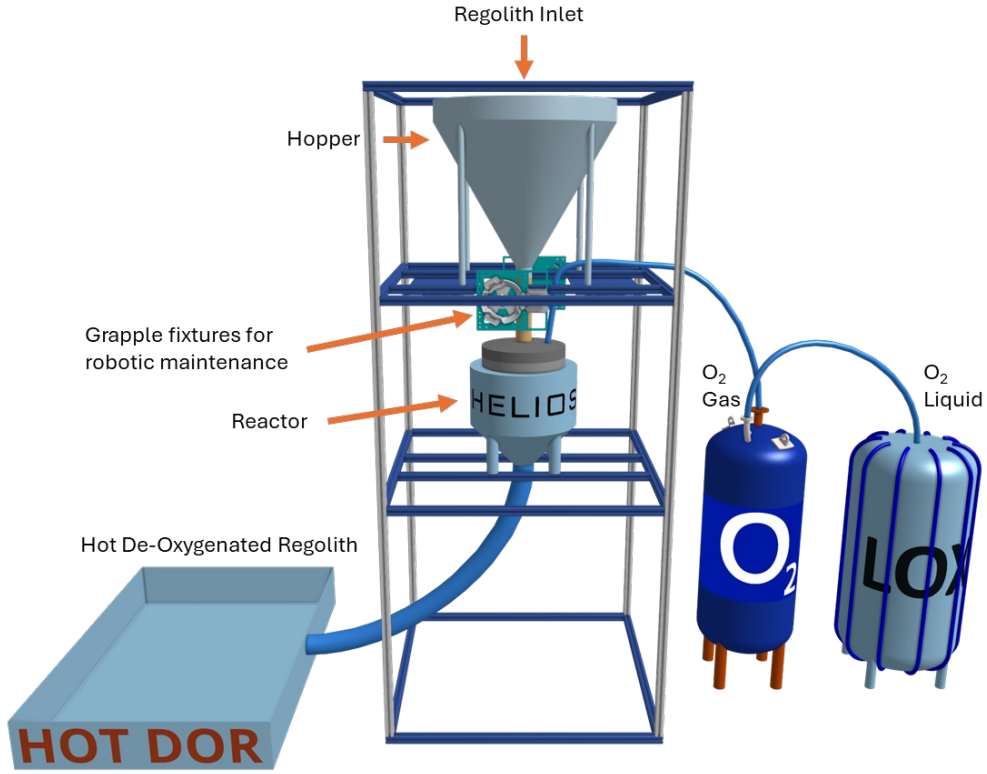
Helios: ISRU plant to produce LOX propellant at scale

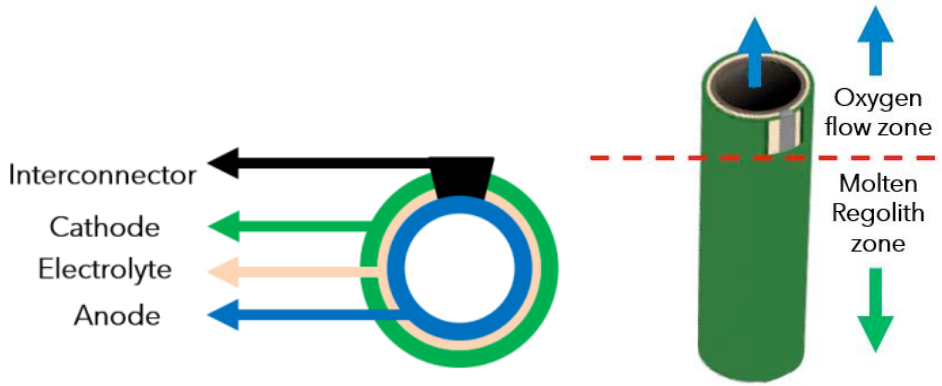
Scalable process for Solid Oxide Electrolysis to extract oxygen from regolith

Products include:

- Gaseous O2
- Liquid O2 (LOX) propellant
- De-oxygenated regolith for further metal refinement & processing



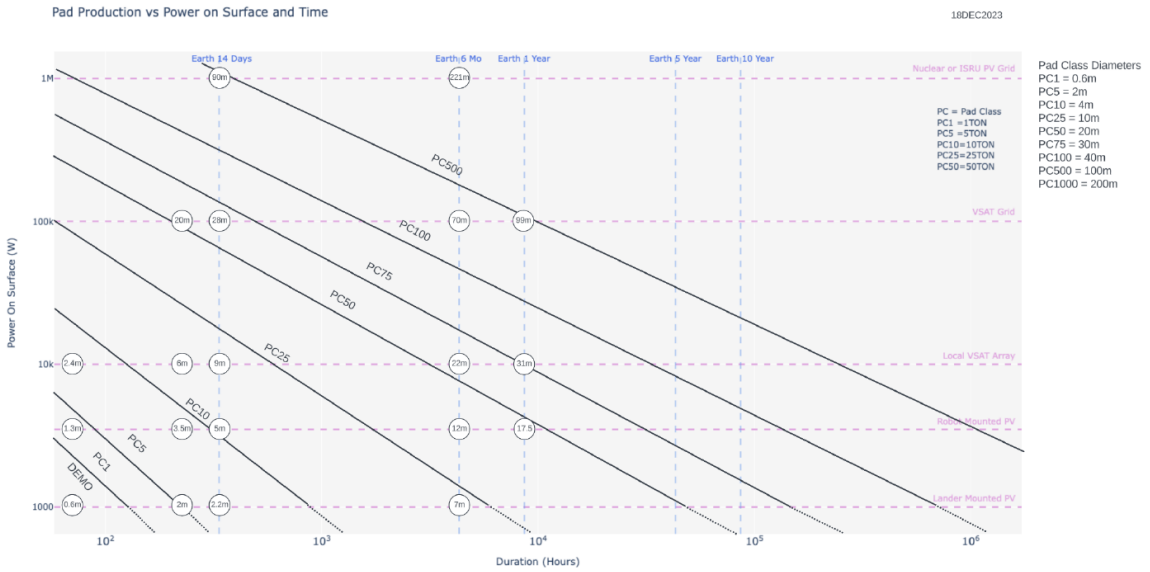


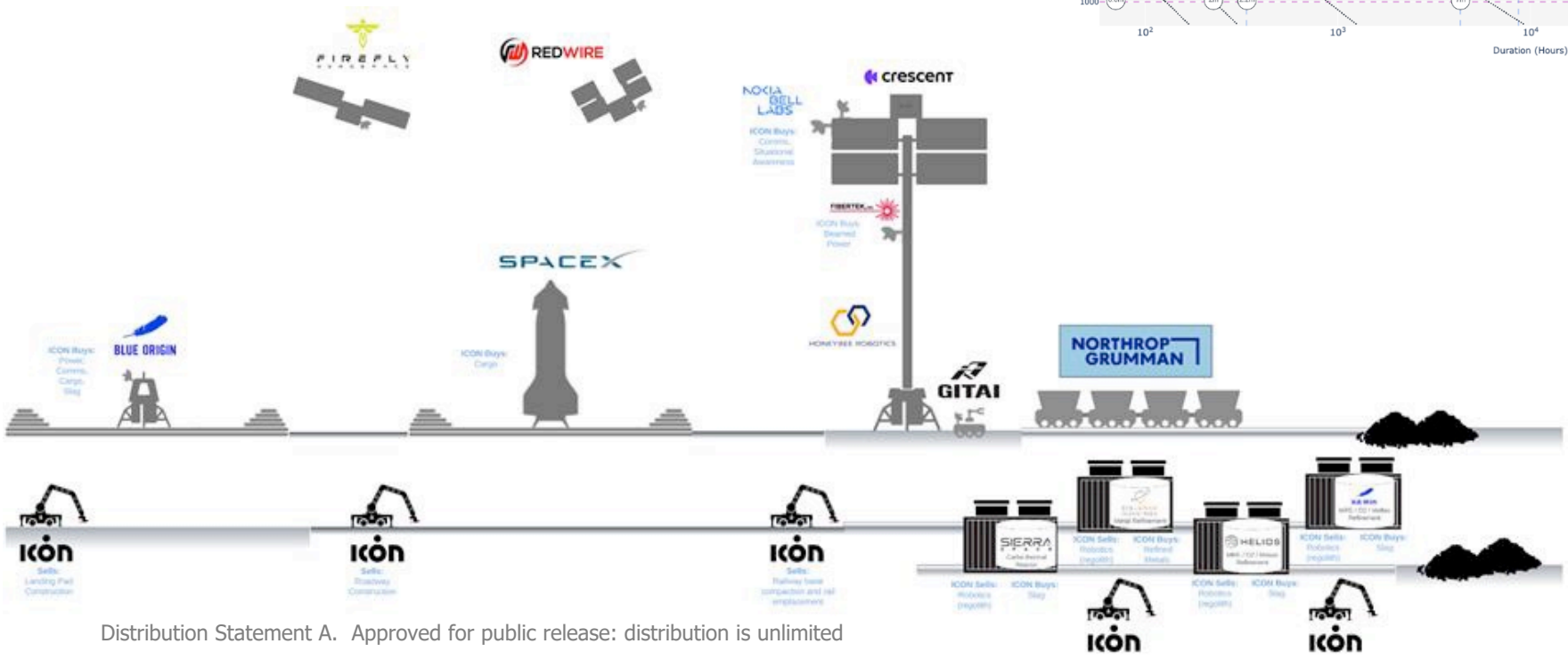


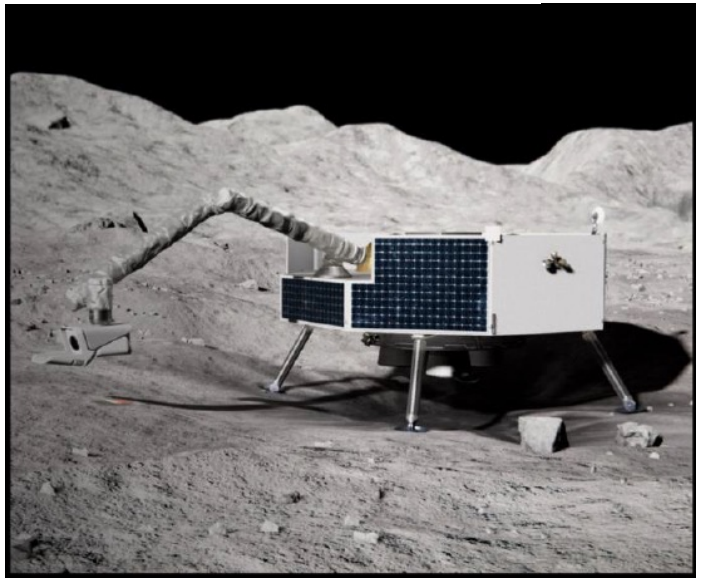
ICON: Sintering regolith for foundational transportation infrastructure

Laser VMX to pave roads and landing pads

- Resource-efficient inputs of raw regolith requires minimal materials launched to surface
- Current production time estimate is ~1 month for a 10m diameter landing pad with 10 kW surface power supplied





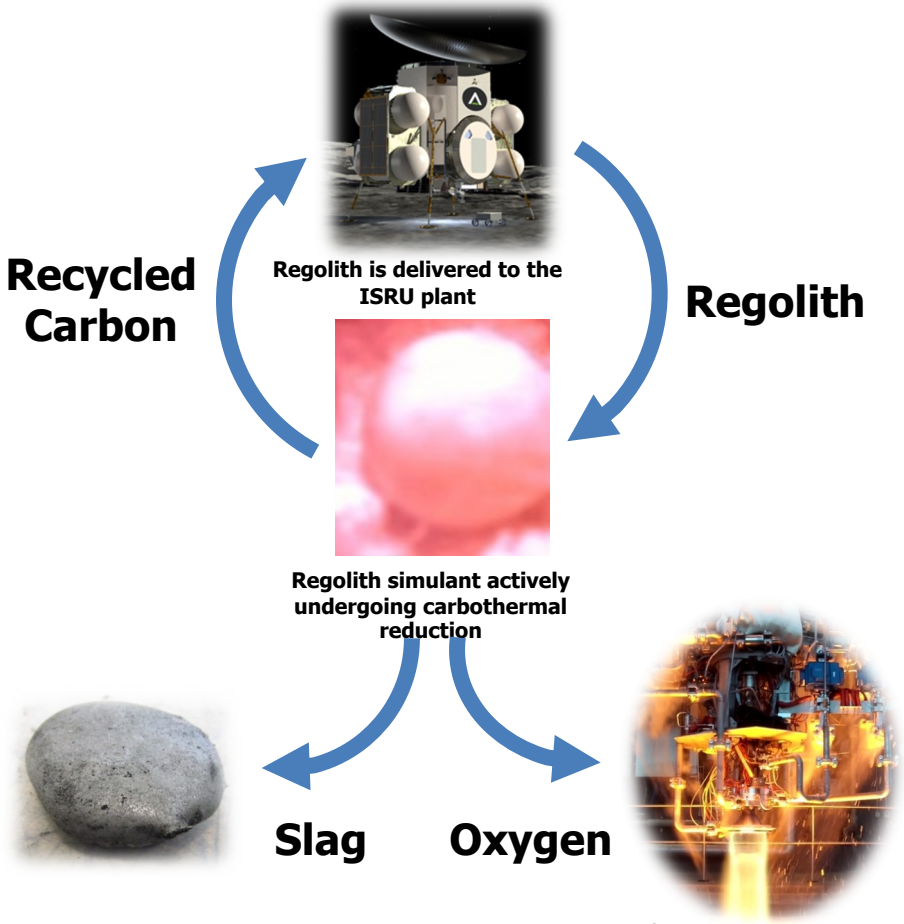


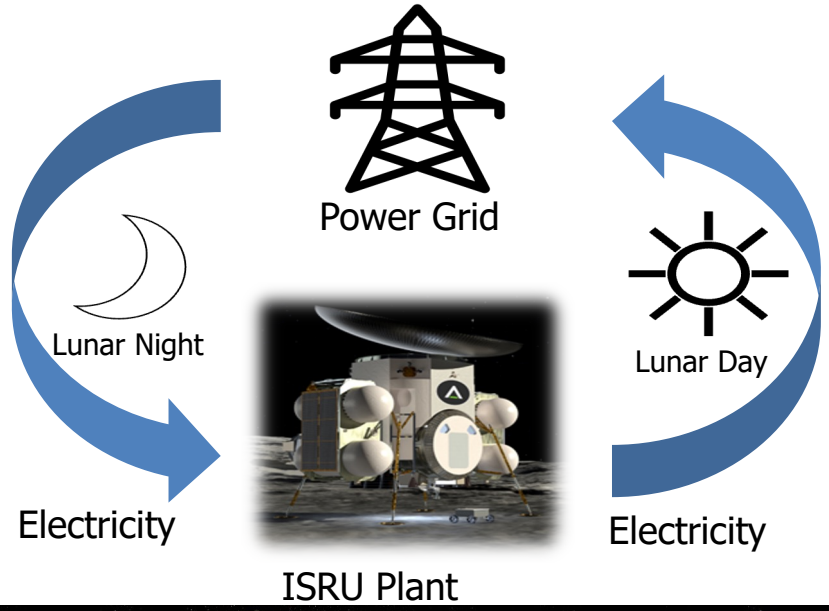
ICON's Project Olympus for NASA and commercial lunar projects

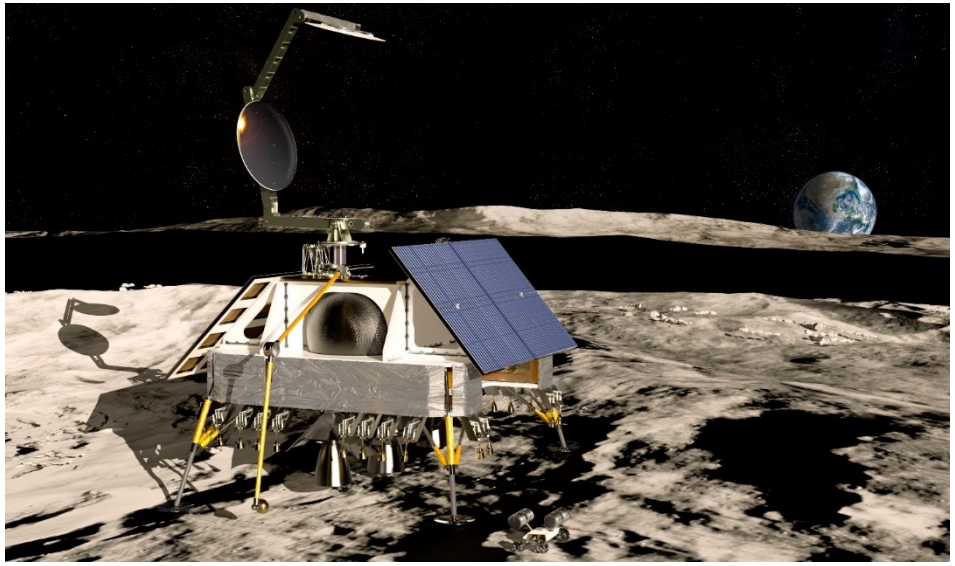
Sierra Space: a night-survivable oxygen plant with integrated fuel cell

Oxygen ISRU plant with three main functions:

1. Oxygen Extraction from Regolith
2. Fuel Cell Energy Storage for STN
3. Chemical Conversion for Recycling and Storage







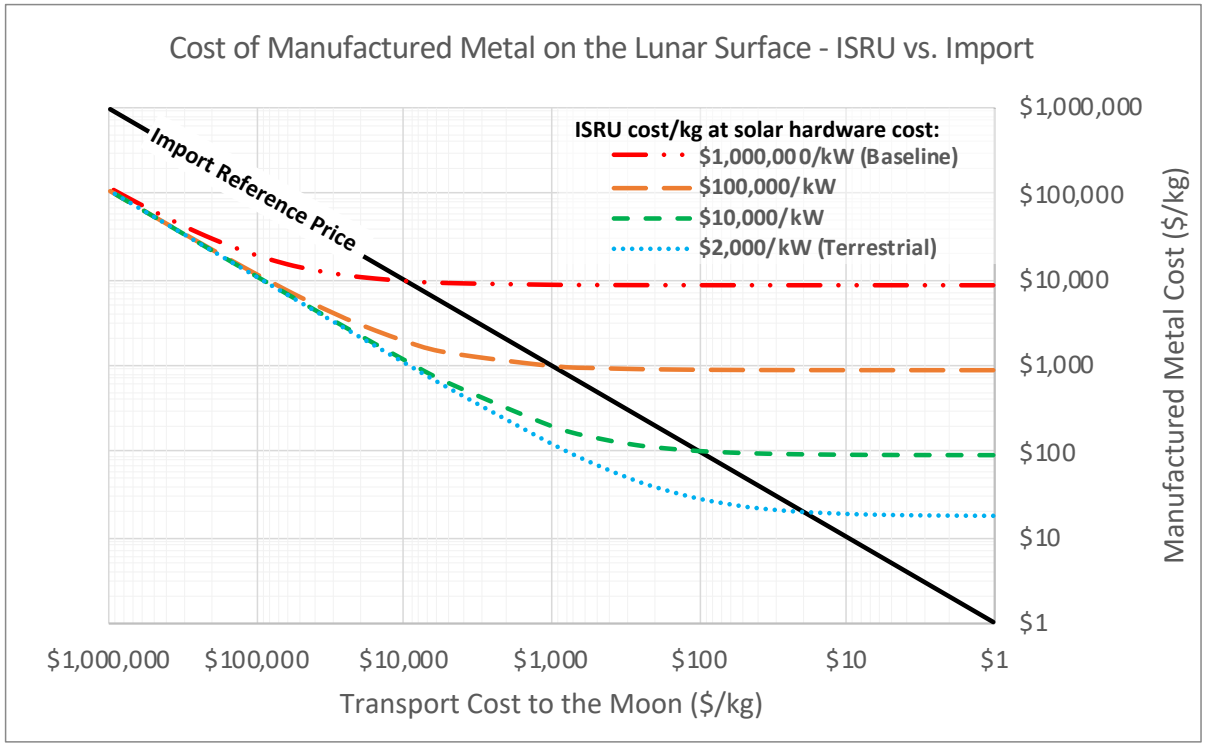
Artist concept of a carbothermal oxygen production plant

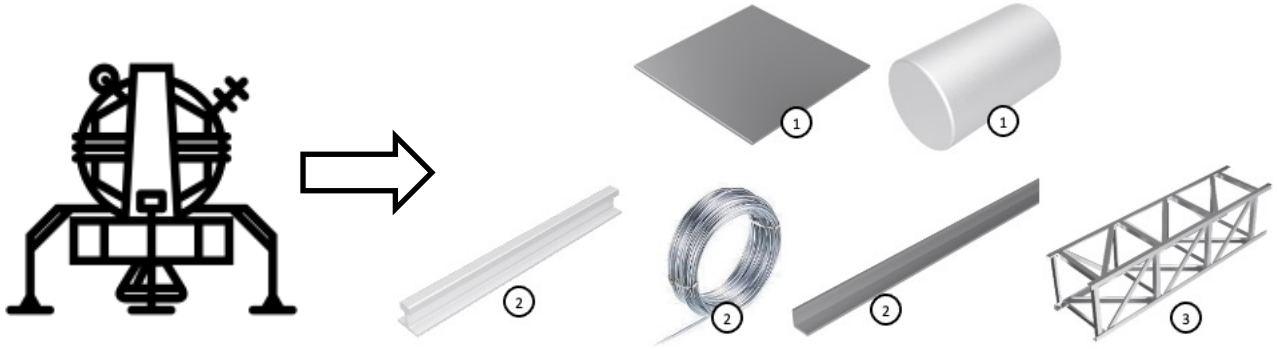
New concept of Re-ISRU: Recyclable ISRU

Man-made equipment on the Moon may grow by an order of magnitude in next 10 years

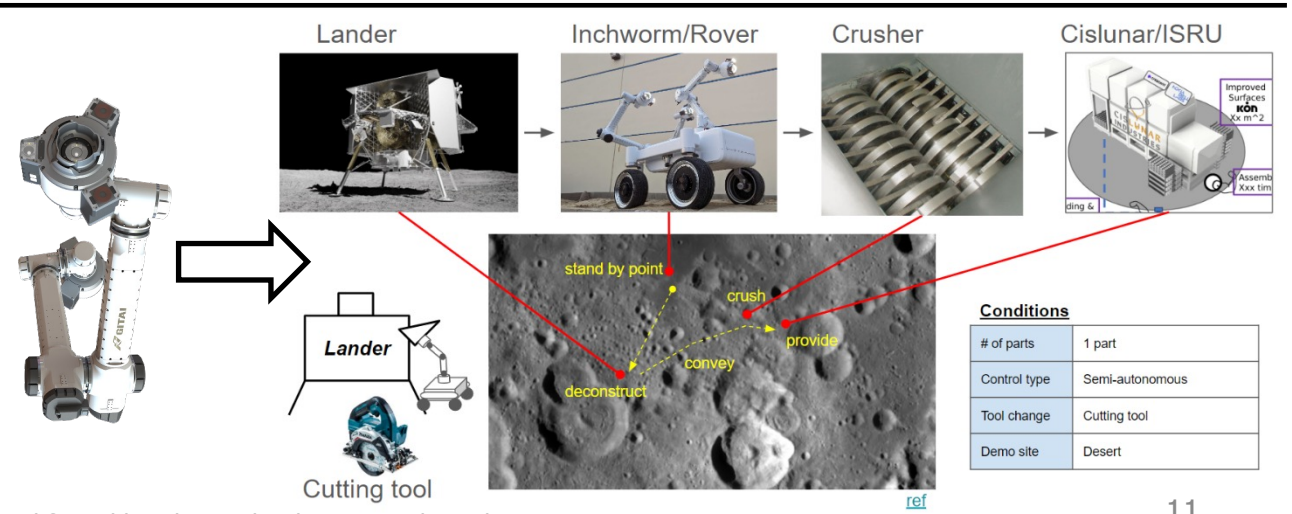
The definition of "in-situ" resources also includes defunct manmade equipment

How do we use that to reduce mass required from Earth?





[1] Casting (radiators, billets); [2] Extrusion (Lunar rail, wire, L-channel); [3] Fabricated products (tower truss)



Enabled by metal recycling and robotic disassembly and foundry ingest

What is the Lunar Economy?

"The Gold Nugget"

CA Gold Rush: Before gold was found at Sutter's Mill,
the initial investment was fur trading.
Fur trails and fur economy enabled the Gold Rush to take place.

Today, the initial investment is O_2 and H_2O.
As the economy and the new market evolves,
new "gold nuggets" may be discovered.

What is a Sustainable Lunar Economy?

Economically Positive (over time)
Converges to a state with little material being brought from Earth
Co-operative, international, and interoperable

The Four Ages of the Lunar Economy

Exploration Age
Years 0-3

- We are here, now!
  Bespoke, self-sufficient missions
  Exploration and Tech Demos

Foundational Age
Years 3-6

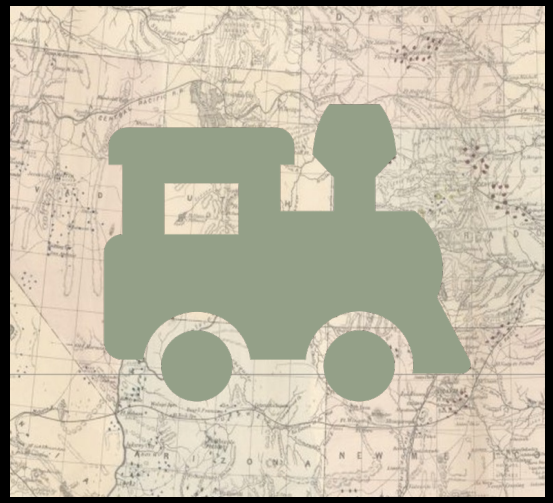
- Larger vehicles and devices
  Some business cases close
  Focused on MVE demos

Industrial Age
Years 6-10

- Large cross-mass (Lunar Rail)
  Recoup of investments
  Fully-functional ISRU

Jet Age
Year 10+

- Economic engine producing 100+ tons of O_2/month
  Multi-site (Equator + Pole)
  Little up-mass from Earth



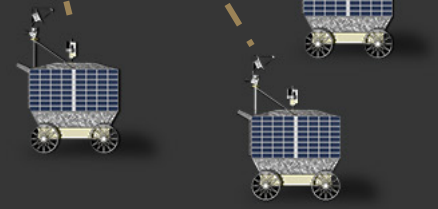
Exploration Age – Ground-Level View

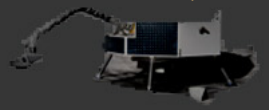
DTE Comms – Optical, 1Gbps (SpaceX)

DTE Comms – RF (Blue Origin, Crescent)

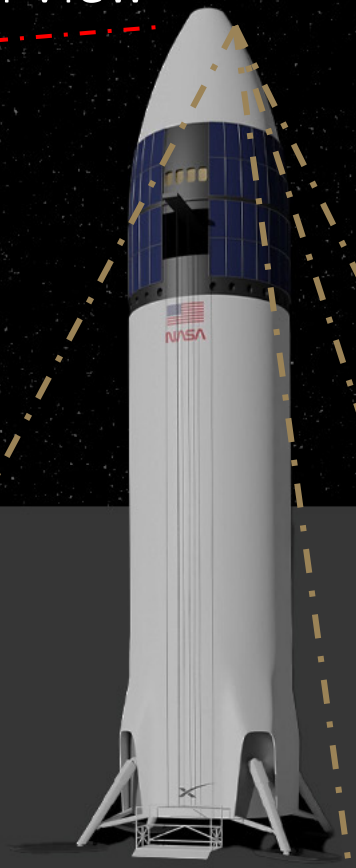
3,000 kg to Surface (Blue Origin)

Local Area Comms (Blue Origin, Crescent)



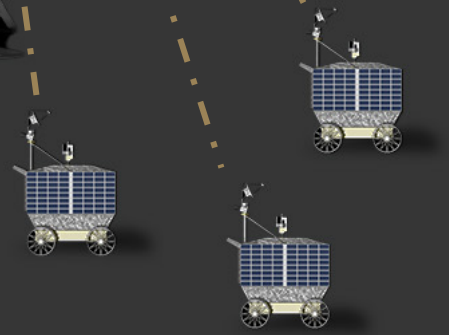


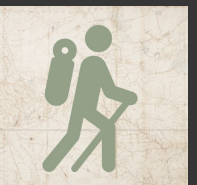
ICON MVE



Local Area Comms via Crescent MUST-Lite

100 MT to Surface (SpaceX)



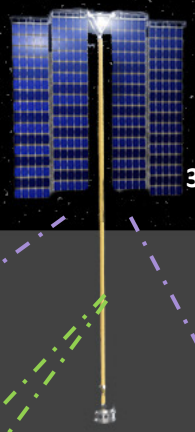


Foundation Building Age– Ground-Level View

Aggregation Hub – "Lunar FBO"
Tranche 1:
Cargo handling and deployment
Data Storage and Edge Computing

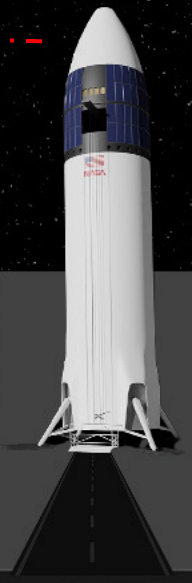
PARSEC PNT demo
South Pole PNT Coverage
100Mbps Comms
SSA Service

Redwire Pilot (LLO)
Orbital PNT, Single Satellite
5m accuracy



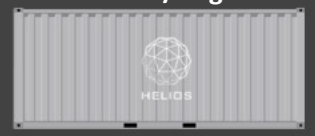
LunarSaber MVE
30m Tower Demo with
Power Beaming
Wired Power Access

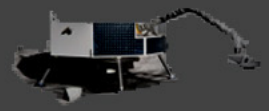
LOX Storage



Oxygen + Night Power Generation

Oxygen Plants– 100 kgO_2 /yr
DOR/Slag

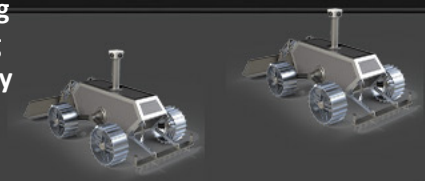




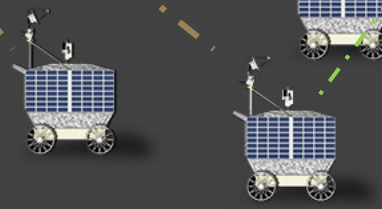
GITAI Rovers/Inchworms
Regolith Loading
DOR Unloading
Facility Assembly

Recycled Materials – 50 tons/yr

Recycled Materials – 50 tons/yr

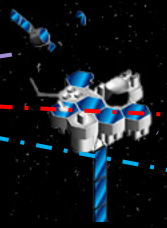


Mining Rovers



Road-Sintering Robot
Lunar Rail Bed
Construction

Industrial Age– Ground-Level View

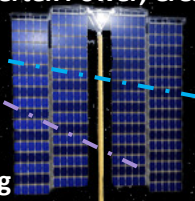


LunarSaber Phase 2
Multi-Unit w/ Mesh Network
Thermal Tent, Fibertek Power, Crescent Comms

Crescent PARSEC
South Pole Coverage
100 Mbps
SSA Service

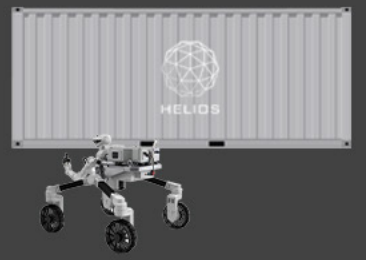
Redwire Orbital PNT (LLO)
Orbital PNT, Comms Relay, SSA
South Pole Coverage

Aggregation Hub – "Lunar FBO" Tranche 2
Comms Relay Services
Cargo handling and deployment Vehicle Refueling
SSA Platform
Data Storage and Edge Computing



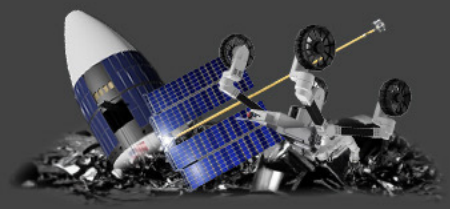
Regolith/Scrap Loading
DOR/Metals Unloading
Facility Assembly

Oxygen Production (Sierra Space, Helios)
1,000 kg/yr + DOR/Slag

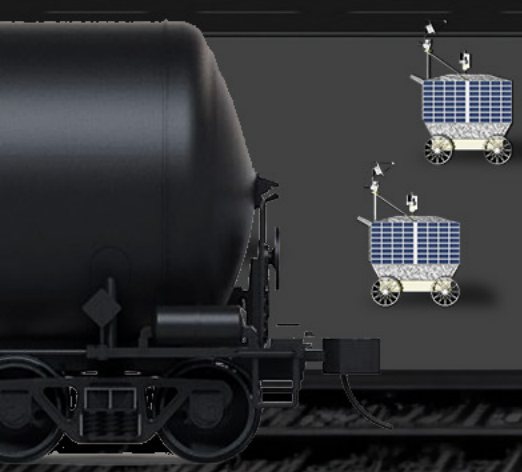


Landing Pad Building
Mk1 Class (ICON)

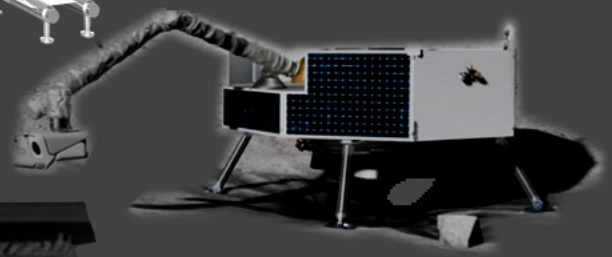
STN Power – 5000 kWh



Scrap Yard
Retired Hardware +
Scrapping Robotics

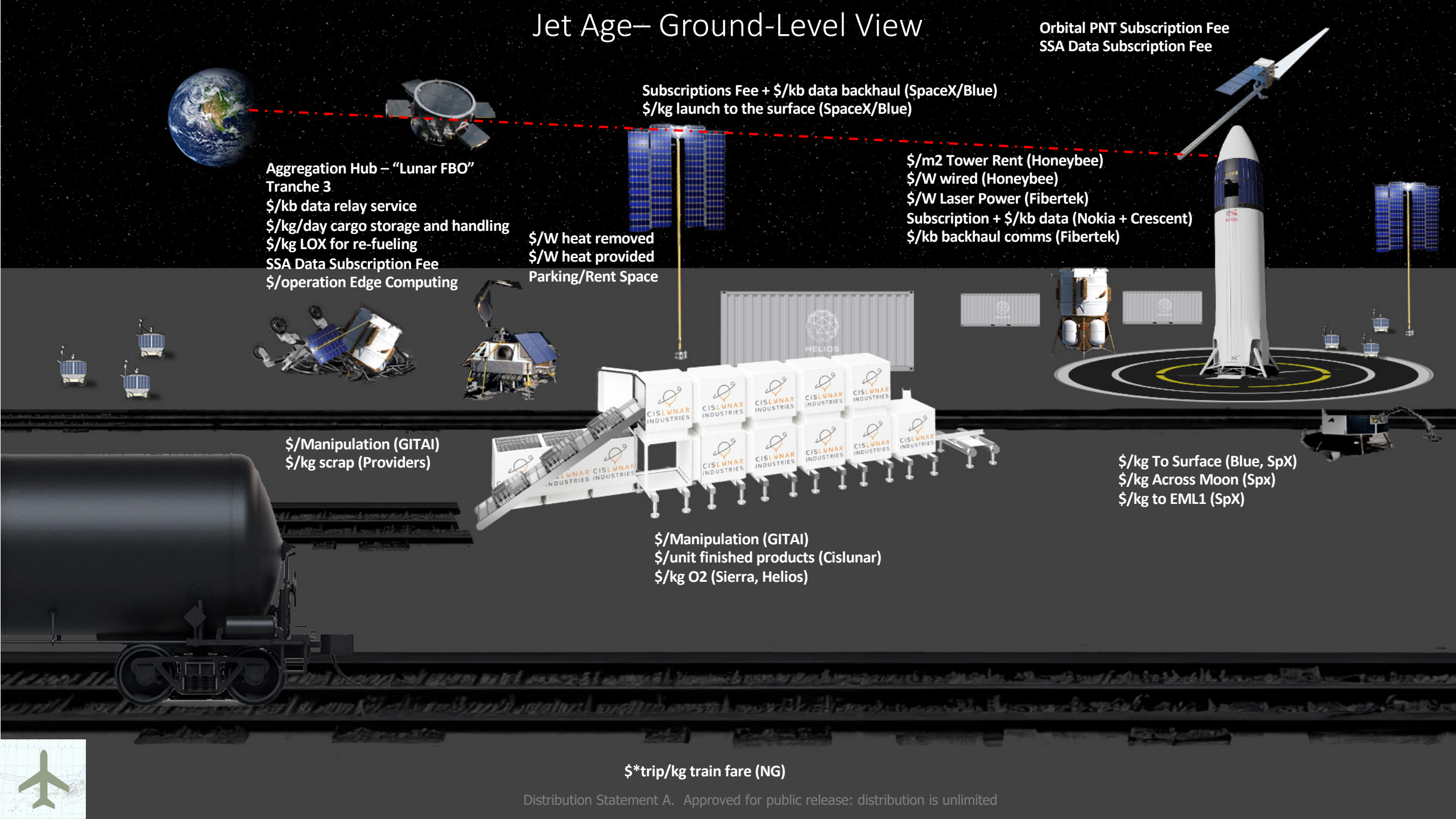


Recycled Metals – 500 tons/yr



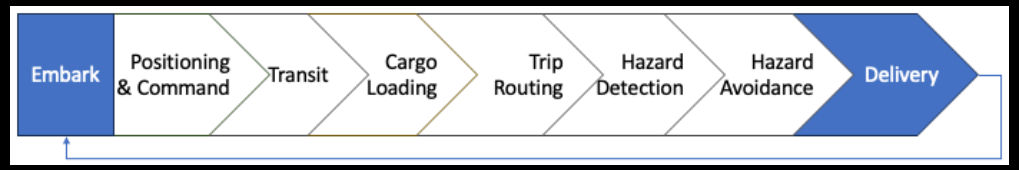
Track Building (Northrup Grumman)
5 km/yr
Rail Line – 10-15 km
Load Capacity – 10,000 kg

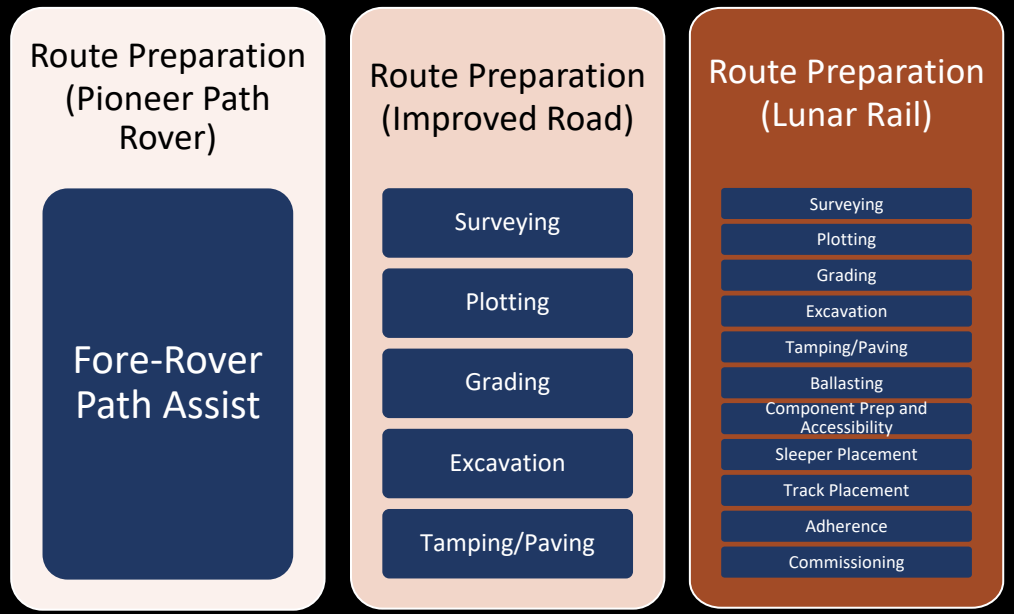
Jet Age– Ground-Level View



Value Chain (VC) Schema

- Establishes an enterprise framework for evaluation of multiple capabilities within a given Technical Area
- Illustrates increasing complexity / developmental gaps of use cases under the same Value chain construct





Element addressed in LunA-10

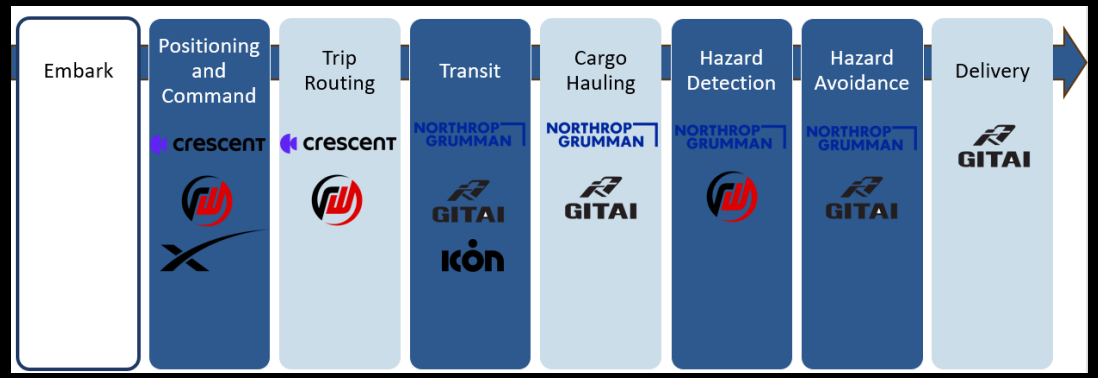
Element tentatively addressed in LunA-10

Element not presently addressed in LunA-10

In/Out Gate

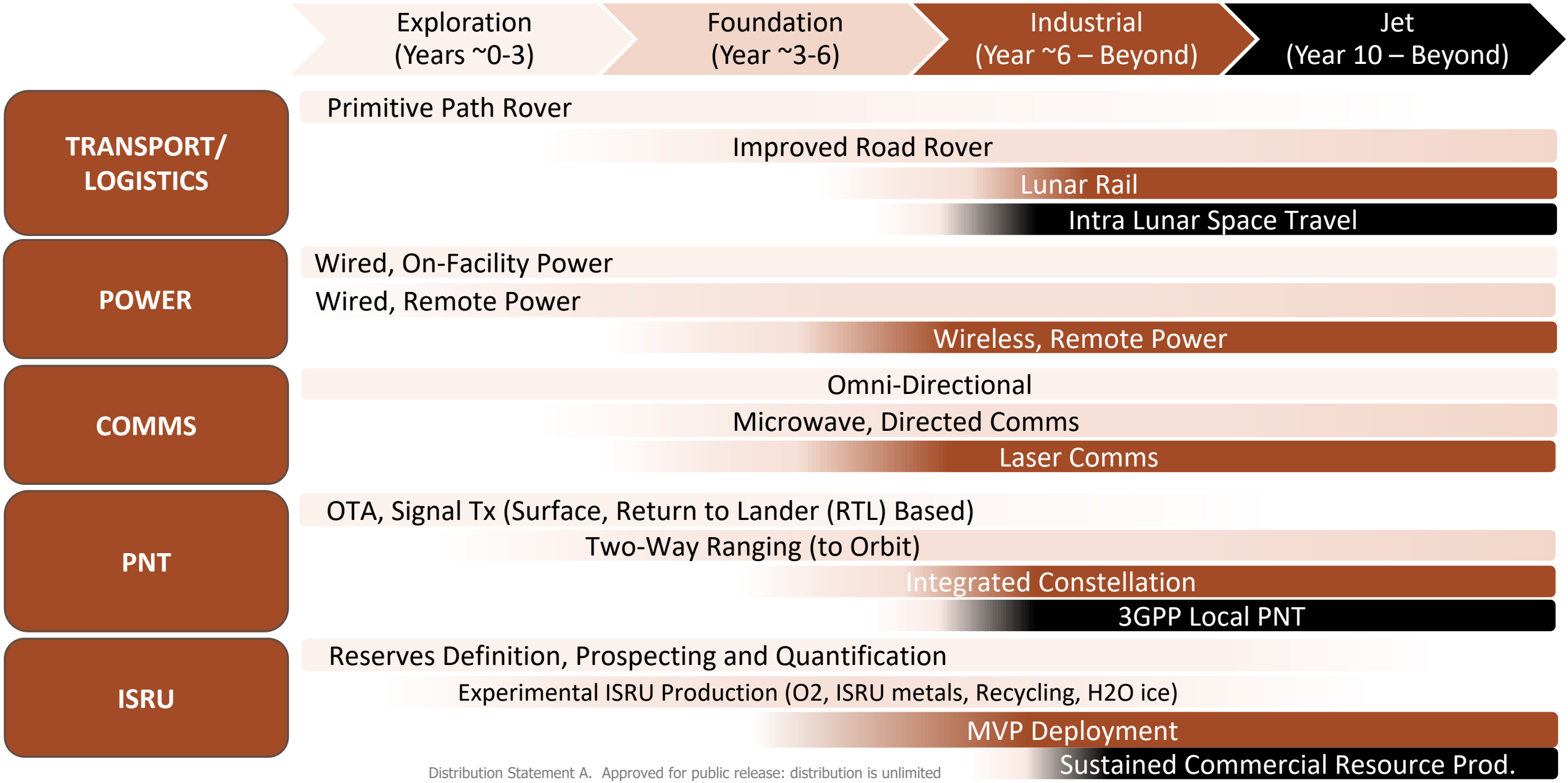
Enabler Connection — Additional engagement from the greater lunar surface community needed or encouraged

VC Connection — Indicates a direct correlation or dependency on a related VC



An expandable and adaptable framework for multiple functional areas and use cases

VCs Through the LunA-10 Decade (and Beyond)



ISRU – REGOLITH DERIVED OXYGEN VC

Exploration Phase (Years 0-3)

Possible Reserves

Probable Reserves

Proven Reserves

Explorer Delivery

Prospect

Explore

Determine Feasibility

SIERRA SPACE

HELIOS

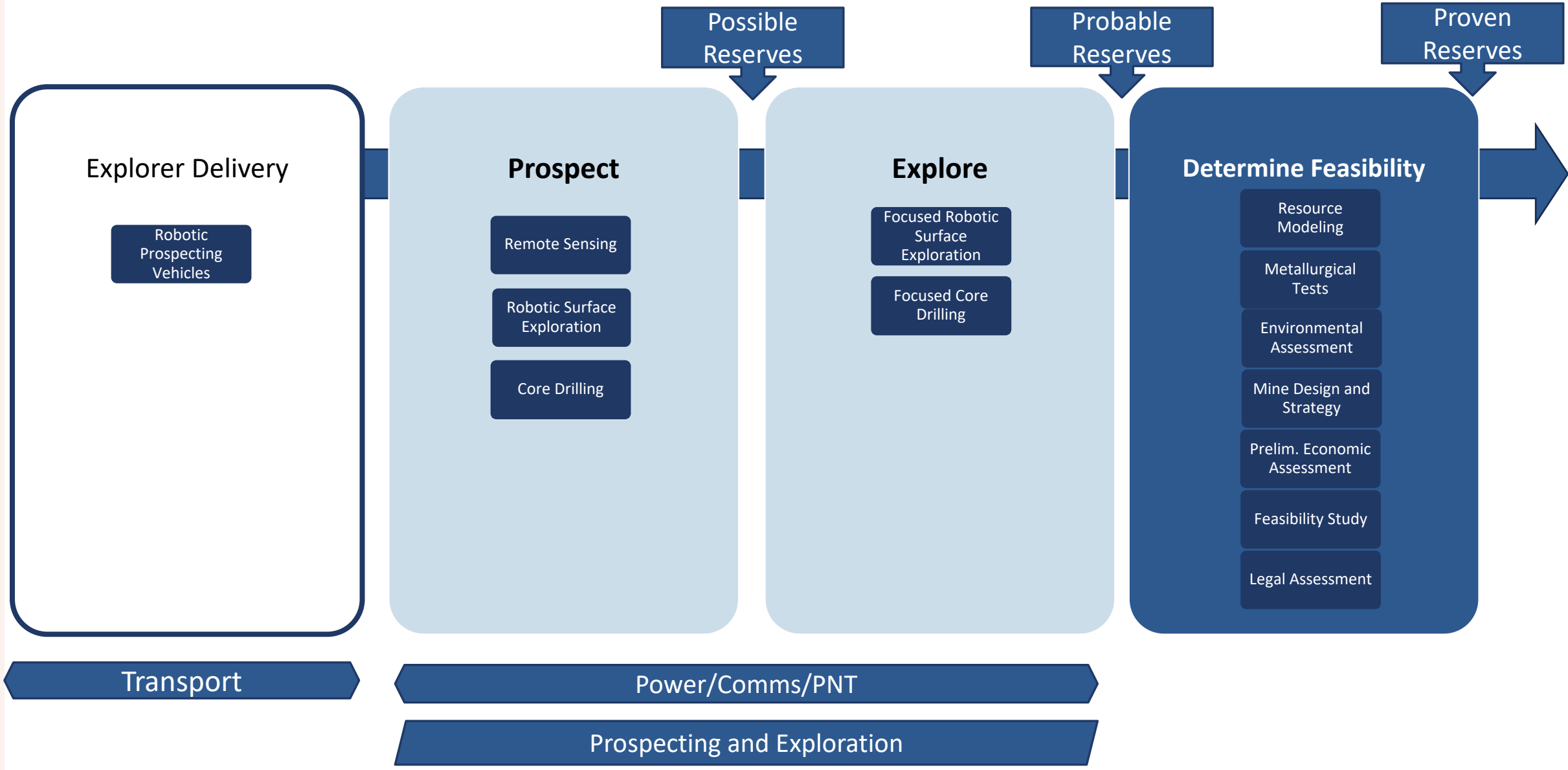
Transpo

Power/Comms/PNT

Prospecting and Exploration

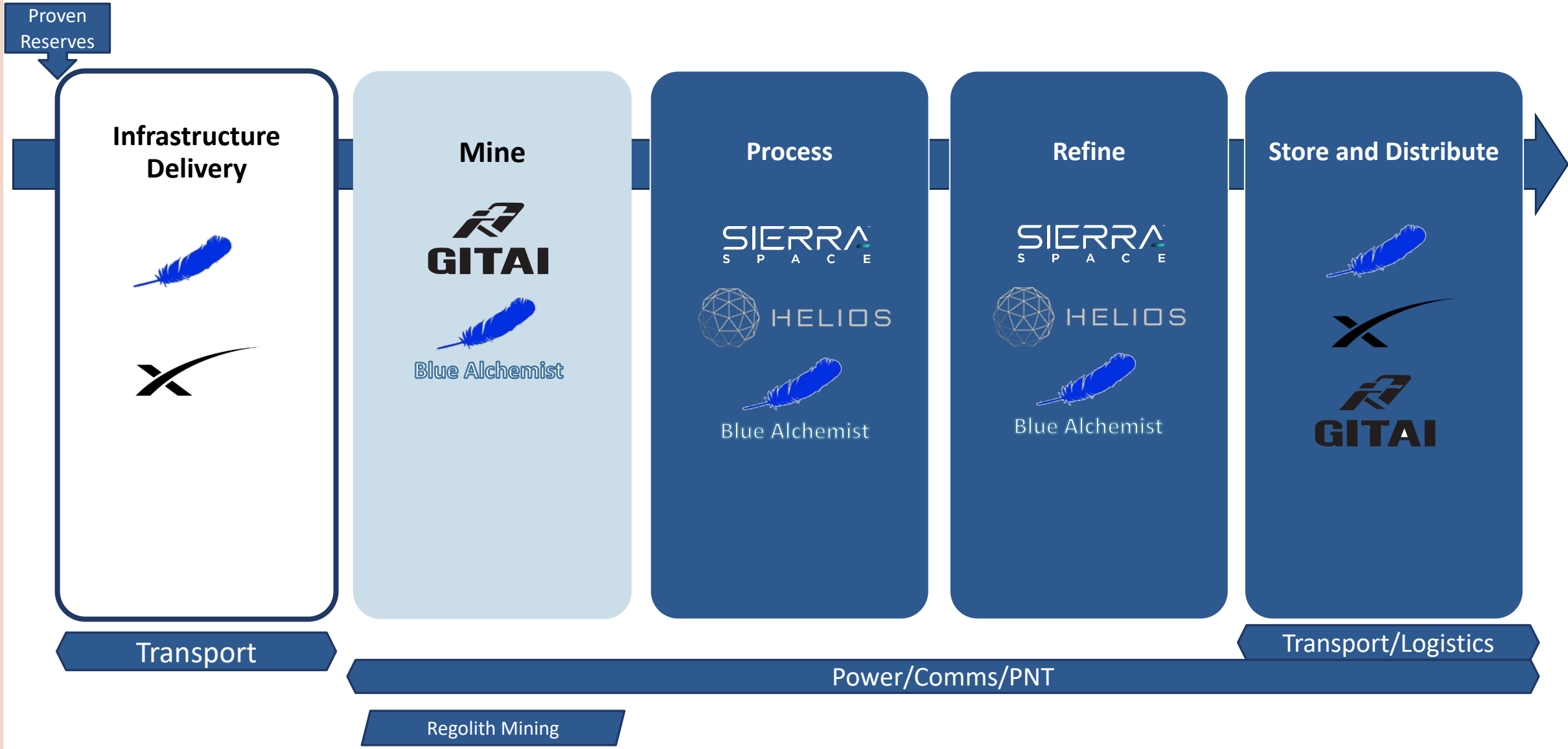
ISRU – REGOLITH DERIVED OXYGEN VC

Exploration Phase (Years 0-3)



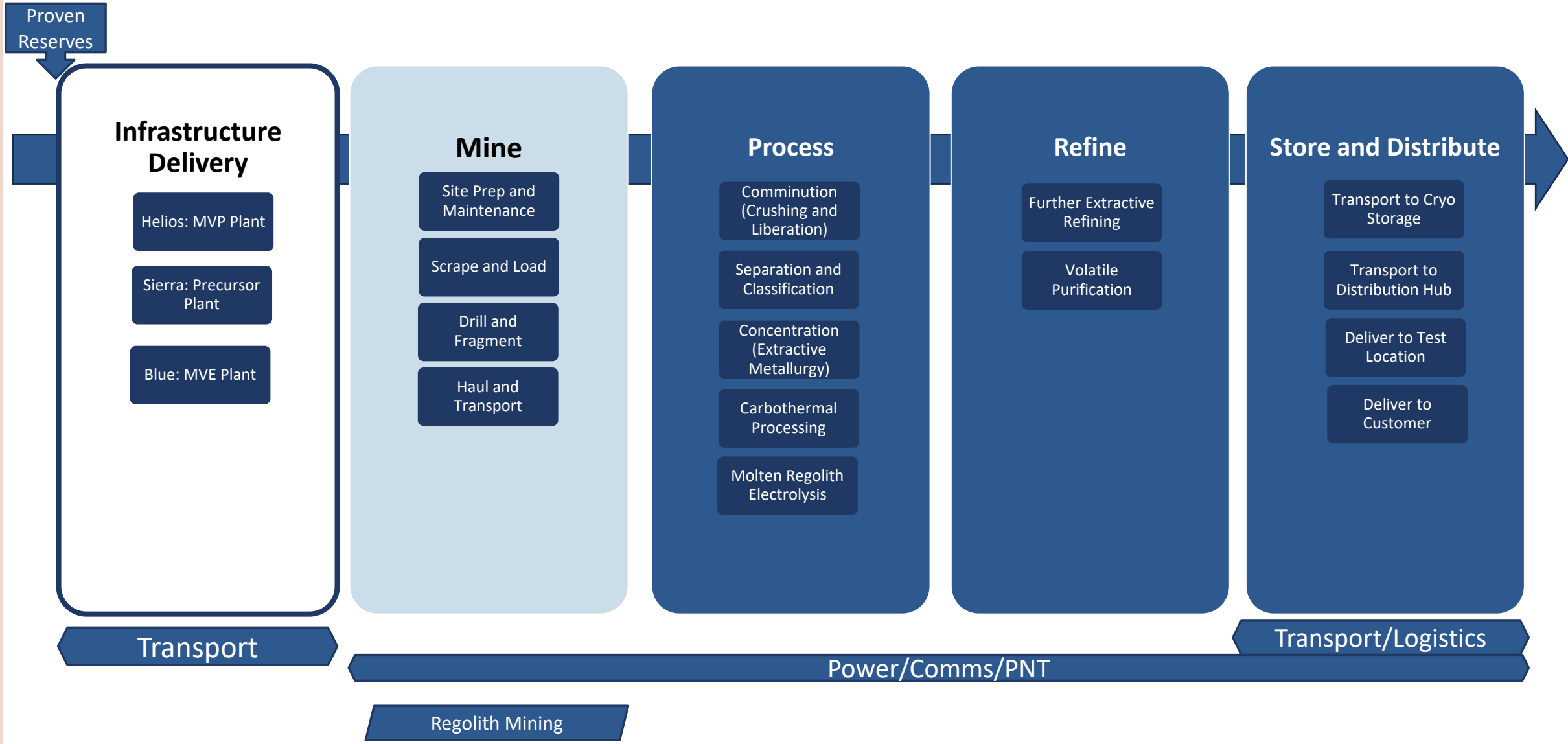
ISRU – REGOLITH DERIVED OXYGEN VC

Foundation Phase (Years 3-6)



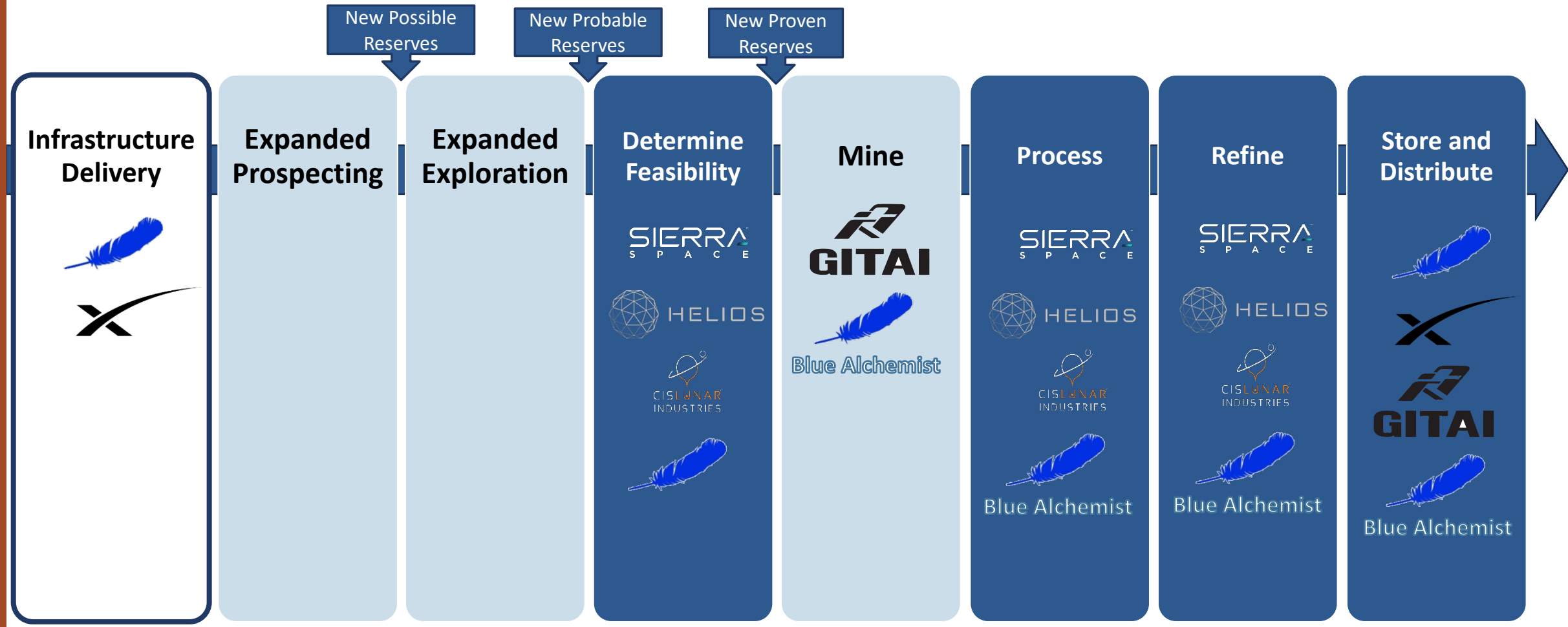
Foundation Phase (Years 3-6)

ISRU – REGOLITH DERIVED OXYGEN VC



ISRU – REGOLITH DERIVED OXYGEN VC

Industrial Phase (Years 6-10)



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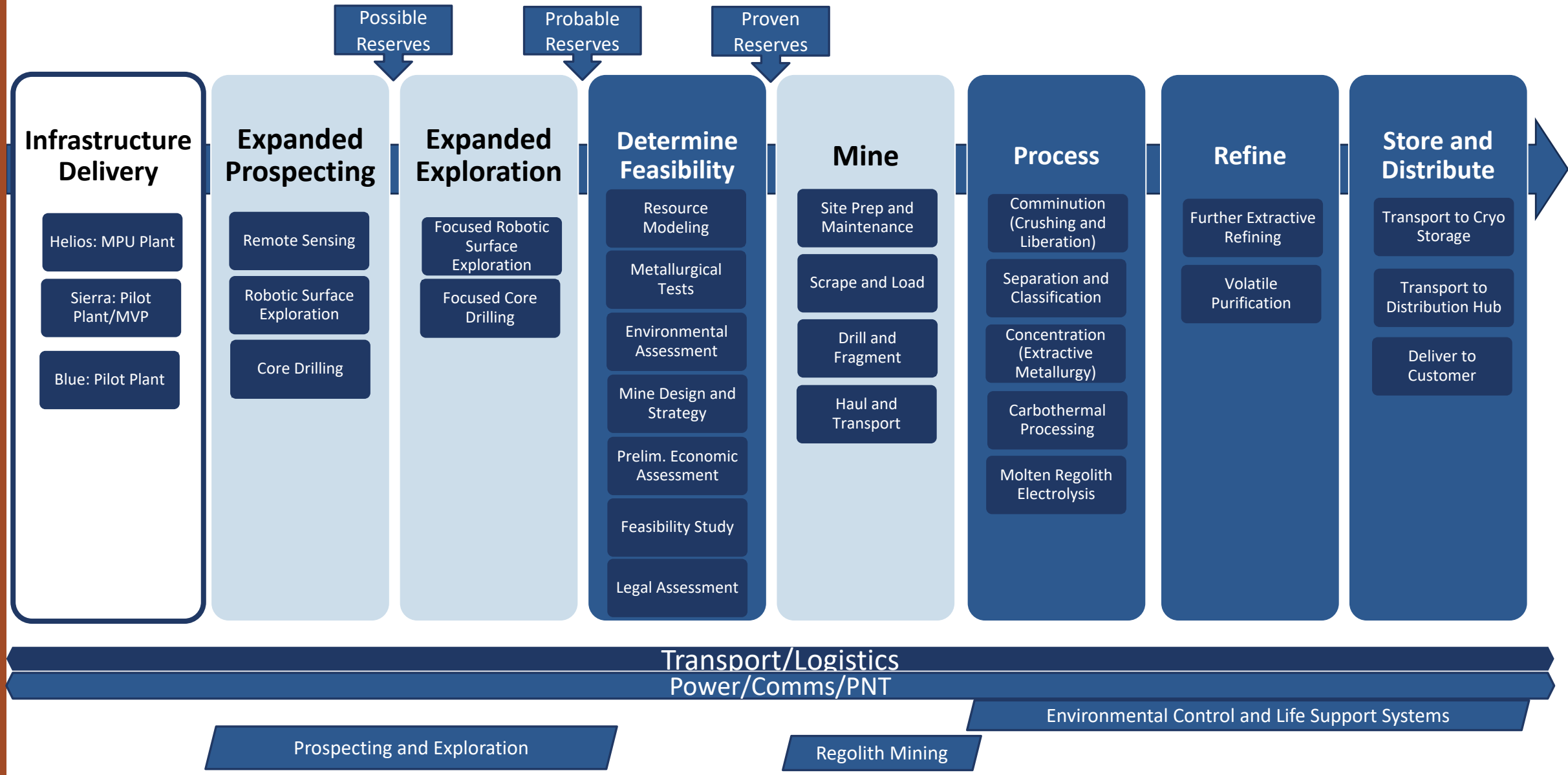
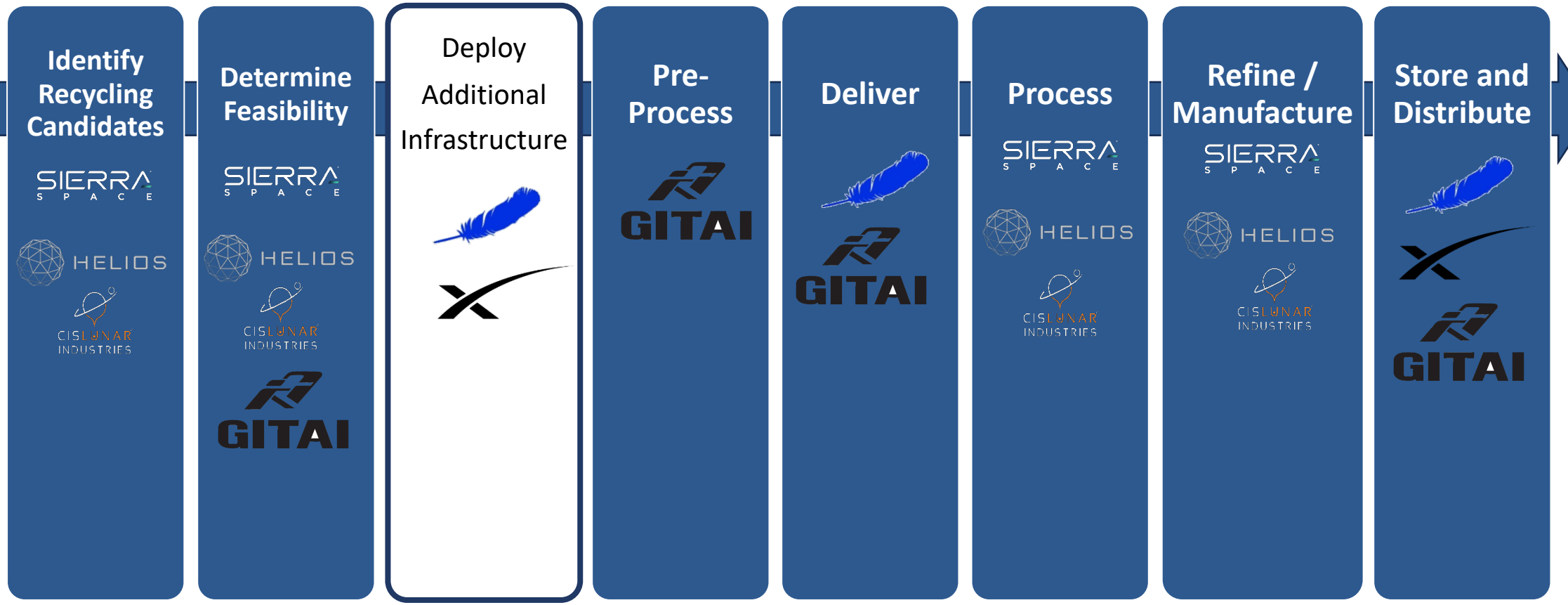


Foundation Phase (Years 3-6)

Industrial Phase (Years 6-10)

ISRU – MATERIAL RECYCLING

It is advantageous to design single-use/limited lifetime materials and ISRU processes for recycling



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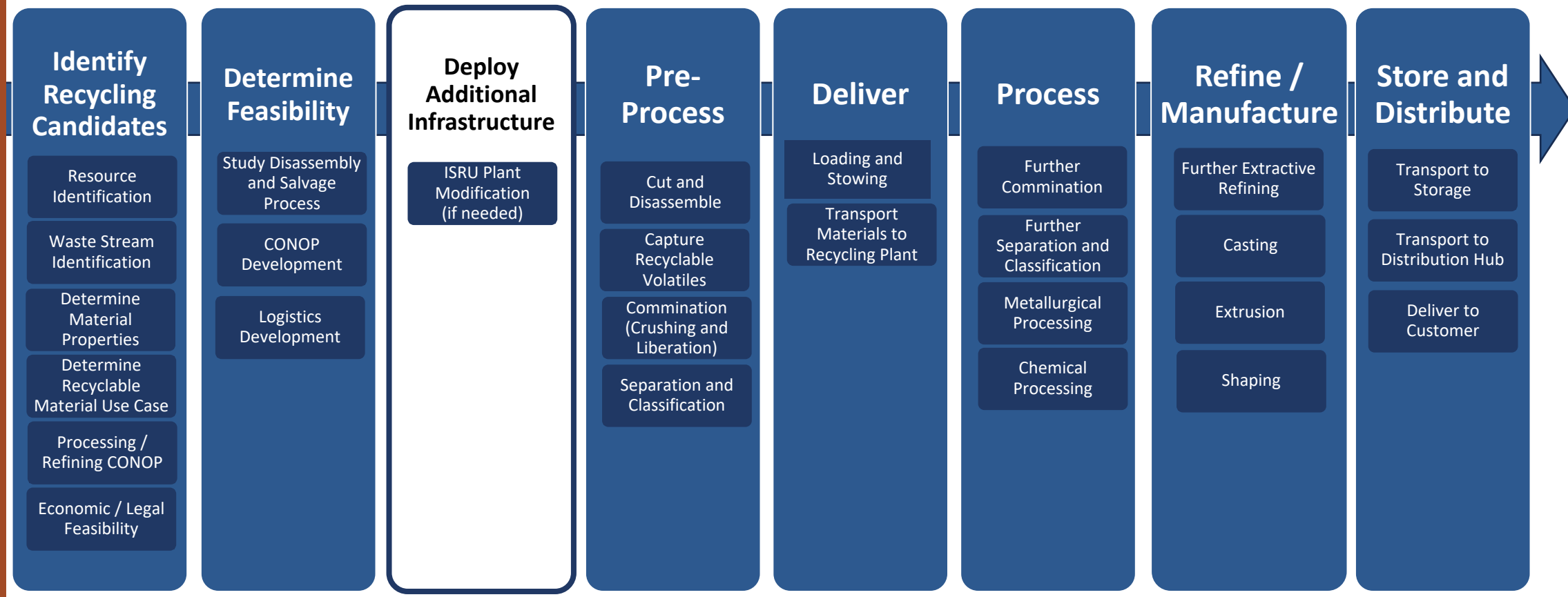
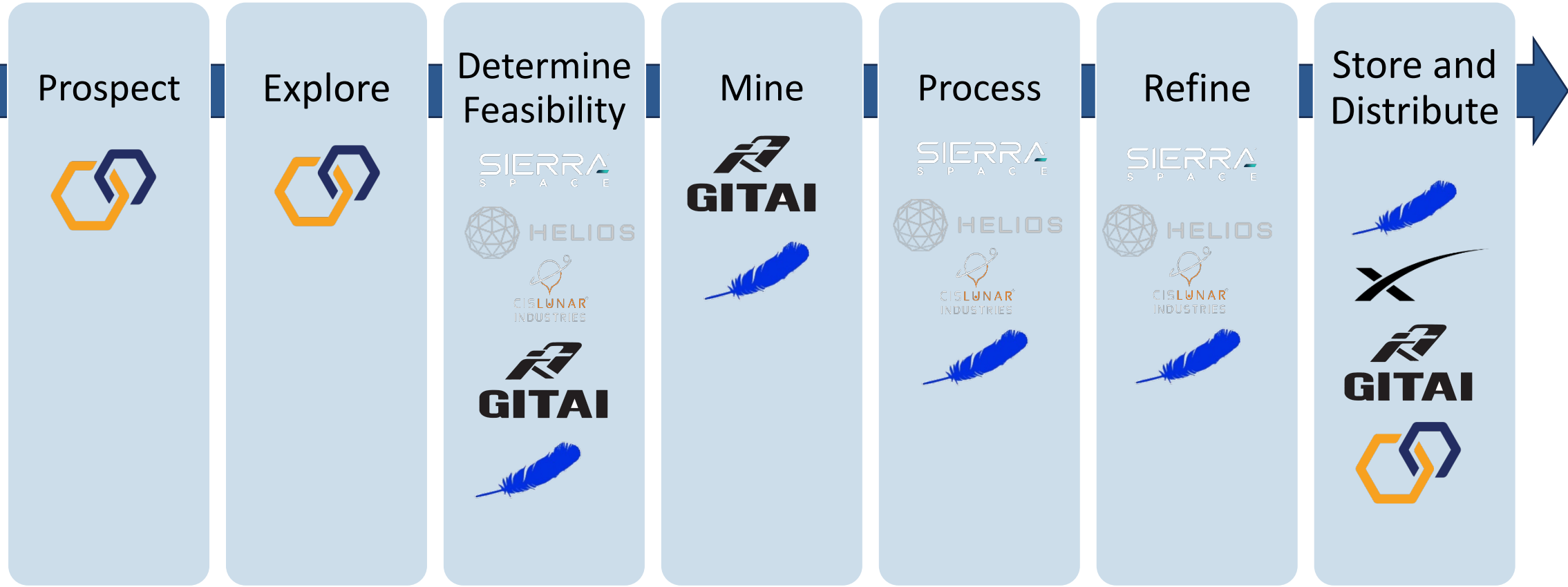


Foundation Phase (Years 3-6)

Industrial Phase (Years 6-10)

FUTURE ISRU – METALS (Fe, Al, Ti), H20 Ice, REE, and Si VCs



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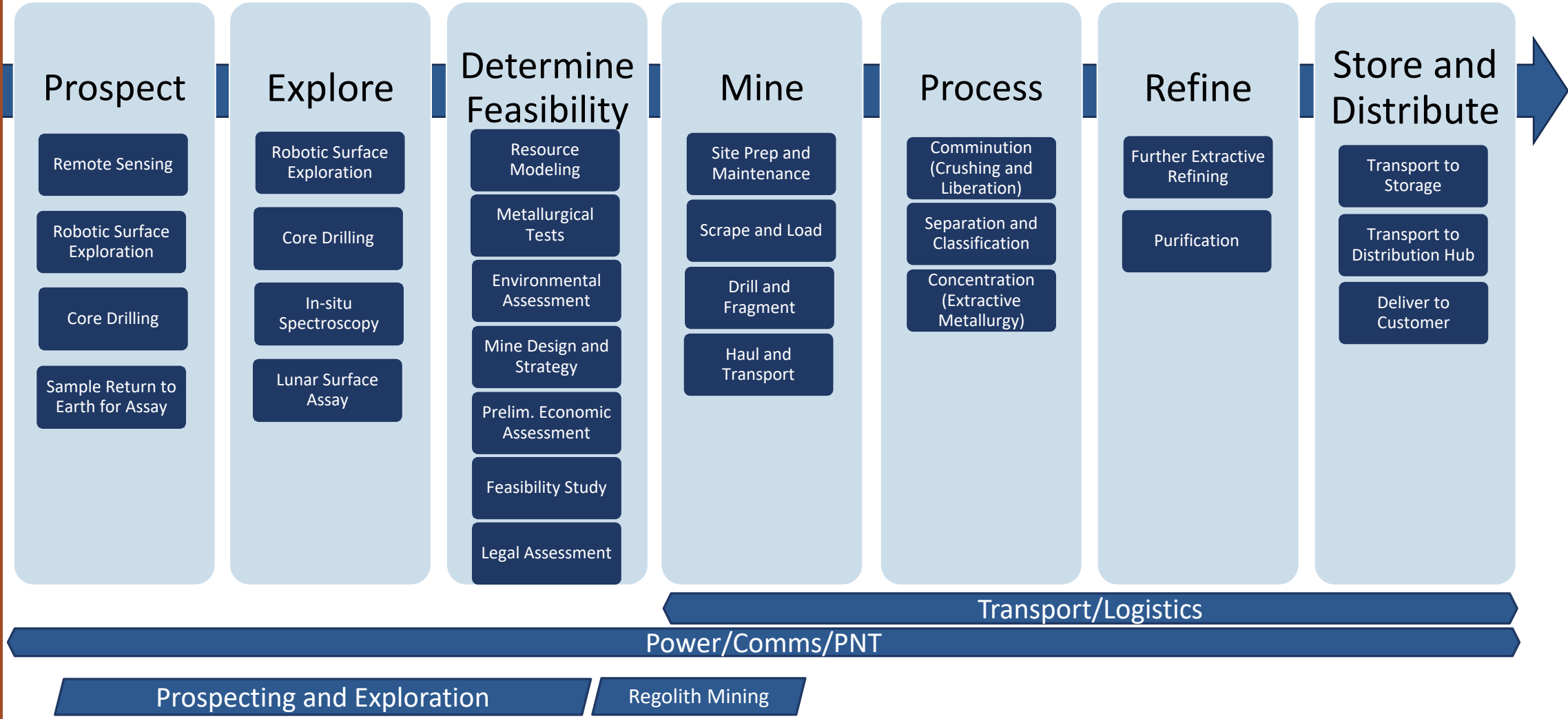


We want to hear your feedback!
LUNA10@DARPA.MIL

Value Chains

What other resource value chains need to be explored?

Any adjustments to order, capability timeline, sub-activities, or connections between value chains?

End of life plans & Recycling of lunar infrastructure

Who should be responsible for regulating disposal plans?

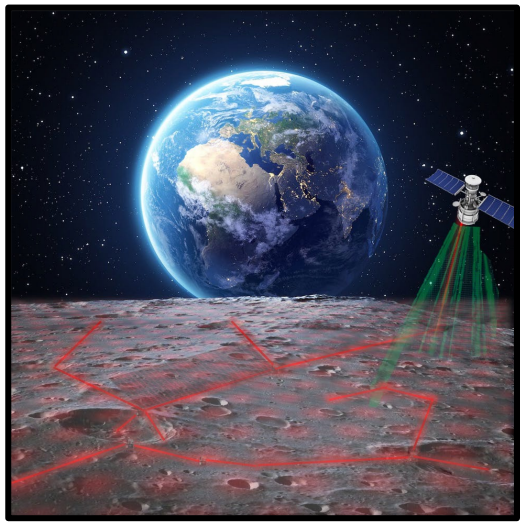
How could your process contribute to a lunar recycling economy?

Lunar Code of Conduct

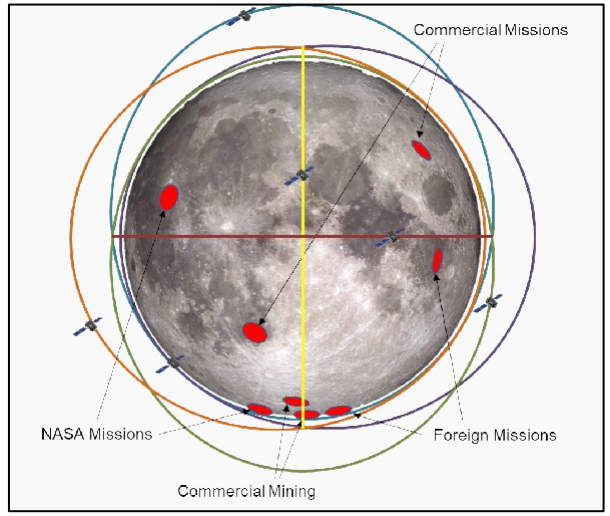
What ISRU-related topics should be covered by a Lunar Code of Conduct?

10-year Lunar Architecture (LunA-10)

Lunar Operating Guidelines for Infrastructure Consortium (LOGIC)



Six Hypotheses for Accelerating the Lunar Economy (SHALE)



Technology

Awardees Announced in November 2023

Interoperability

Currently **804** members

15% Academic
49% Industry
22% Government
11% Nonprofit
3% Other

Scalability