LSIC SPRING MEETING

APRIL 25, 2024

10-Year Lunar Architecture Capability Study (LunA-10) Government Integration Team

Government Integration Team

Elizabeth (Liz) Hyde
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Co-Lead

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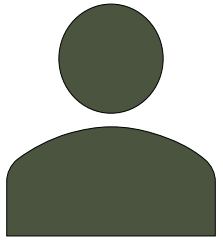

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Luke Sauter
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Daniel Kulp
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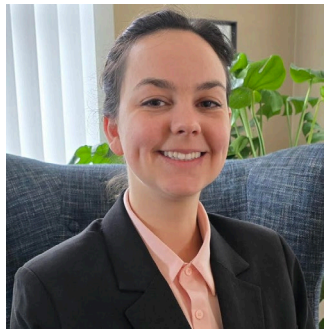
ISRU/Logistics



Katie Eppich
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Comms/PNT

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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?

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

Commercial Lunar Framework Assumptions

- Robotic only: No Human Spaceflight
  - Using standards (LunaNet) is acceptable
  - Avoid use of Govt. Infrastructure (DSN, TDRSS, etc.)
- Focus on Cislunar Space to Lunar Surface
  - Not focusing on down mass to Earth
  - Direct to Earth comms is an exception
- No Nuclear Power
- Geographic Location Agnostic
  - Solutions provided for either Equatorial or Polar cases.

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

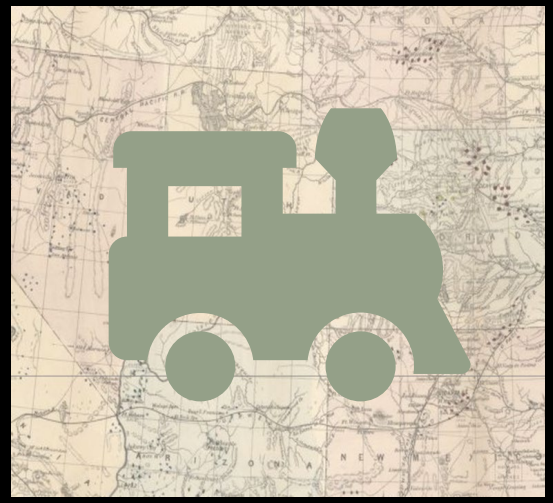
- Larger vehicles and devices
  Some business cases close
  Focused on MVE demos

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



The Exploration Age

Image Credit: National Park Service

Exploration Age Definition

We are here, now.

Bespoke rovers and instruments, self-sustaining (no grid)

Determine mining reserves, and plan locations to utilize resources

Demonstrate enabling technologies (Reactors, power, etc.)

- Tech-demo experiments, which will lead to commercial MVE experiments

Lander-based equipment staging, which will be connected with later

- "Fort Astoria"

Assumptions

Launch Costs: $1M/kg

Orbital PNT/STM Services – Little to none

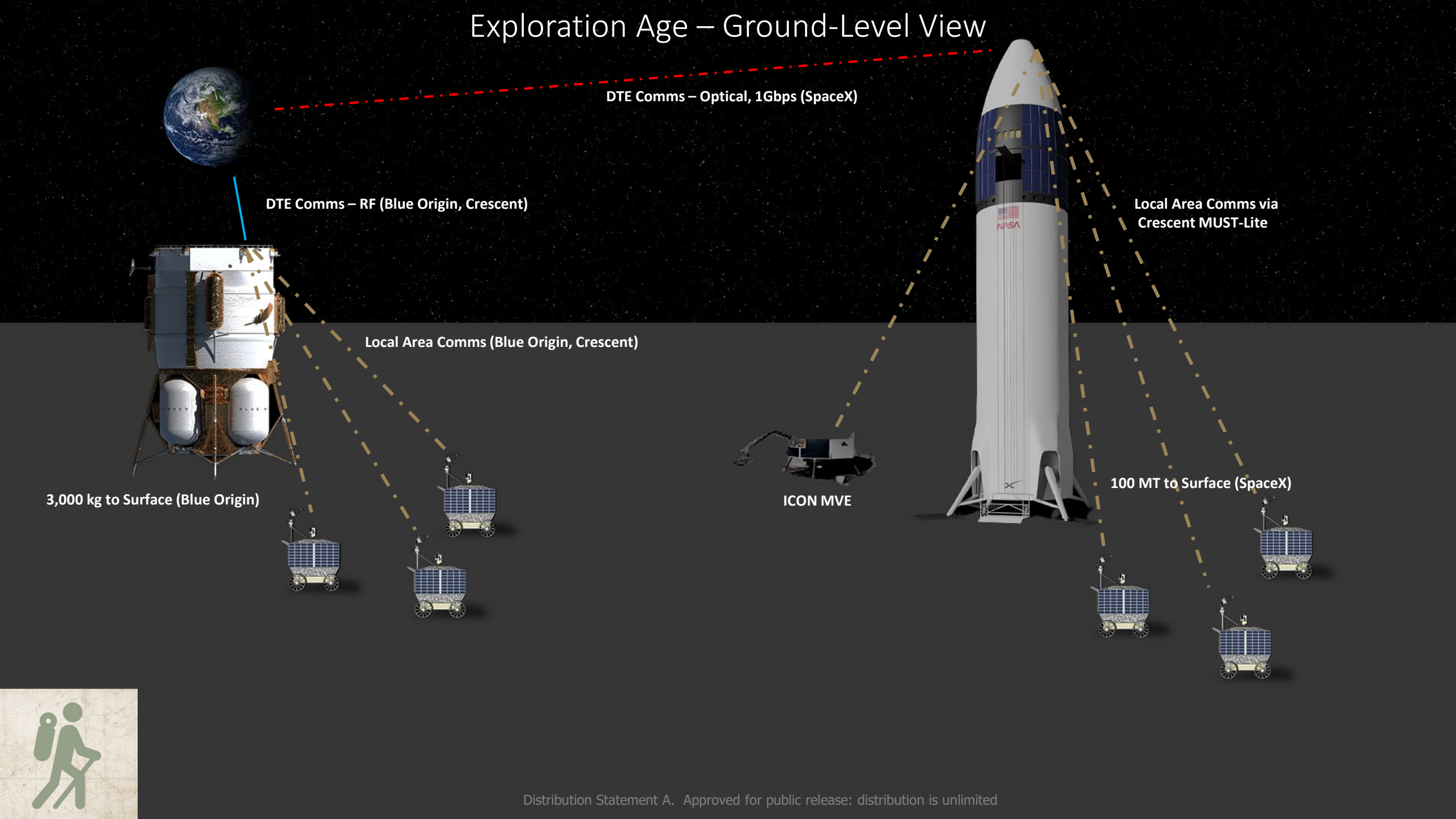
All services are lander based, to include comms backhaul to Earth

Today's Rover tech (VIPER-class)

- Carrying Capacity = ~100 kg max
- Speed = ~1 km/hr
- Limited to no survive the night capability

Experimental ISRU

Exploration Age – Ground-Level View



Exploration Age – Economy

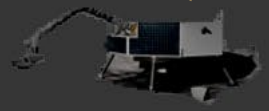
$1-5M/mo subscription service (SpaceX)

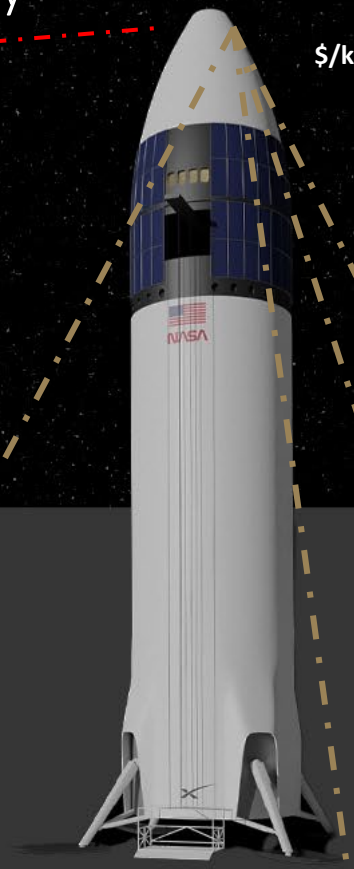
$/kg mass to surface (SpX)

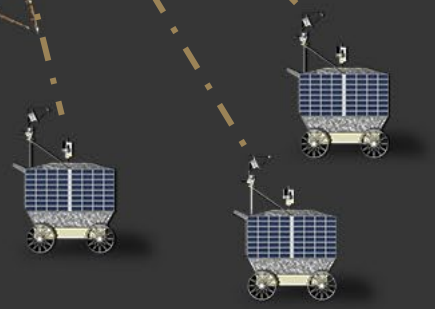
Subscription Fee + $/kb
data backhaul (Blue Origin)

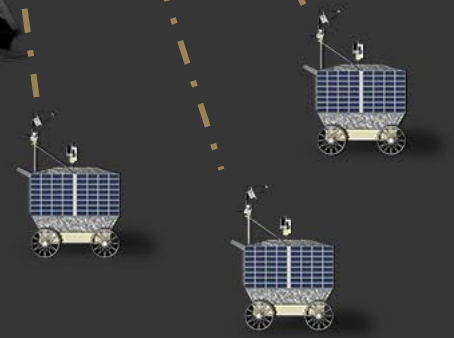
$10M/mo local data w/ SpaceX
backhaul (Crescent)

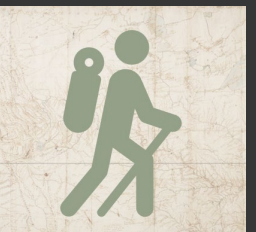
$/kg mass to surface (Blue Origin)
$/W wired power (Blue Origin)
$/W beamed power (Blue Origin)











The Foundational Age

Image Credit: National Park Service

Foundational Age Definition

Faster, heavier, standardized rovers, with roads/trails to ride on [Covered Wagons]

Improved Surface building (roads, landing pads, foundations)

Building of Power/PNT/Comms infrastructure

Prep-work and MVEs for future tech (Lunar rail beds and fabrication)

Functional ISRU begins.

Assumptions

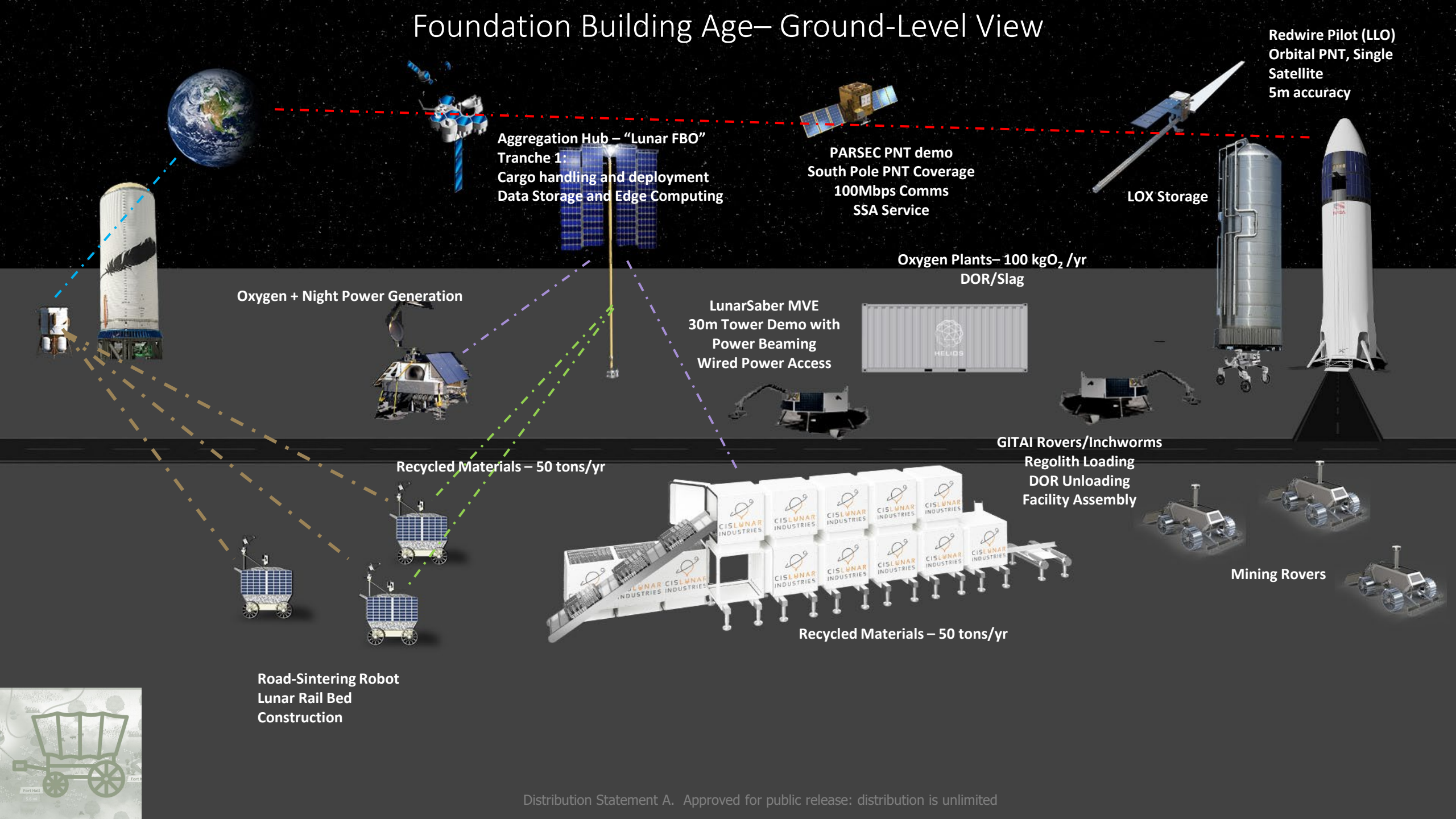
Decreasing launch Costs: $.75M/kg

Commercial Orbital PNT and STM services in infancy

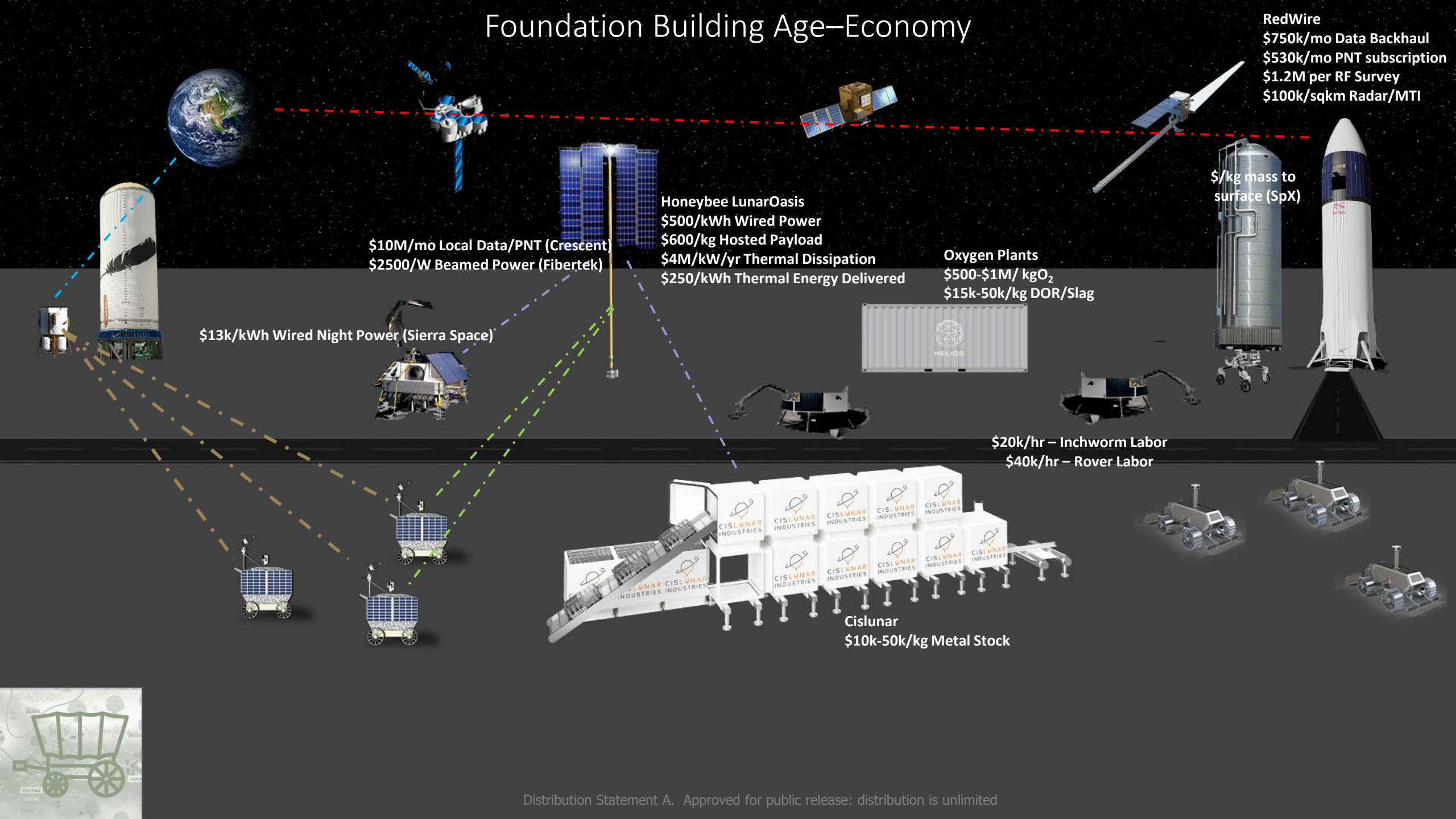
Commercial Orbital Comms Relays growing

Initial ISRU reserves across the Moon are determined, and can begin to be mined

Foundation Building Age– Ground-Level View



Foundation Building Age–Economy



The Industrial Age

Image Credit: Library of Congress

Industrial Age Definition

Lunar Rail logistics backbone ("Transcontinental Railroad")

Large, excavation-class rovers (needed for rail construction, reused for mining)

As hardware lifetime of pilot plants ends, recycling begins

- The pioneer "forts" close, and RR stops become the center of economic activity

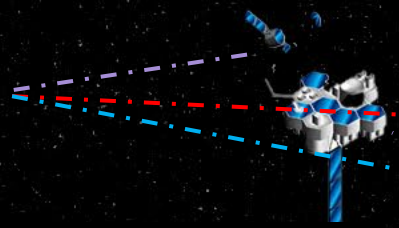
Assumptions

Orbital PNT and STM have reached full constellation status

Large-scale power generation on the surface has started; lunar utilities are commercially viable

Comms coverage and latency allow routine teleoperation of robotics

Industrial Age– Ground-Level View

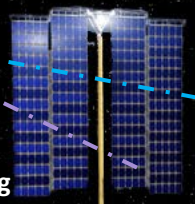


LunarSaber Phase 2
Multi-Unit w/ Mesh Network
Thermal Tent, Fibertek Power, Crescent Comms

Crescent PARSEC
South Pole Coverage
100 Mbps
SSA Service

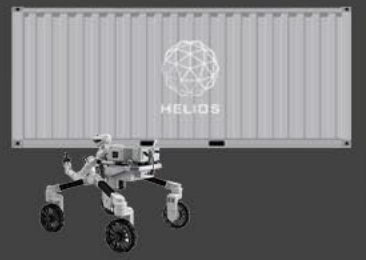
Redwire Orbital PNT (LLO)
Orbital PNT, Comms Relay, SSA
South Pole Coverage

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



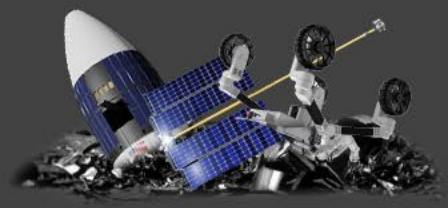
Regolith/Scrap Loading
DOR/Metals Unloading
Facility Assembly

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

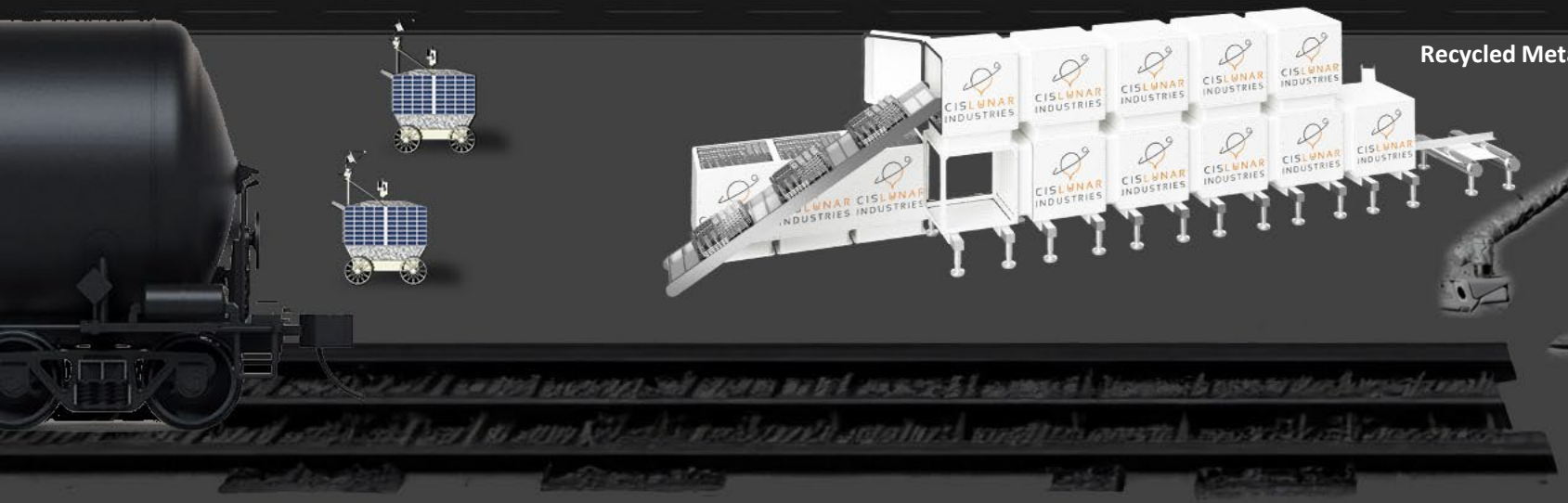


Landing Pad Building
Mk1 Class (ICON)

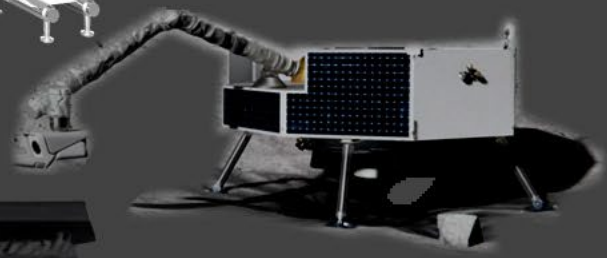
STN Power – 5000 kWh



Scrap Yard
Retired Hardware +
Scrapping Robotics



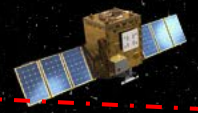
Recycled Metals – 500 tons/yr



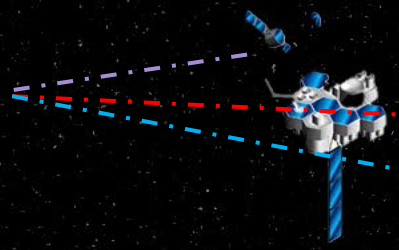
Track Building (Northrup Grumman)
5 km/yr
Rail Line – 10-15 km
Load Capacity – 10,000 kg

Industrial Age– Economy

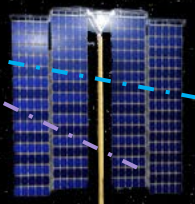
Honeybee Lunar Oasis
$270/kWh Wired Power
$360k/kg Hosted Payload
2.1M/kW/yr Thermal Dissappation
$130/kWh Thermal Energy Delivered

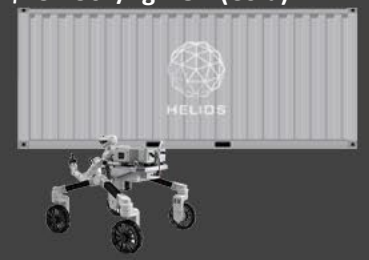


Redwire
$750k/mo Data Backhaul
$530k/mo PNT Subscription
$1.2M per RF Survey
$100k/sqkm Radat/MTI



$1000/kWh Beamed Power (Fibertek)
$1/Gb Optical DTE comms (Fibertek)
$850k/mo Local Data + PNT (Crescent)

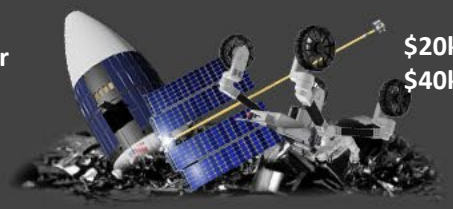




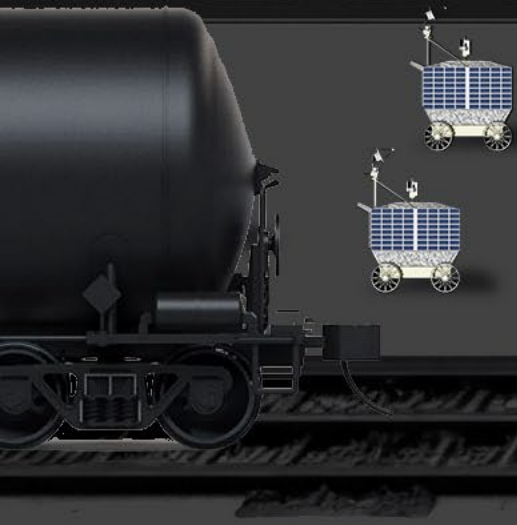
Oxygen Plants (Sierra Space, Helios)
$500k-1M/kg$O_2$
$15k-50k/kg DOR (Cold)

ICON Landing Pad Building
$500k/landing
Road Building
$25k/sqM

$6,500/kWh Wired Night Power

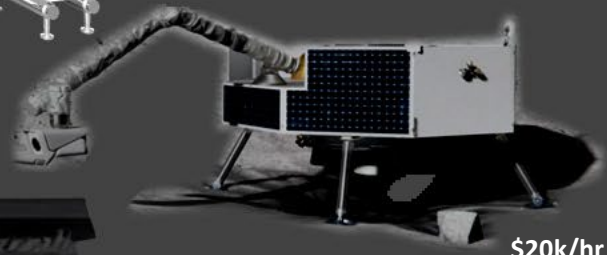


$20k/hr Inchworm (GITAI)
$40k/hr Rover (GITAI)



$10-15k/kg Recycled Metals(Cislunar)

$2-5M/trip Train Fare
$20/kg-km



$20k/hr Inchworm (GITAI)
$40k/hr Rover (GITAI)

The Jet Age

Image Credit: Liz Hyde (USGS)

Jet Age Definition

Trans -lunar and Back to Earth rocket transportation becomes commonplace

Ability to produce 100+ tons O2/month

- This will enable in-situ refueling of Starship, which can transit to other areas of the Moon

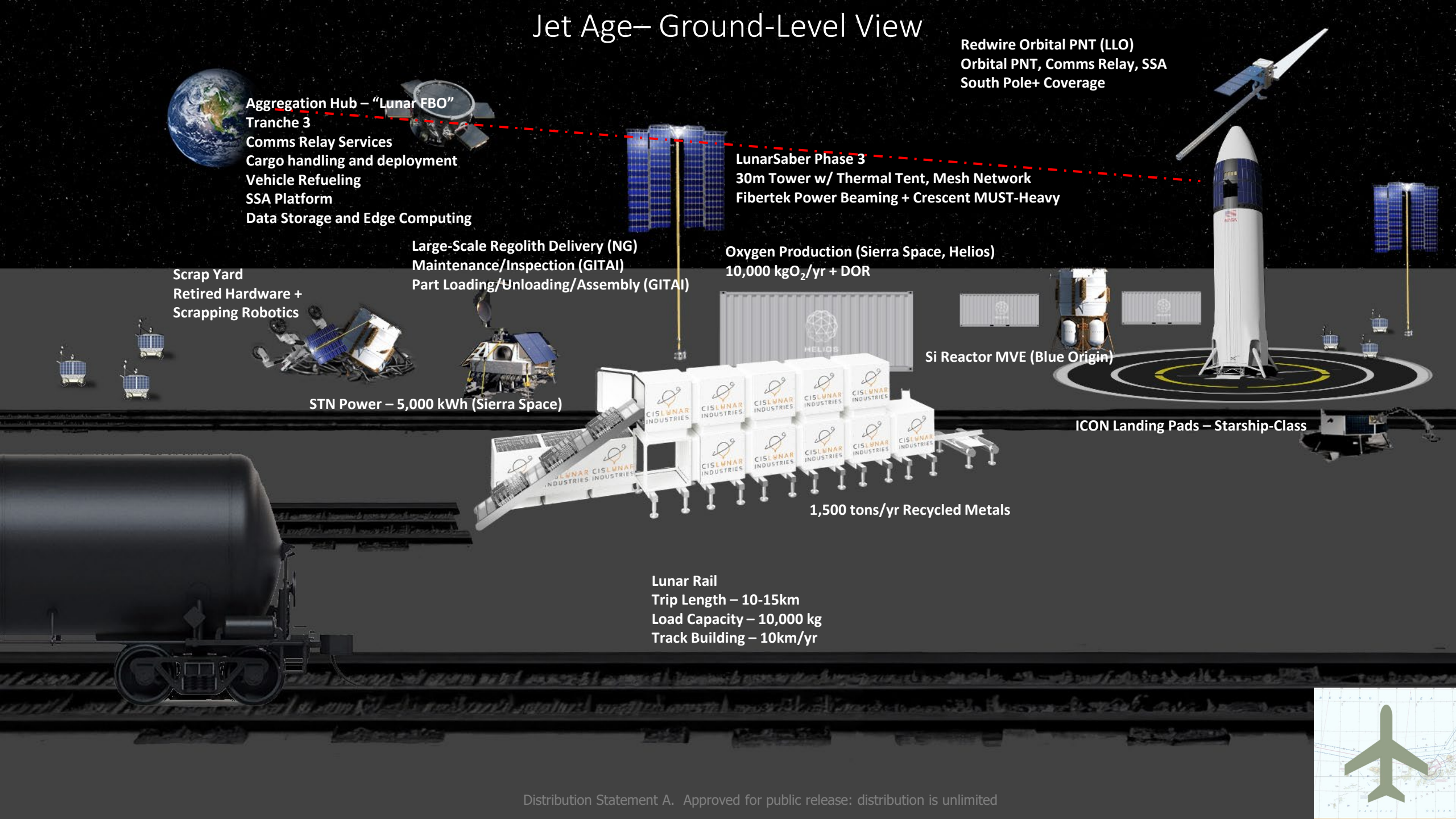
Assumptions

Full PNT and STM covered (of populated areas)

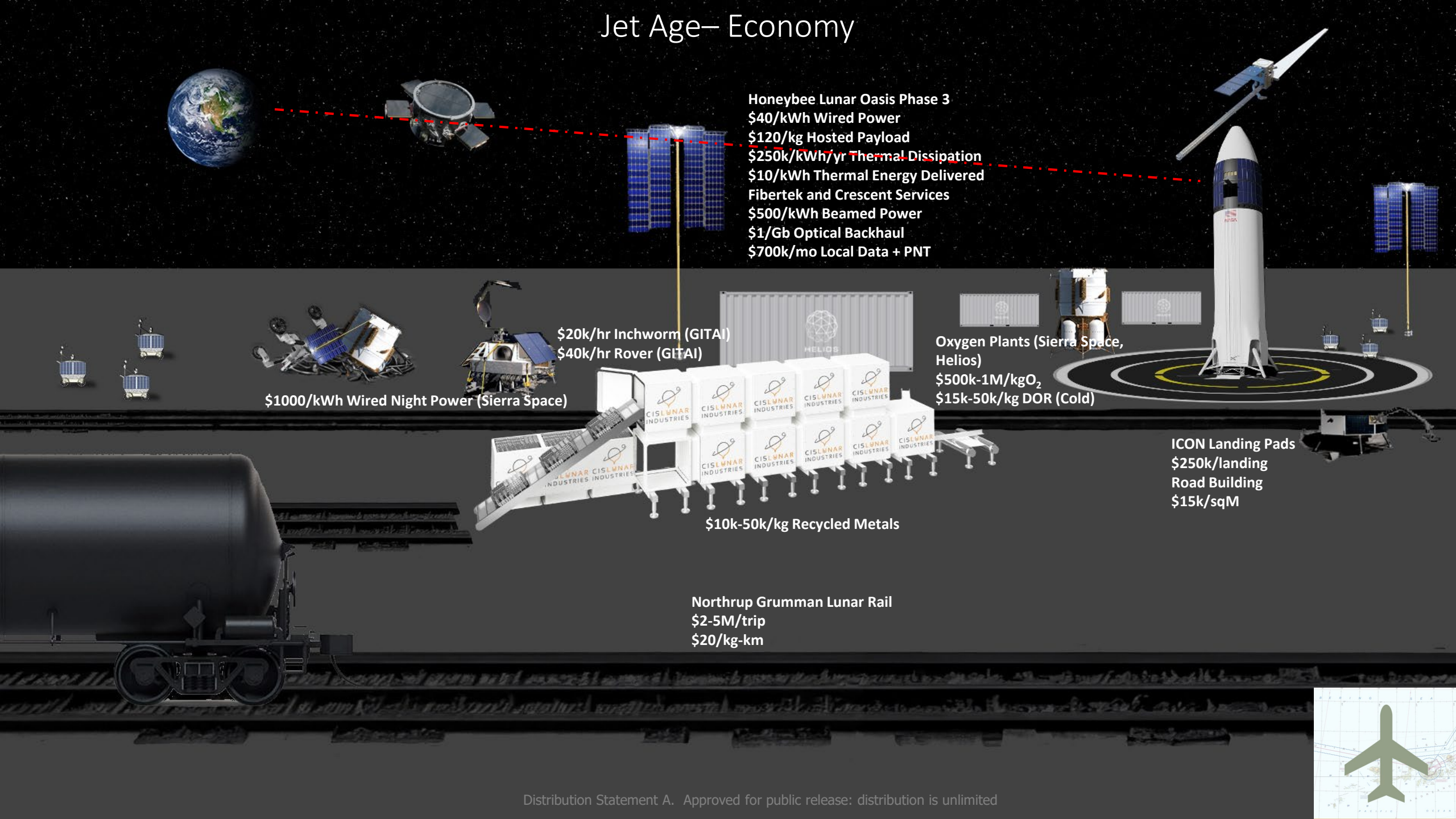
Full communications coverage around the Moon

Thermal rejection and Survive the Night shelters are realized

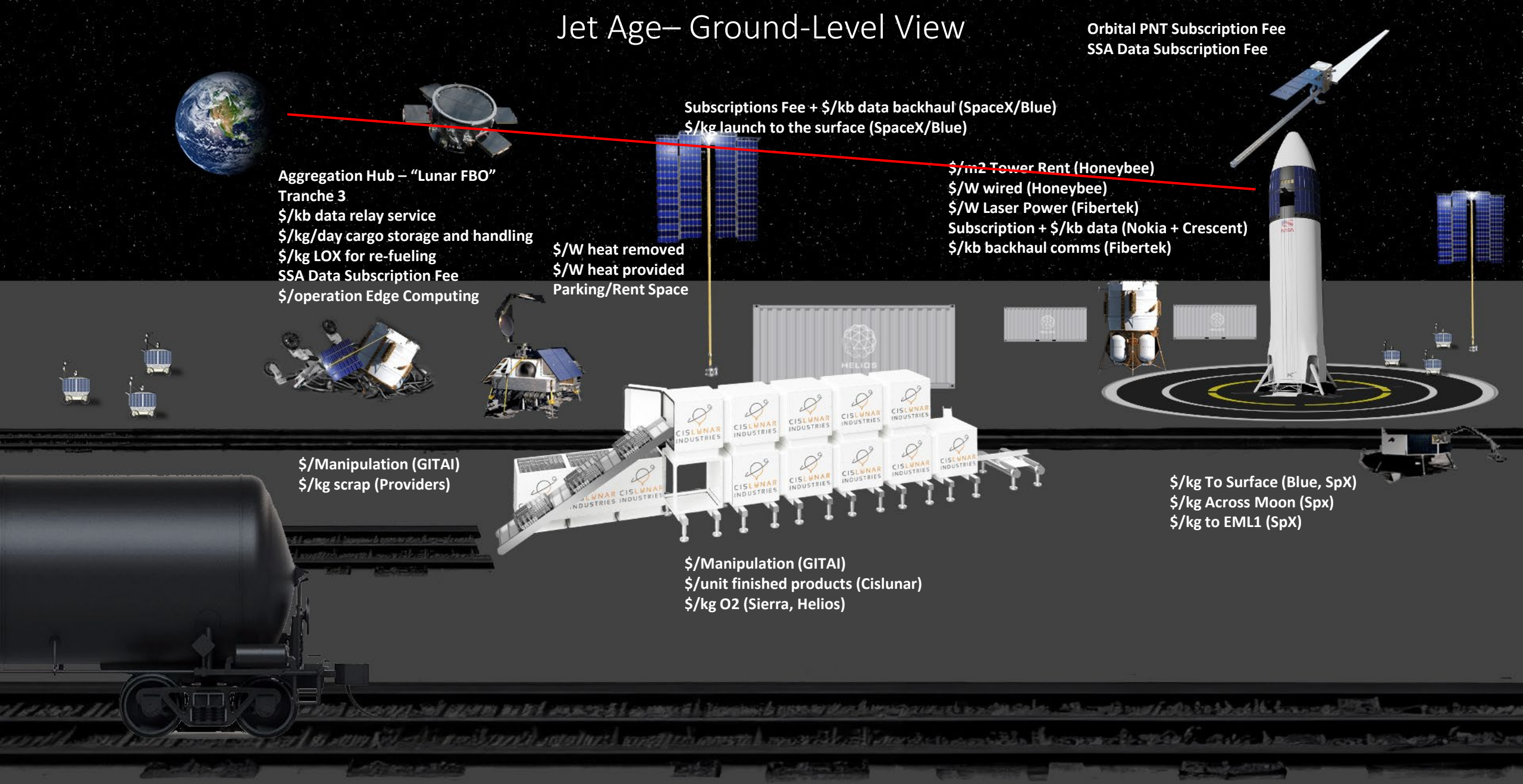
Jet Age– Ground-Level View



Jet Age– Economy



Jet Age– Ground-Level View



Value Chains

Image Credit: TechNewsWorld

Value Chain (VC) Development

- Five Enterprise Value Chains (VCs) by Five primary elements:
  - Transport/Logistics
  - Power
  - Communications
  - PNT
  - ISRU
- An enterprise chain has multiple candidate use cases: based on technical difficulty, CONOPS, location, or implementation timeline
- Primary Elements sub-divided into series of tasks to accomplish an element (2nd order analysis)

Value Chain Candidate Use Cases

5 Enterprise Value Chains per Primary Elements:

Transport/Logistics
"Pioneer Path" Rover
"Improved Road" Rover
Lunar Rail
Intra Lunar Space Travel

Position, Navigation, Timing
Two-Way Ranging
Traditional (GPS-Like)
Surface Traffic Management
Space Traffic Management

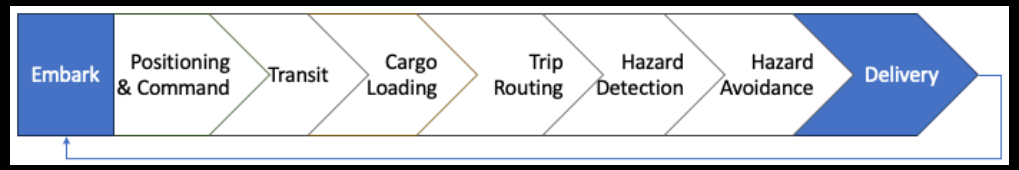
Communications
Surface – RF
Surface – Optical
Surface to Orbit – RF
Surface to Orbit – Optical
Direct to Earth – RF/Optical

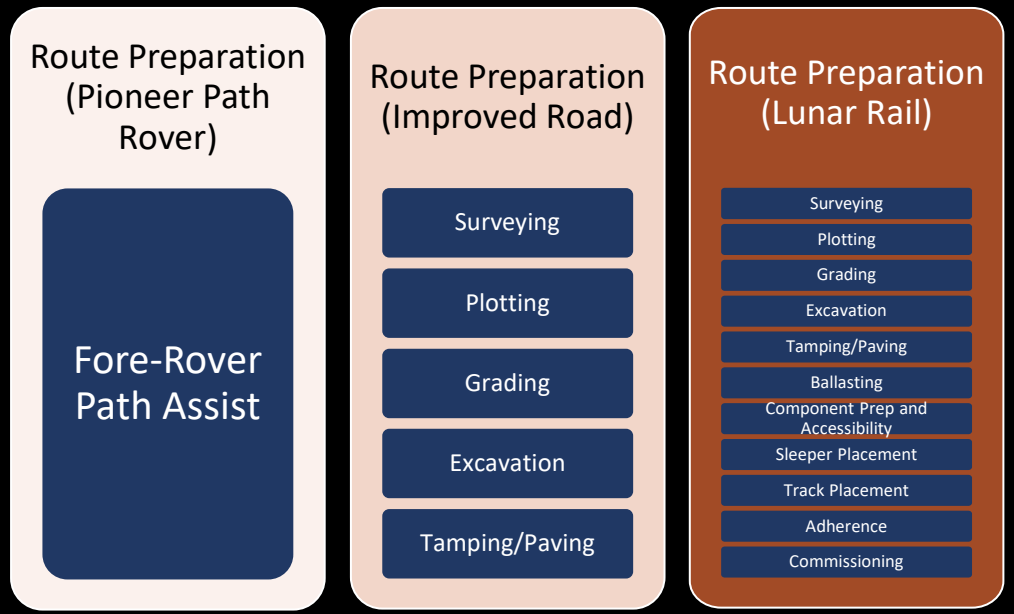
Power
Wired – On Lander/Ship
Wired – Remote
Wireless – Remote

In-Situ Resource Utilization
Oxygen (From Regolith)
Material Recycling
Metals/Water Ice/REE/Si

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

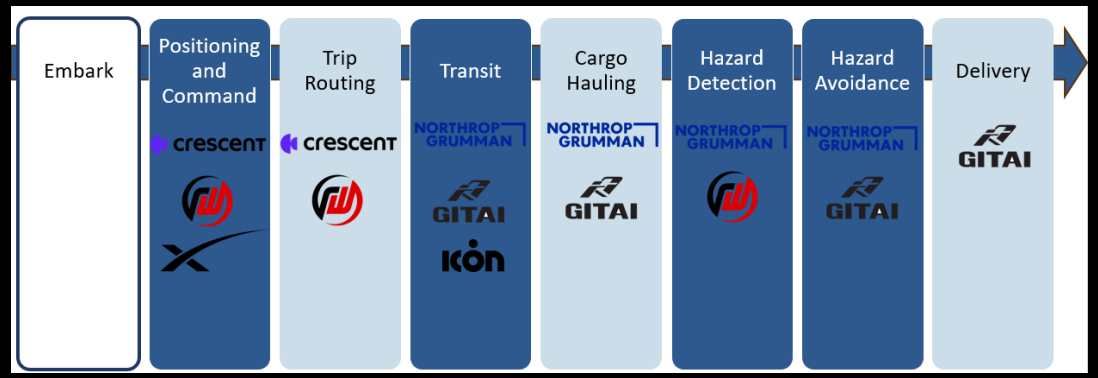
Element tentatively addressed in LunA-10

Element not presently addressed in LunA-10

In/Out Gate

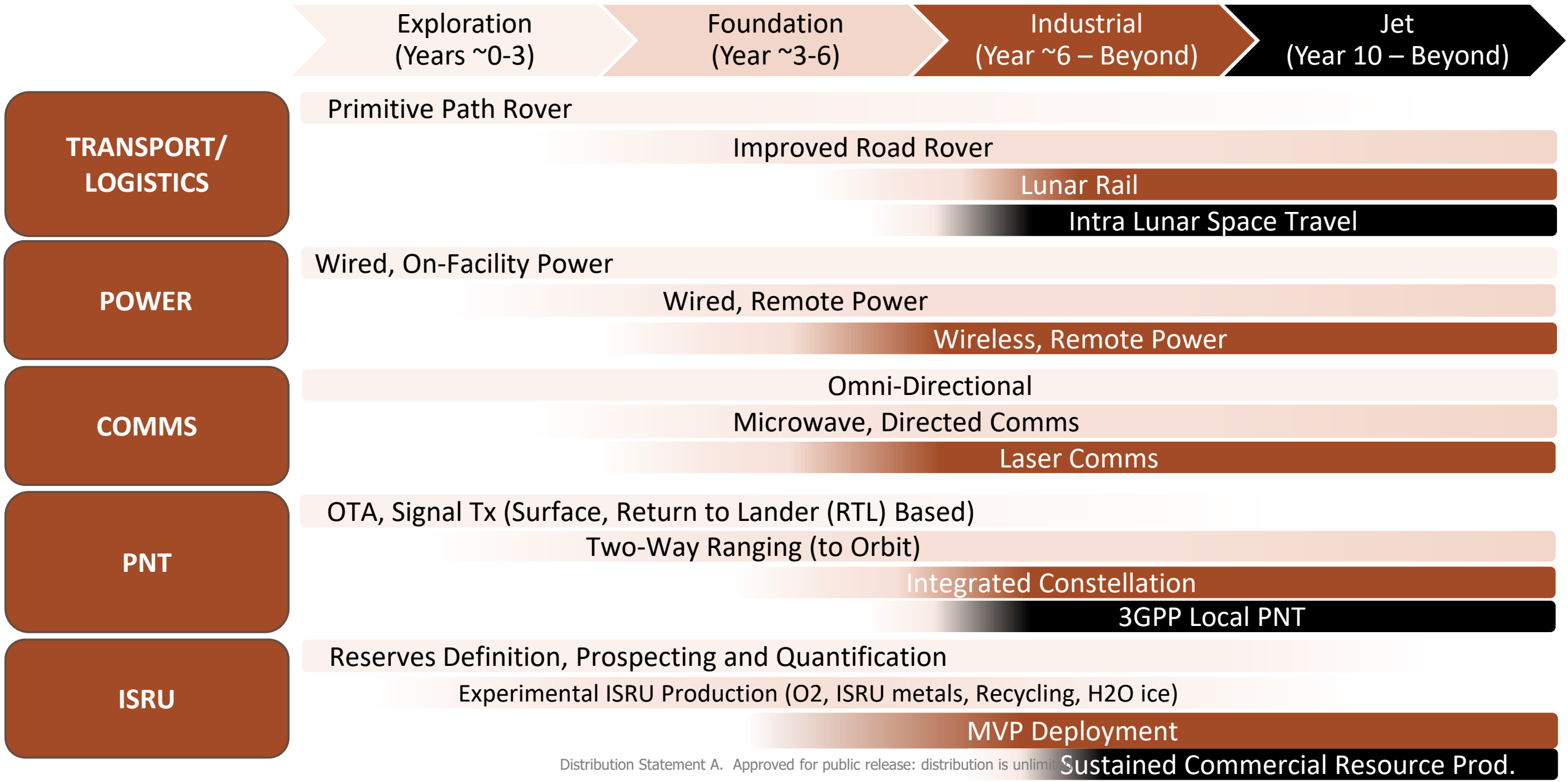
Enabler Connection — Additional engagement from the greater lunar surface community needed or encouraged

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



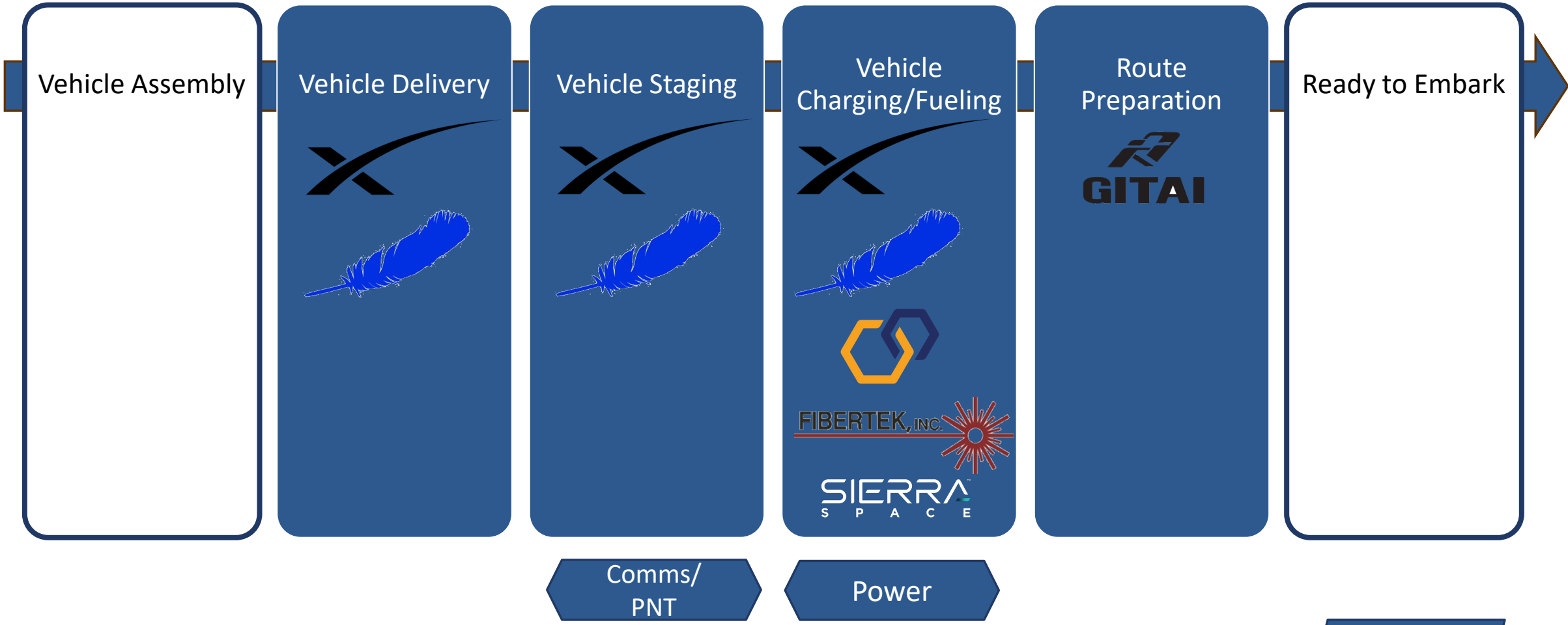
An expandable and adaptable framework for multiple functional areas and use cases

VCs Through the LunA-10 Decade (and Beyond)



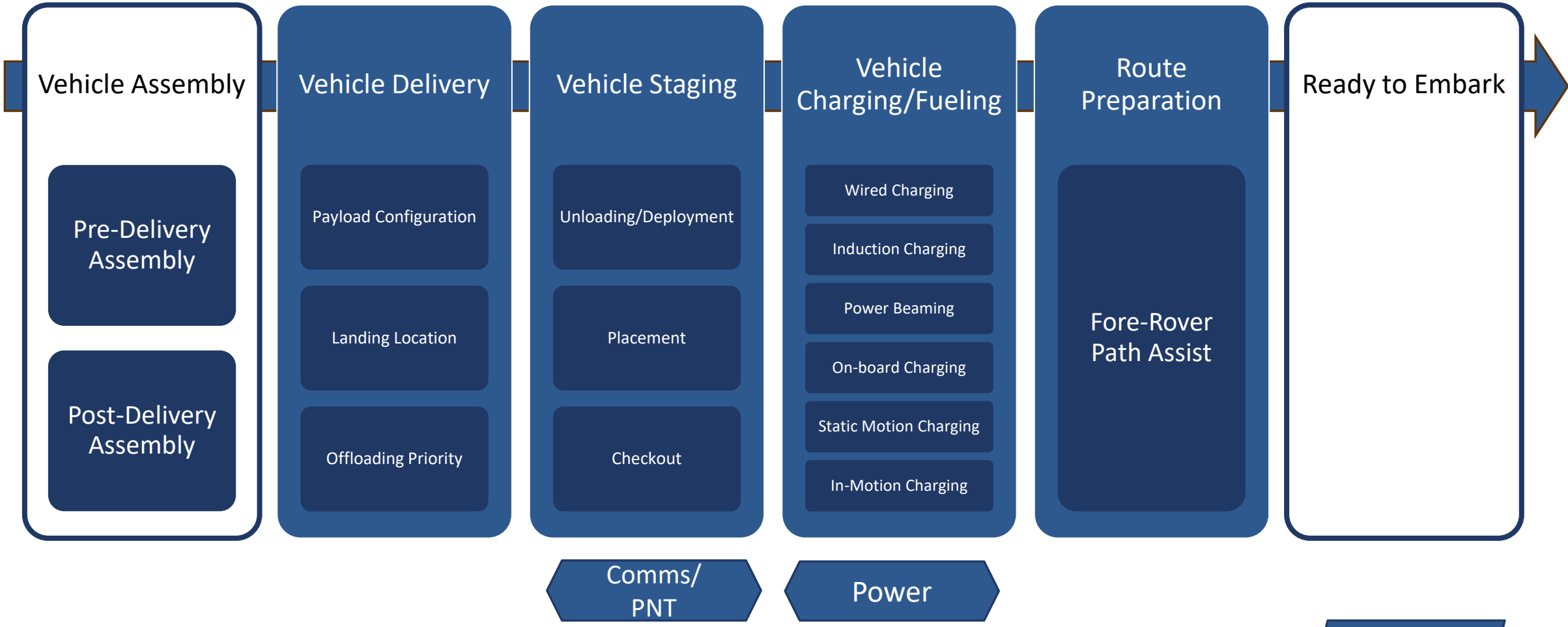
Exploration Phase (Years 0-3)

Logistics and Transportation Value Chain 1
Pioneer Path Rover (Prior to Embarking)



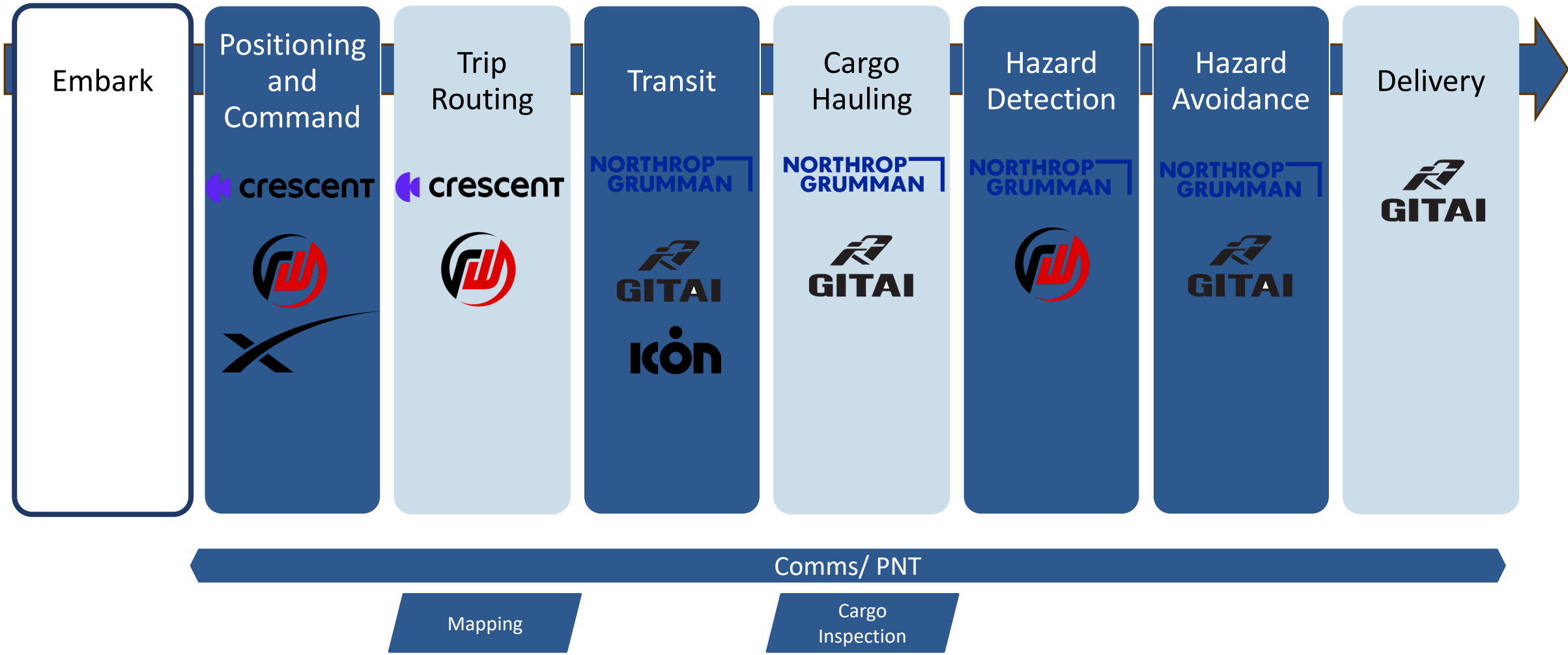
Exploration Phase (Years 0-3)

Logistics and Transportation Value Chain 1 Pioneer Path Rover (Prior to Embarking)



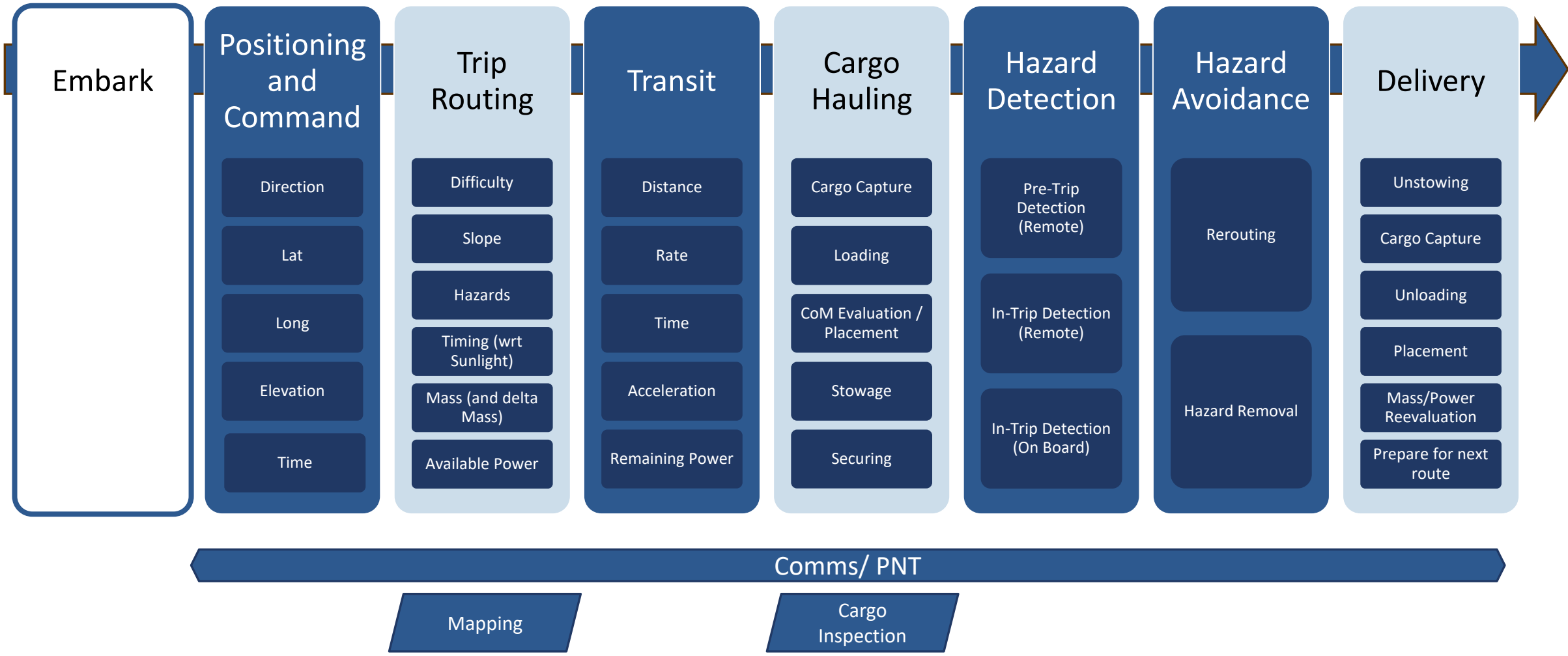
Exploration Phase (Years 0-3)

Logistics and Transportation Value Chain 1 Pioneer Path Rover (Embarked)



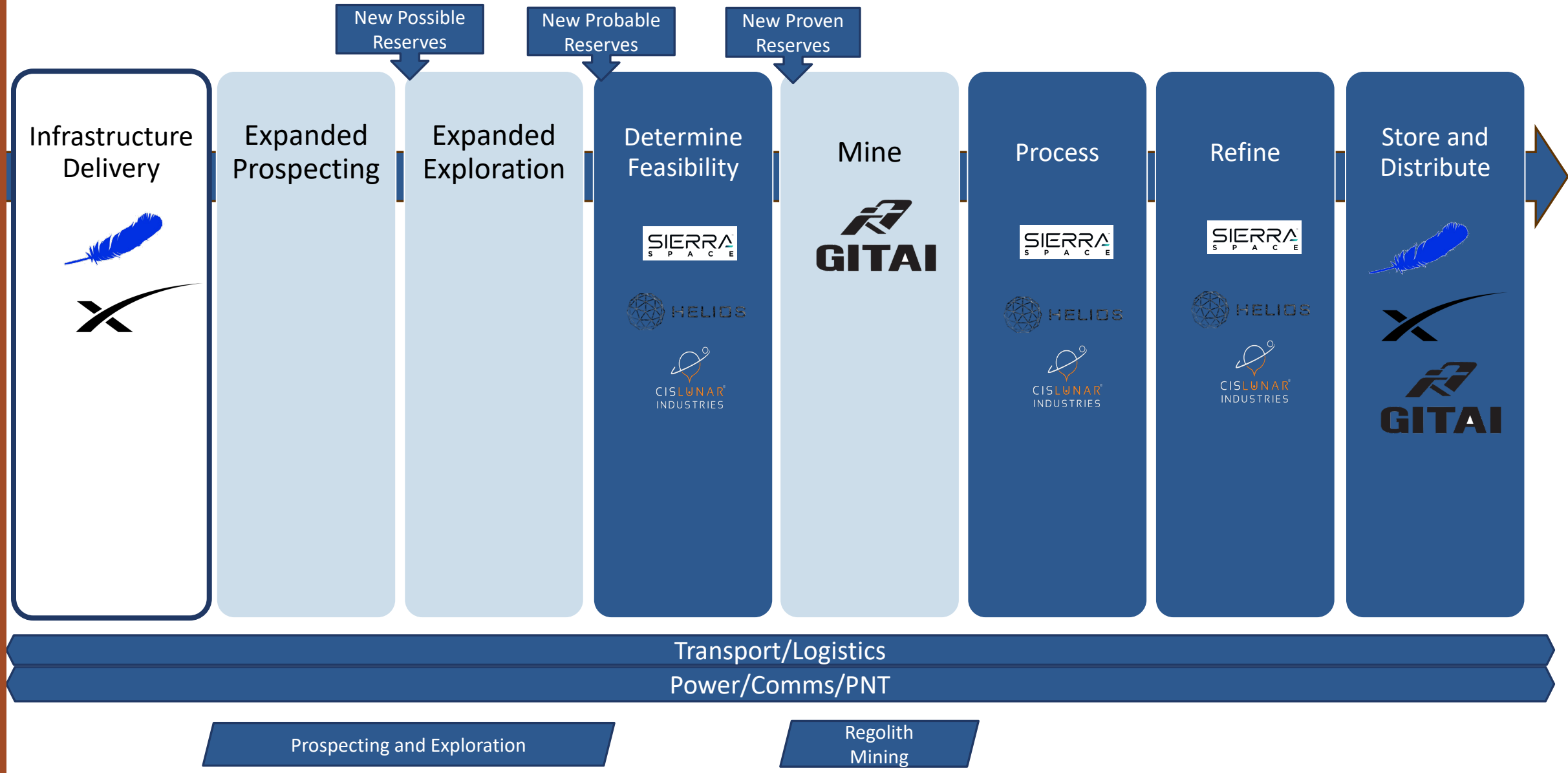
Exploration Phase (Years 0-3)

Logistics and Transportation Value Chain 1 Pioneer Path Rover (Embarked)



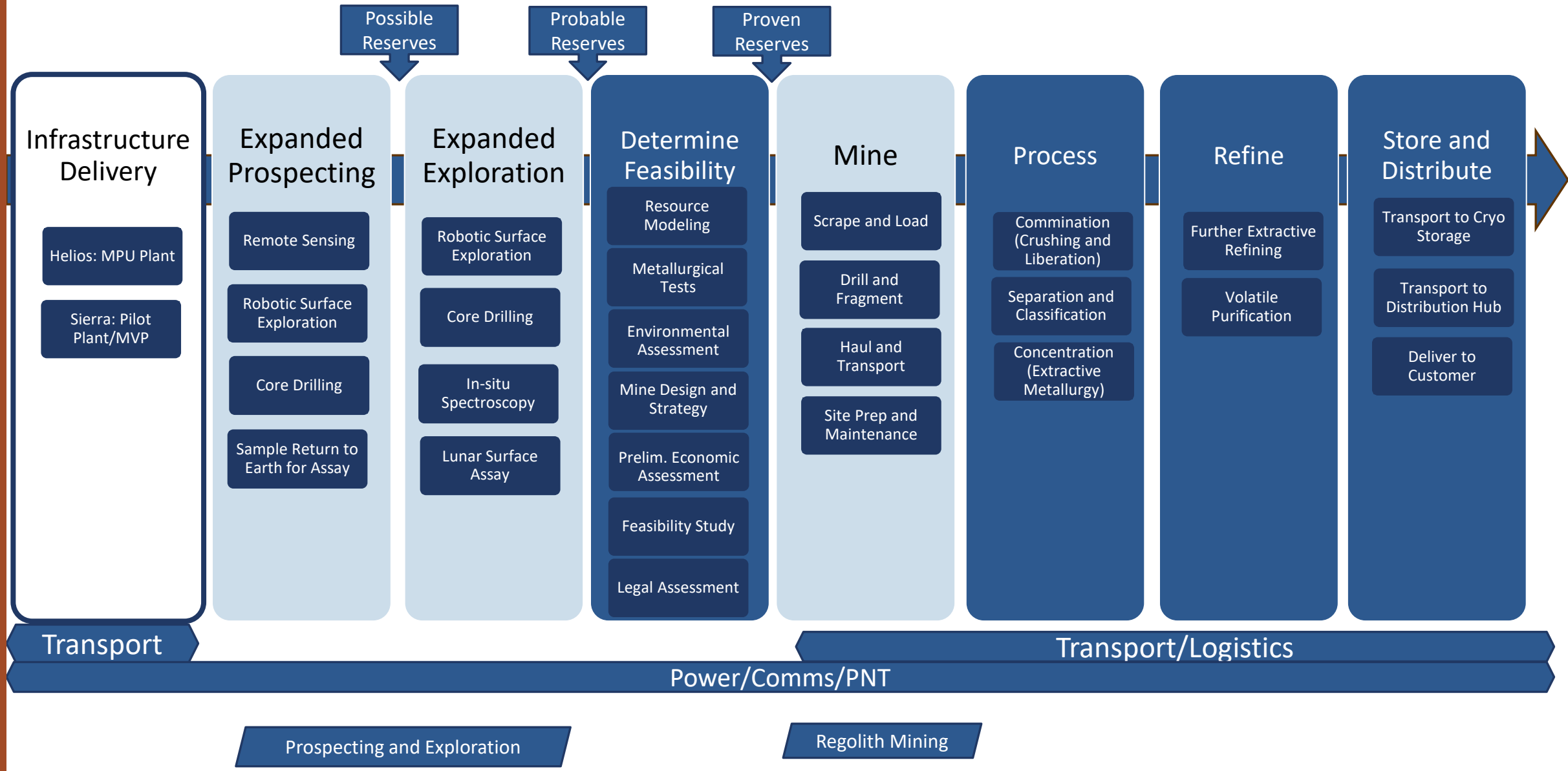
ISRU – Regolith Derived Oxygen Value Chain

Industrial Phase (Years 6-10)



ISRU – Regolith Derived Oxygen Value Chain

Industrial Phase (Years 6-10)



Have Any Questions?

Come talk to us here at LSIC!

Breakout Session 1

Transportation, Robotics, ISRU Team Presentations
Power, Communications, PNT/SSA Team Presentations

Breakout Session 2

Government Integration Team Frameworks & Value Chains

Appendices and Backup Slides

Appendix 1 – Nomenclature/Glossary

DOR – De-Oxygenated Regolith (waste material from O2 Reactors)
DTE – Direct-to-Earth (communications)
ISRU – In-Situ Resource Utilization
LTM – Lunar (surface) Traffic Management
MPU – Maximum Performance Unit – Commercially viable product
MVE – Minimum Viable Experiment – Demo-level proof of concept system
MVP – Minimum Viable Product – Deployment level system, at a minimum performance threshold
PNT – Position, Navigation, and Timing
Re-ISRU – ISRU for Recycling
SSA – Space (orbital) Situational Awareness
STN – Survive The (Lunar) Night

Appendix 2 – LunA-10 Timeline

LunA-10 Framework Timeline

Year/Task	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Age	Exploration Age			Foundational Age			Industrial Age				Jet Age
Artemis	Artemis II	Artemis III Gateway Launch		Artemis IV		Artemis V LTV	Artemis VI	Artemis VII Gateway Ops Pressurized Rover			
Other NASA	LRO Coverage	LRO Coverage Nokia LTE/4G Demo (PRIME-1)	LCRNS Alpha LRO Coverage Ends	LCRNS Bravo LIFT-1	LCRNS Charlie RFM Rover			LIFT-2			
Aggregation Hub			Tranche 1				Tranche 2			Tranche 3	
Orbital PNT							MUST corrections from Redwire			MUST 3GPP Service, <1m accuracy	
Surface PNT	MUST Two-Way Ranging			MUST Hybrid - 2-Way Ranging + Orbital Corrections						MUST 3GPP, <1m accuracy	
Orbital PNT & SSA (Redwire)			MVE - Single Satellite			MVP Constillation - South Pole coverage			Additional assets for equatorial coverage		
DTE Comms - RF	MK1-based DTE Li	Parsec Demo	Parsec Lunar Relay - South Pole Coverage			Redwire Constillation Access					
DTE Comms - Optical	Starship-based Optical Starlink										
Surface Comms - Optical					MVE - Nano LION		LION Micro				Multiple LIONs
Surface Comms - RF	MK1-based SAN	MUST MVP demo, Pathfinder node (ECS, DT		More MUST MVP/SAN units deployed: ECS (Comm via Lunar Relay, DTE Comm) SAN Service (Surface Comm)		Extend MUST network & implement 3GPP: ECS (Comms via Lunar Relay) SAN Service (Surfa					Extend network: MUST-Heavy, MUST units
Power Beaming					MVE - Nano LION		LION Micro				Multiple LIONs
Power Generation	Lander-based Solar			LunarOasis MVE		LunarOasis Network			LunarOasis Extended Network		
Thermal/STN				LunarOasis MVE		LunarOasis Network			LunarOasis Extended Network		MUST Heavy/NITE
ISRU (O2)			Initial Plants (100 kg/yr)			Commercial Plants (1,000 kg/yr)			Large-Scale Plants (10,000 kg/yr)		
ISRU (Recycling)				MVE Deployed	1st MSF Deployed				2nd MSF	3rd MSF	4th MSF
Roads and Pads		MVE/Tech Demo Mission		Road, Railbed, MK1-class Pad Building			Lunar Rail Build; Starship Pad begins			Starship Pads Complete, Extend Rail	
Lunar Rail				MVE Equipment Launched	Pilot Rail (0.2 km) MVE	Engineering Track, Start Building Operational Rail			10-15 km of Rail	Expand rail to outer settlements	

Appendix 3 – Value Chain Candidate Use Cases

5 Enterprise Value Chains per Primary Elements:

Transport/Logistics
"Pioneer Path" Rover
"Improved Road" Rover
Lunar Rail
Intra Lunar Space Travel

Position, Navigation, Timing
Two-Way Ranging
Traditional (GPS-Like)
Surface Traffic Management
Space Traffic Management

Communications
Surface – RF
Surface – Optical
Surface to Orbit – RF
Surface to Orbit – Optical
Direct to Earth – RF/Optical

Power
Wired – On Lander/Ship
Wired – Remote
Wireless – Remote

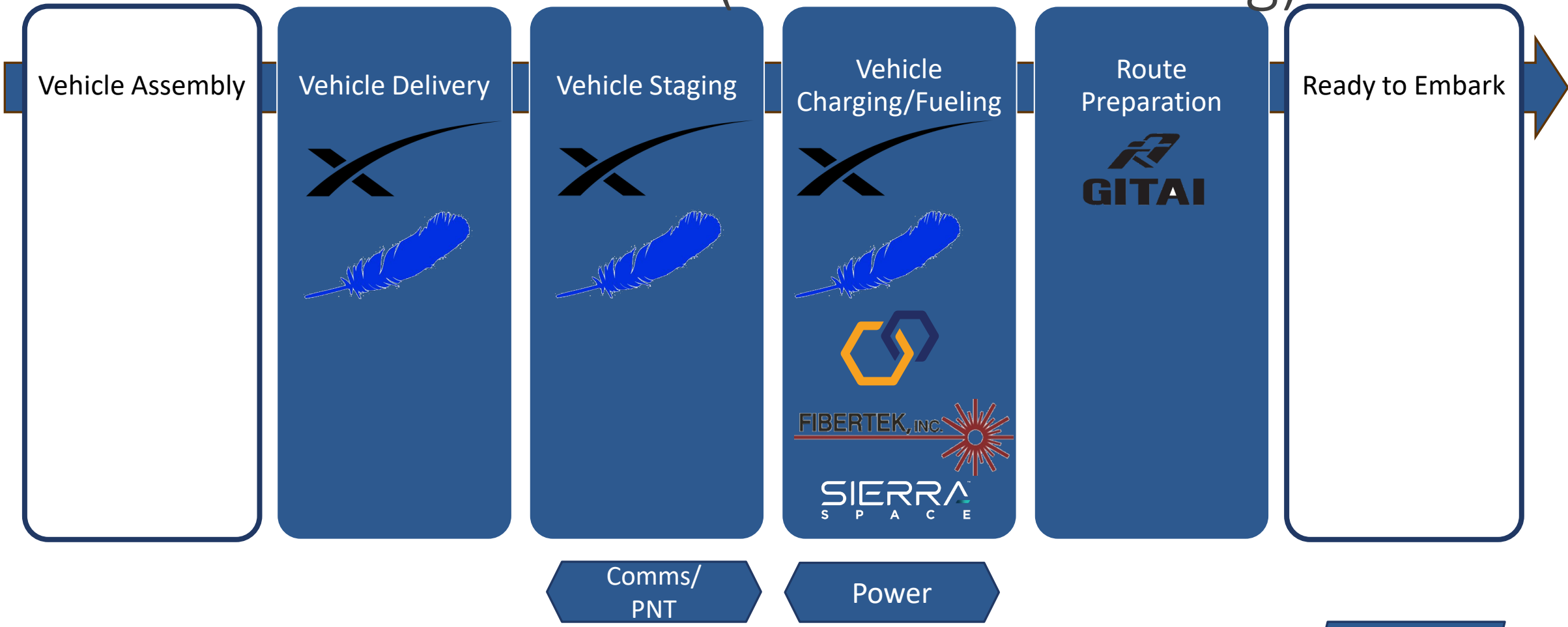
In-Situ Resource Utilization
Oxygen (From Regolith)
Material Recycling
Metals/Water Ice/REE/Si

Appendix 4 – Logistics and Transportation Value Chains

Image Credit: Icon

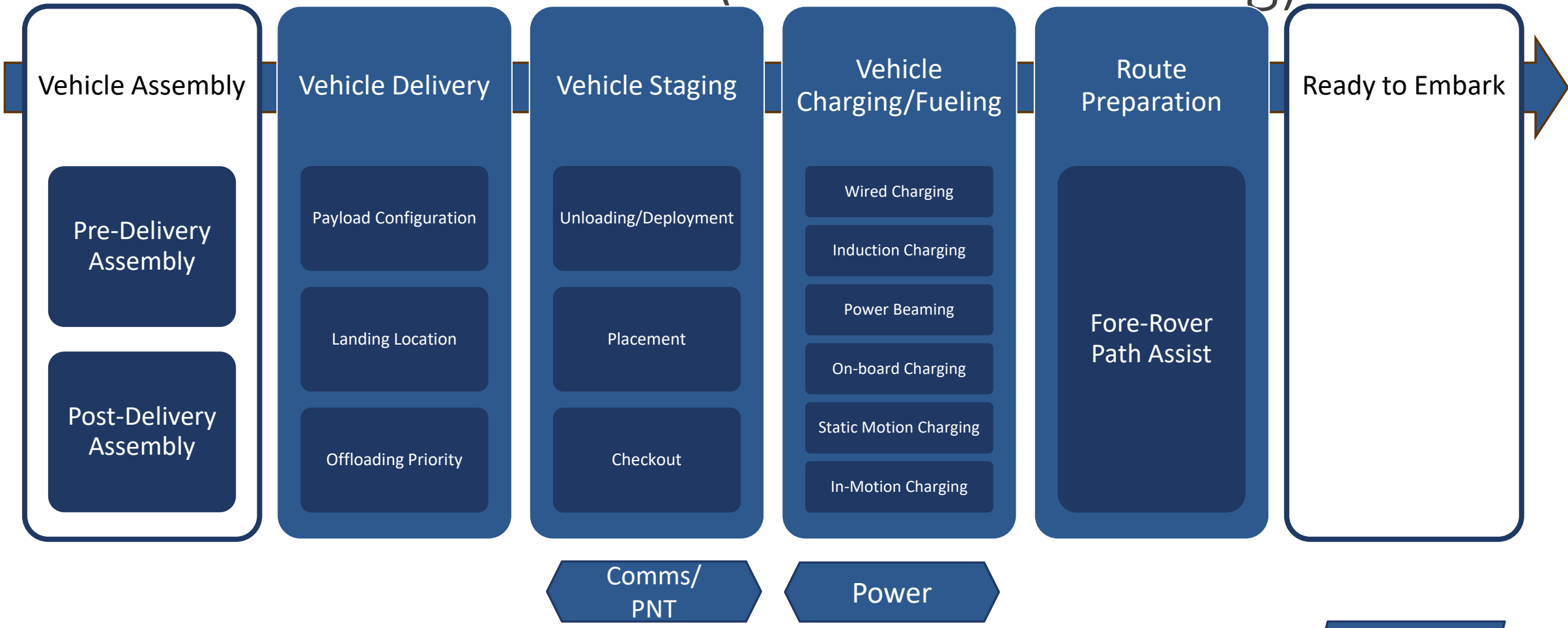
Exploration Phase (Years 0-3)

Logistics and Transportation Value Chain 1 Pioneer Path Rover (Prior to Embarking)



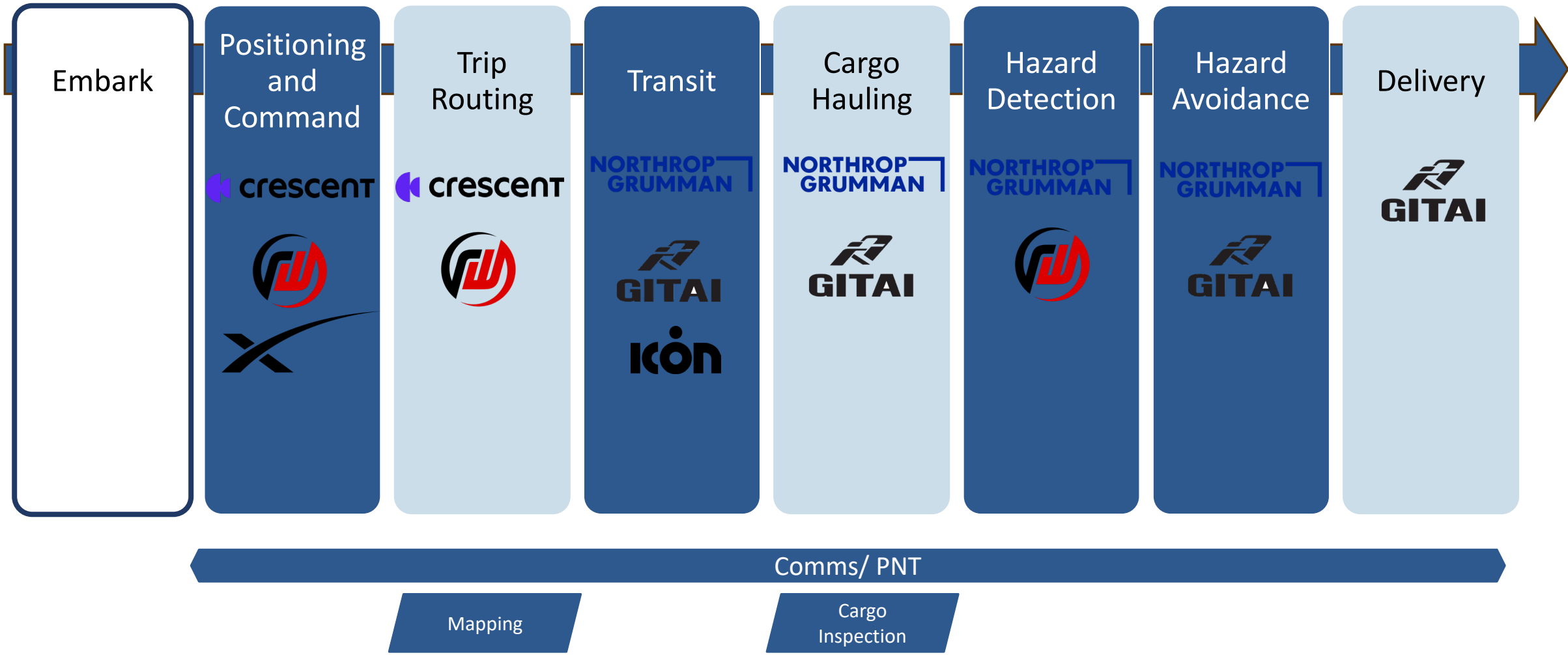
Exploration Phase (Years 0-3)

Logistics and Transportation Value Chain 1 Pioneer Path Rover (Prior to Embarking)



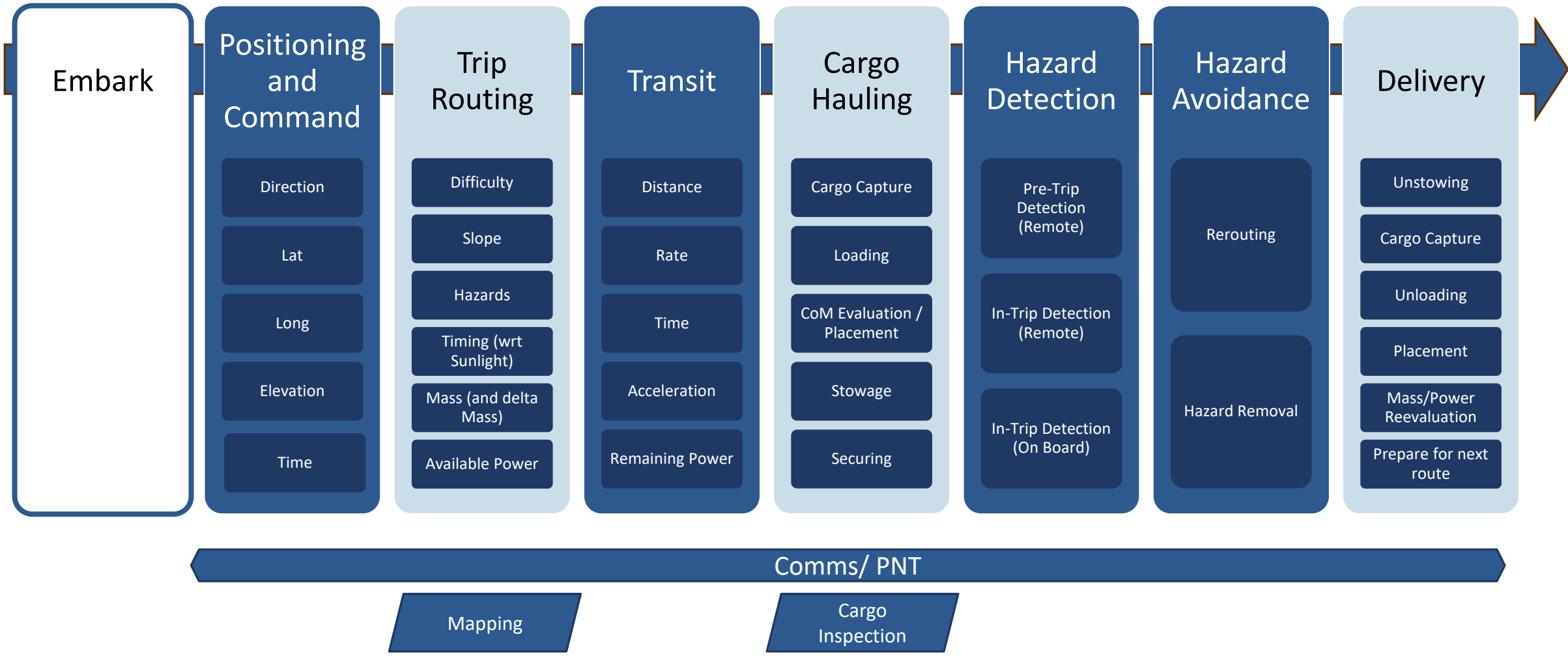
Exploration Phase (Years 0-3)

Logistics and Transportation Value Chain 1
Pioneer Path Rover (Embarked)



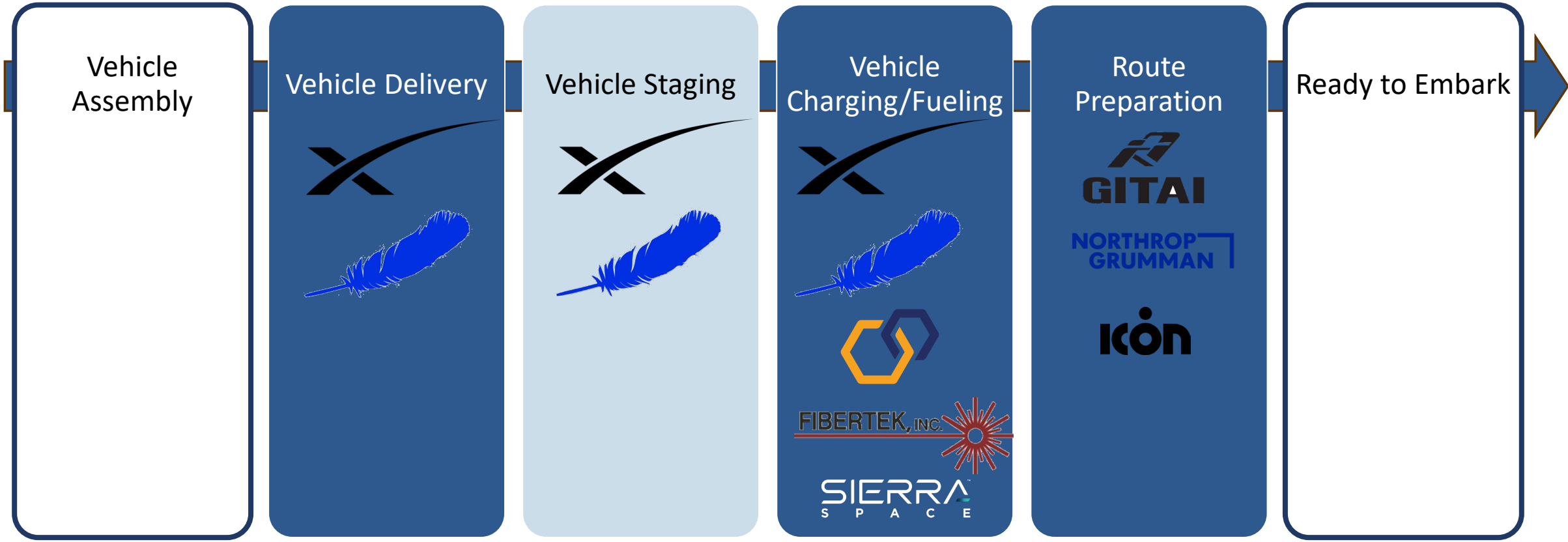
Exploration Phase (Years 0-3)

Logistics and Transportation Value Chain 1 Pioneer Path Rover (Embarked)



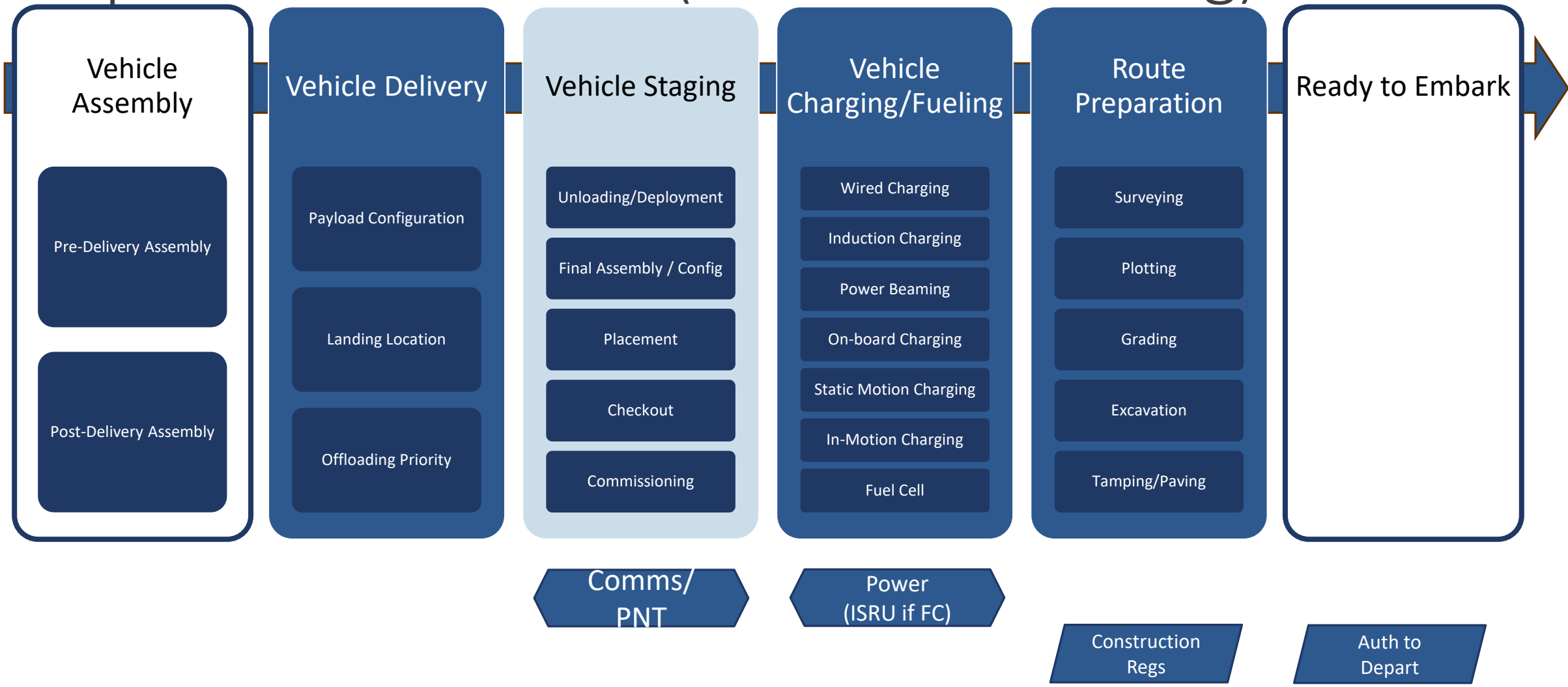
Foundation Phase (Years 3-6)

Logistics and Transportation Value Chain 2 Improved Road Rover (Prior to Embarking)



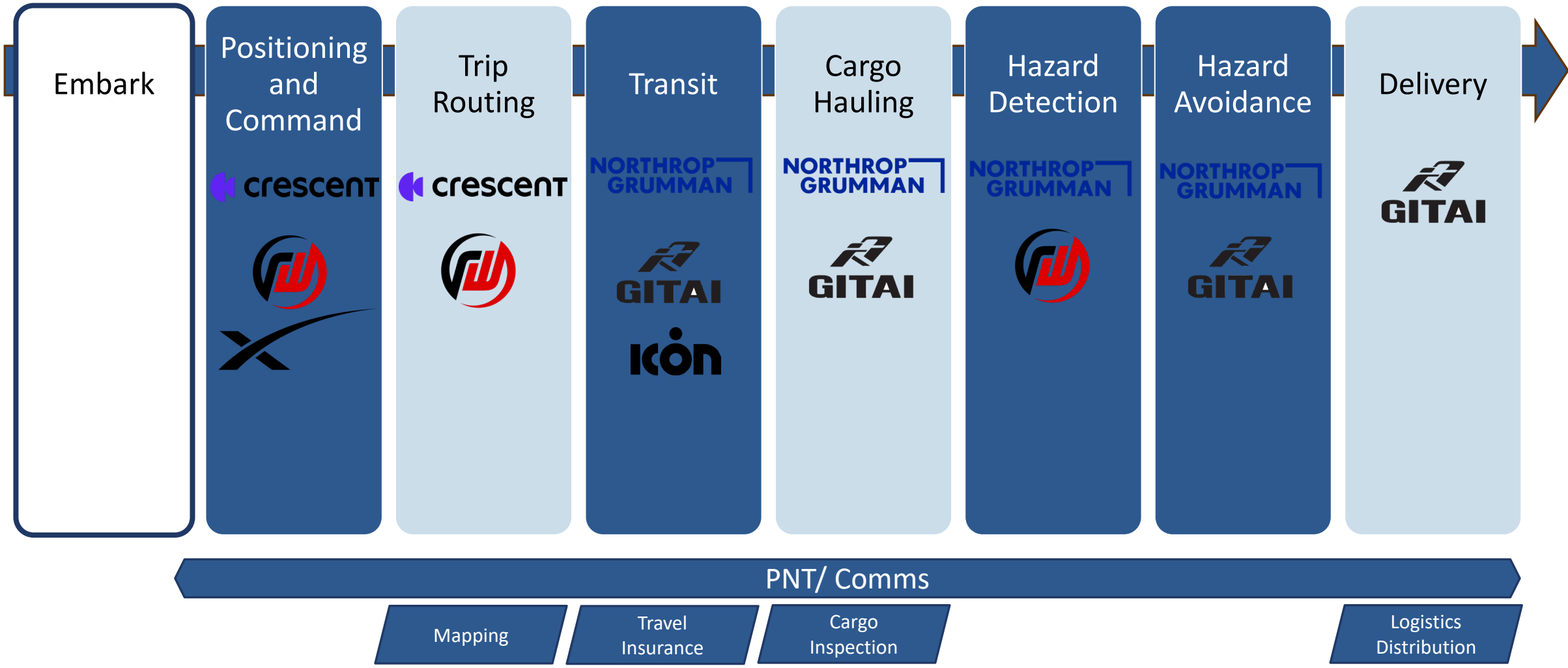
Foundation Phase (Years 3-6)

Logistics and Transportation Value Chain 2 Improved Road Rover (Prior to Embarking)



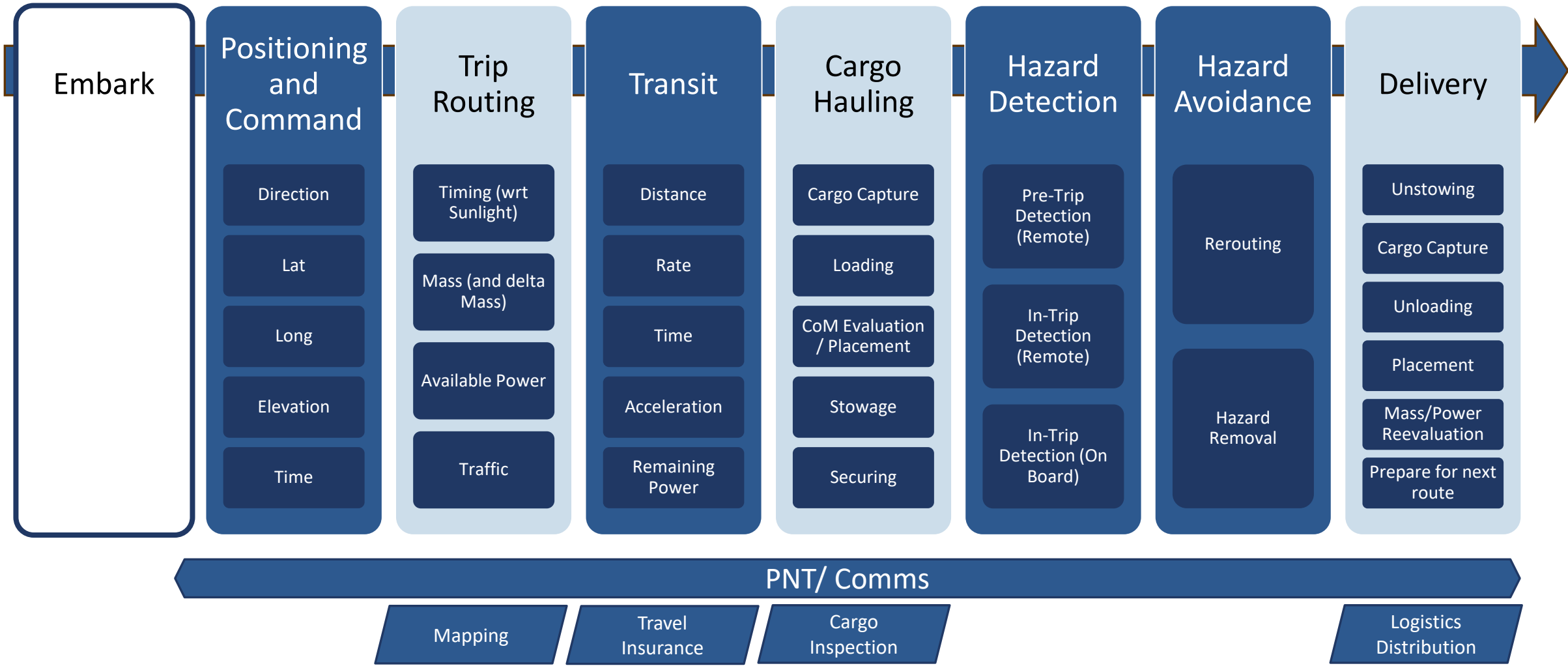
Foundation Phase (Years 3-6)

Logistics and Transportation Value Chain 2 Improved Road Rover (Embarked)



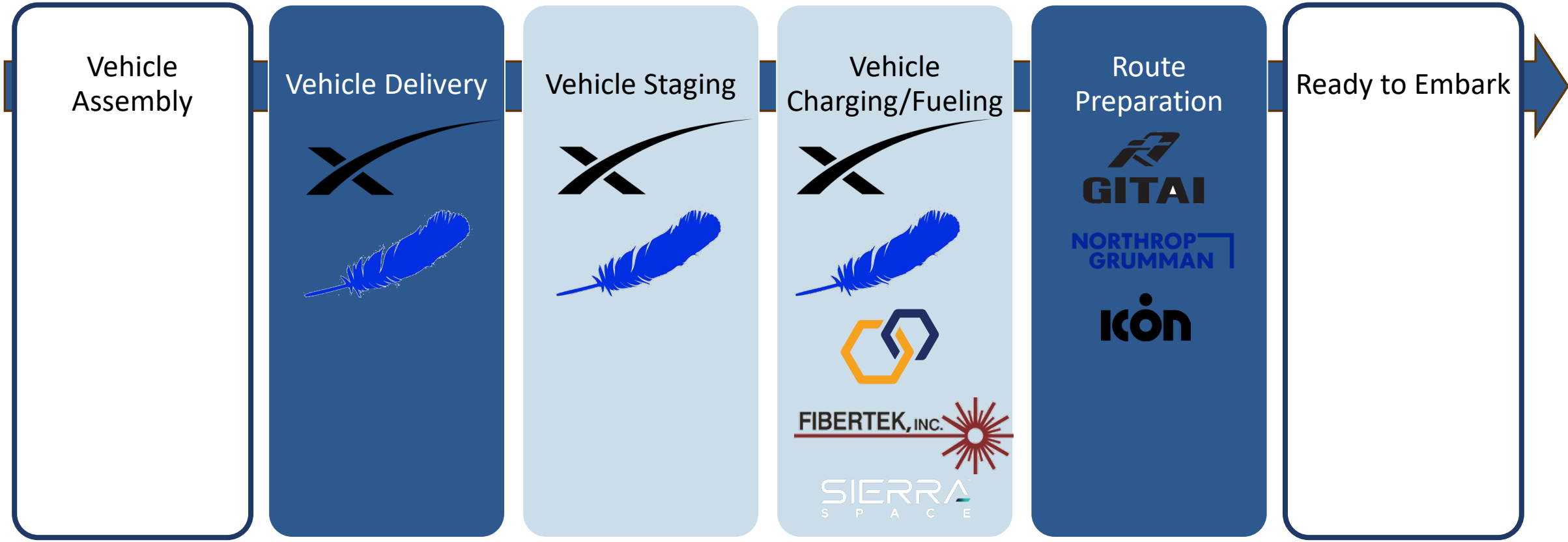
Foundation Phase (Years 3-6)

Logistics and Transportation Value Chain 2 Improved Road Rover (Embarked)



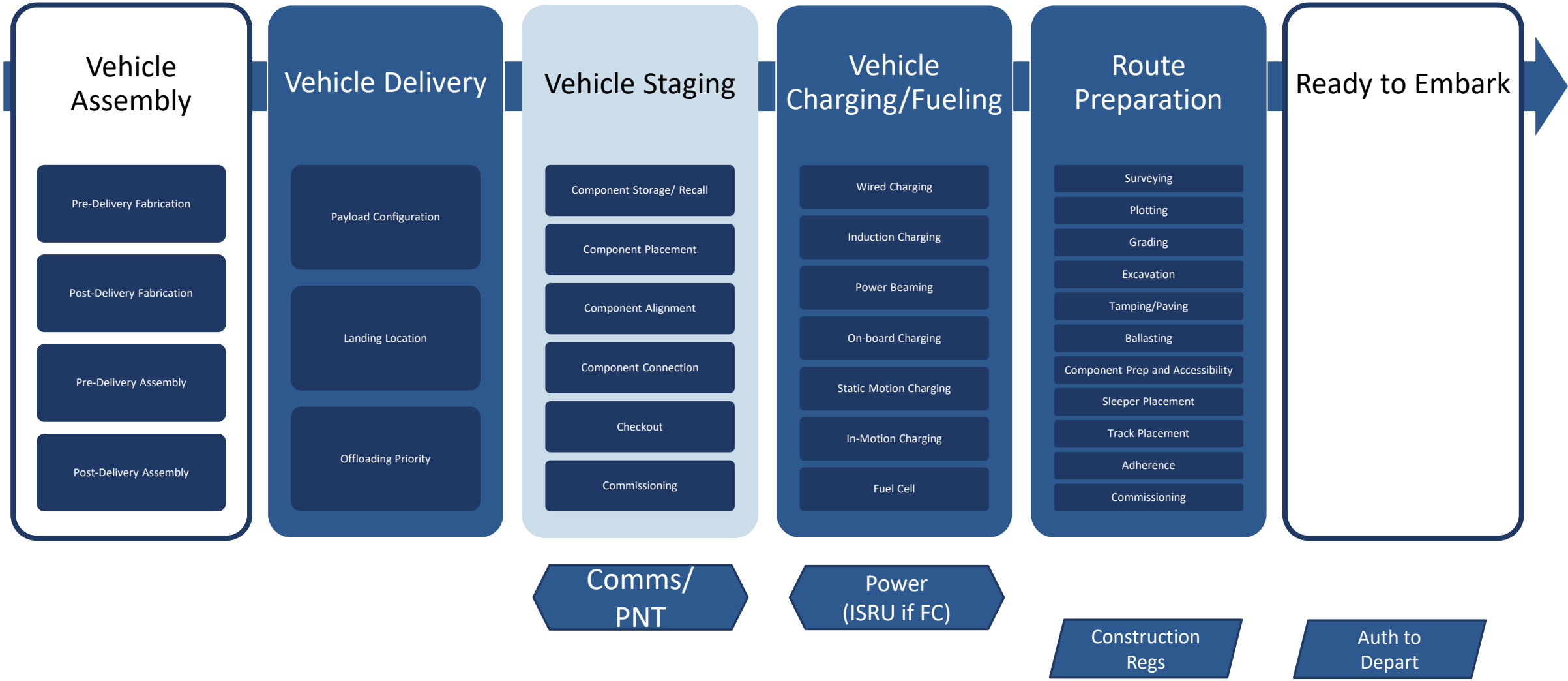
Industrial Phase (Years 6-10)

Logistics and Transportation Value Chain 3
Lunar Rail(Prior to Embarking)



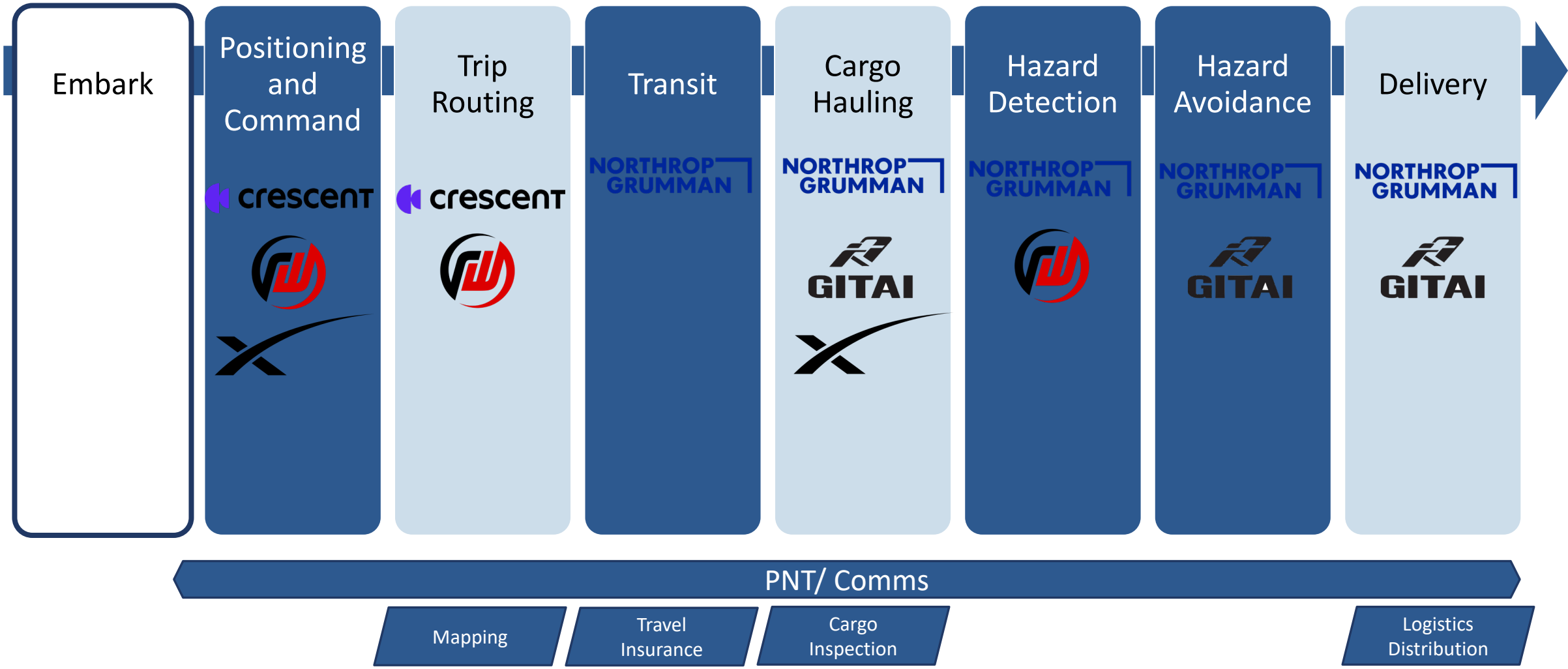
Industrial Phase (Years 6-10)

Logistics and Transportation Value Chain 3 Lunar Rail(Prior to Embarking)



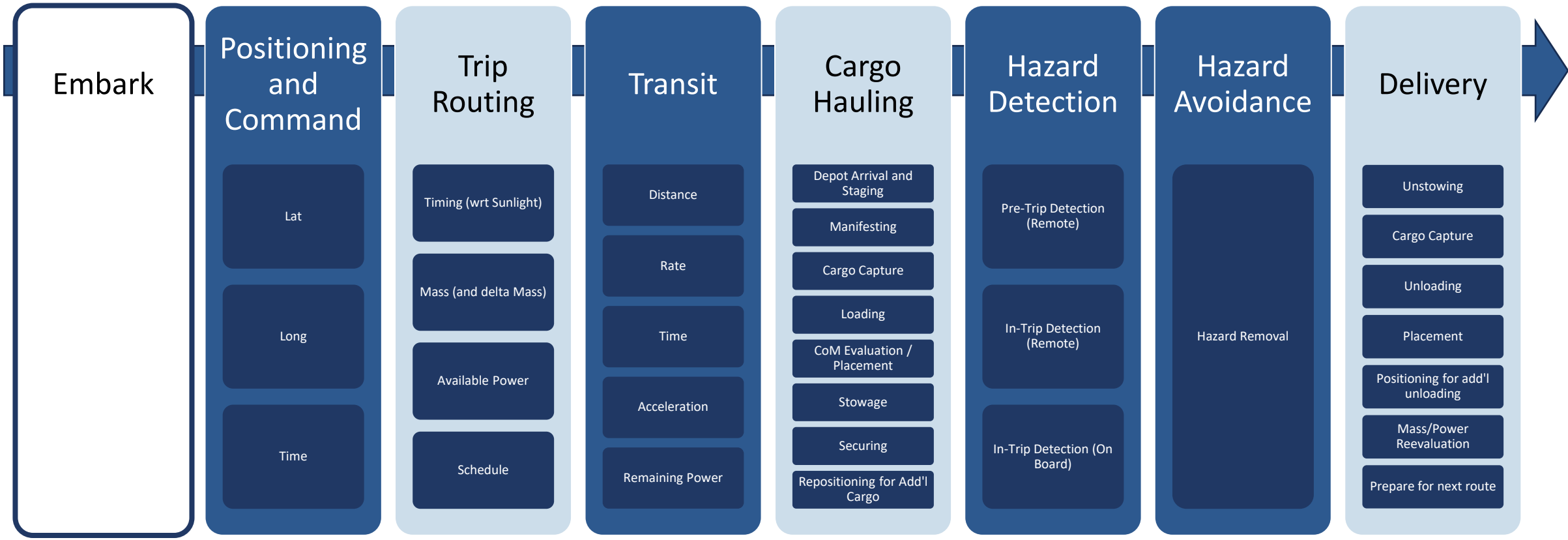
Industrial Phase (Years 6-10)

Logistics and Transportation Value Chain 3 Lunar Rail (Embarked)



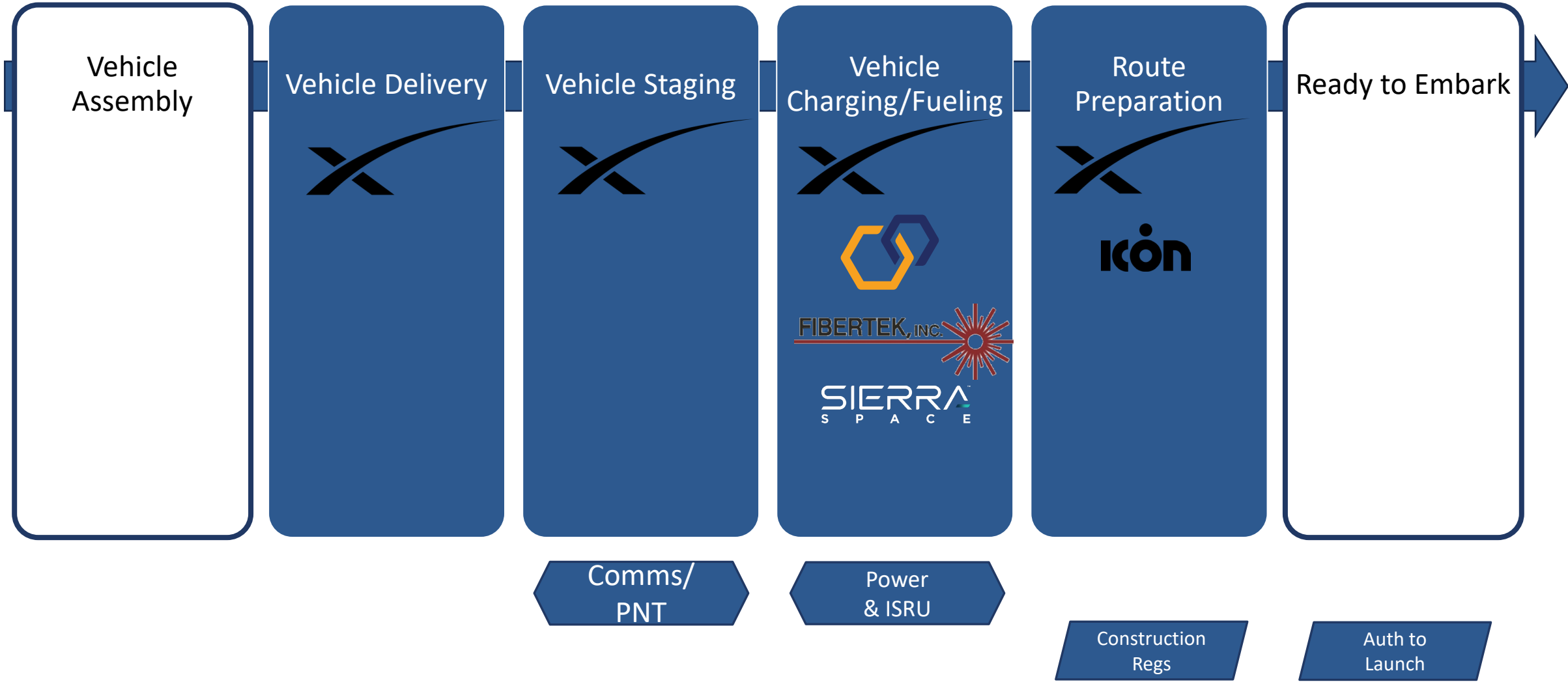
Industrial Phase (Years 6-10)

Logistics and Transportation Value Chain 3 Lunar Rail (Embarked)



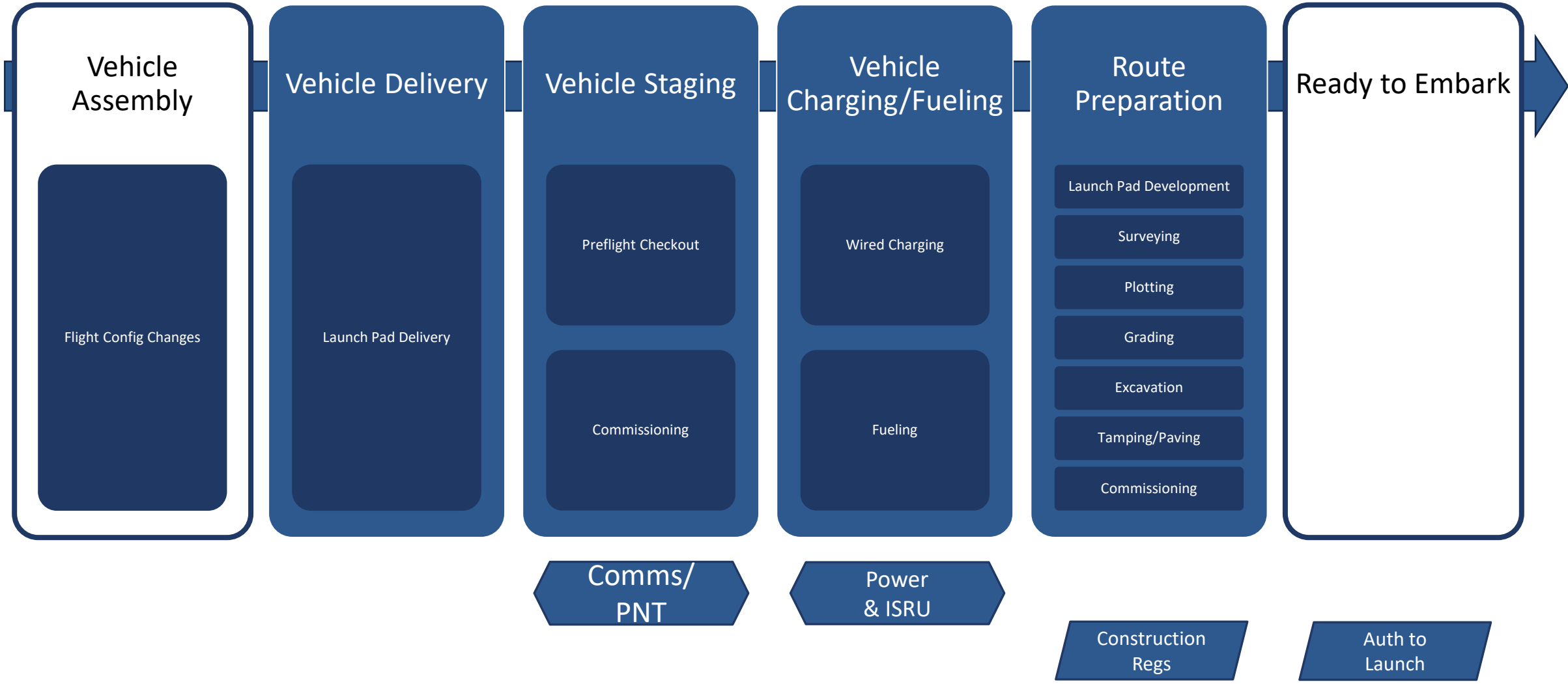
Industrial Phase (Years 6-10)

Logistics and Transportation Value Chain 4
Inter-Lunar Space Travel (Prior to Embarking)



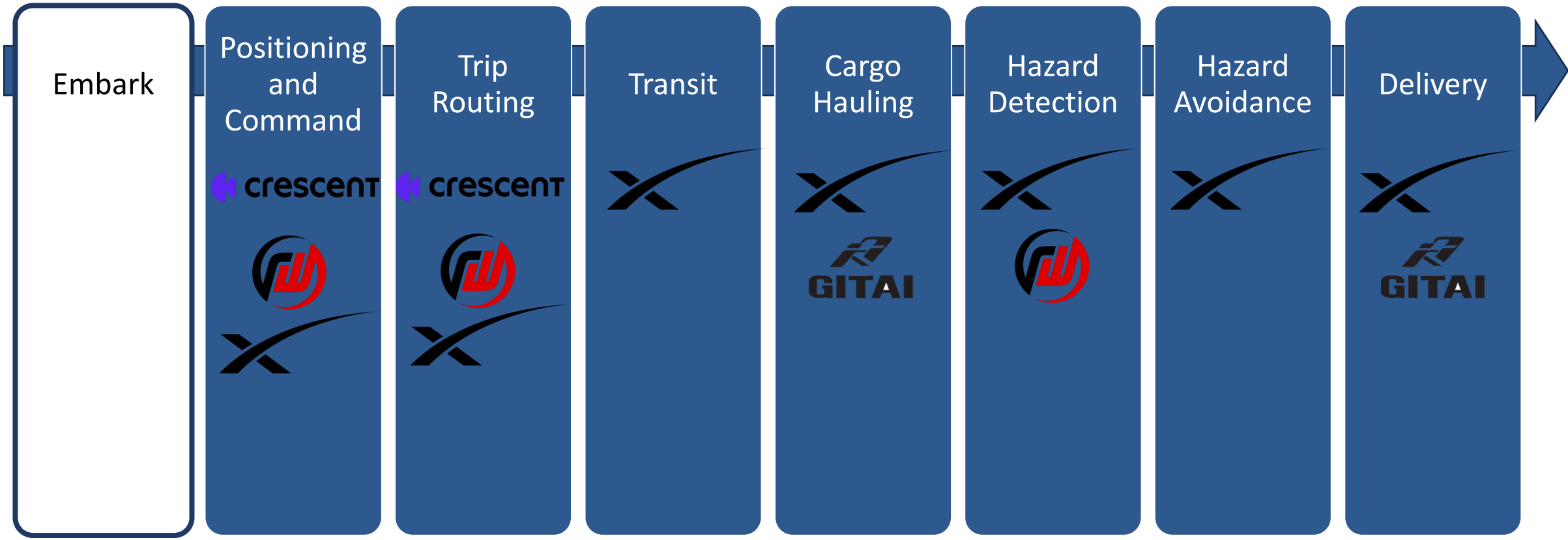
Industrial Phase (Years 6-10)

Logistics and Transportation Value Chain 4
Inter-Lunar Space Travel (Prior to Embarking)



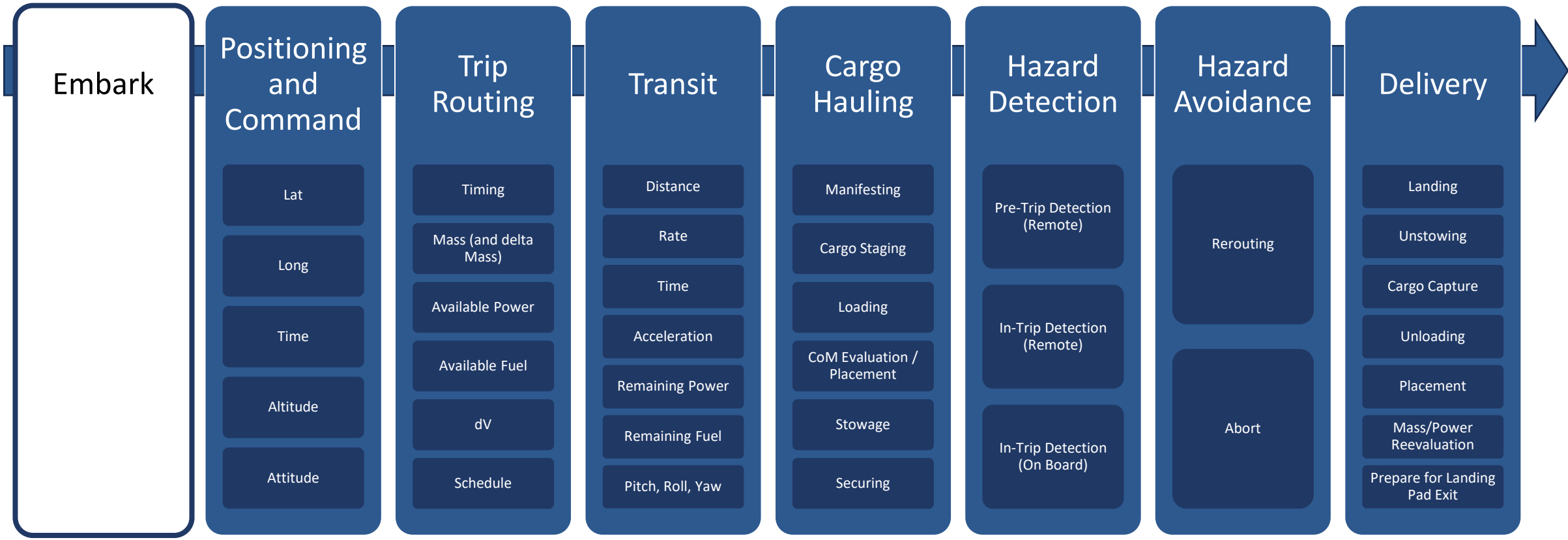
Industrial Phase (Years 6-10)

Logistics and Transportation Value Chain 4 Inter-Lunar Space Travel (Embarked)



Industrial Phase (Years 6-10)

Logistics and Transportation Value Chain 4 Inter-Lunar Space Travel (Embarked)



Appendix 5 – Position, Navigation, Timing, and Space Situational Awareness Value Chains

Image Credit: NASA

Position, Navigation and Timing Value Chains

Foundation Building Phase: Two-Way Ranging

- Uses Crescent's Parsec constellation
- Higher revisit rate and more observations gives greater accuracy in shorter timespans (down to 5m accuracy)

Industrial Building Phase: Traditional "LPS" PNT

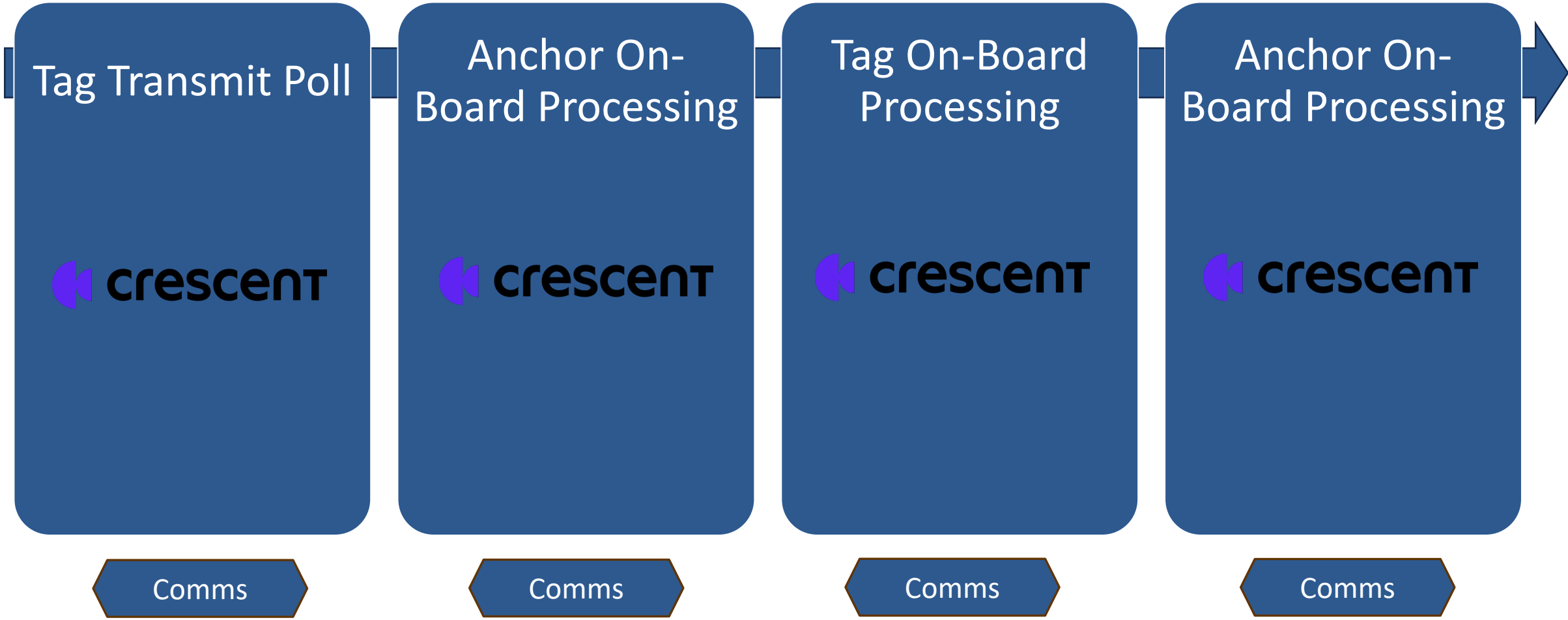
- Focuses on Redwire orbital constellation => 1m positional accuracies
- NIBs/MUSTs mounted on stationary object can serve as DGPS stations
  - Sub-meter accuracies when within range of DGPS station

Jet Age: 3GPP-Integrated PNT

- Relies upon critical mass of 3GPP nodes (Crescent)
- Hybrid Solution utilizing local comms & orbital constellation

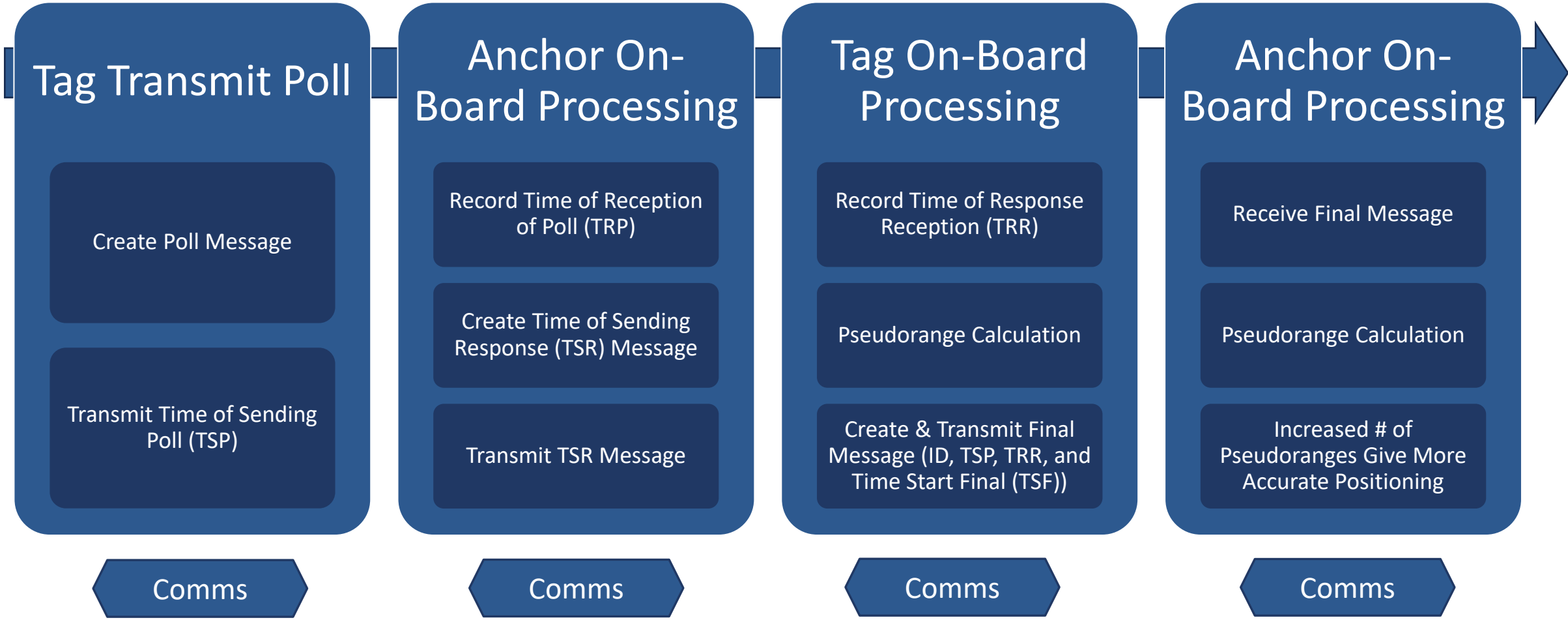
Foundation Phase (Years 3-6)

Position, Navigation, and Time Value Chain (Two-Way Ranging)



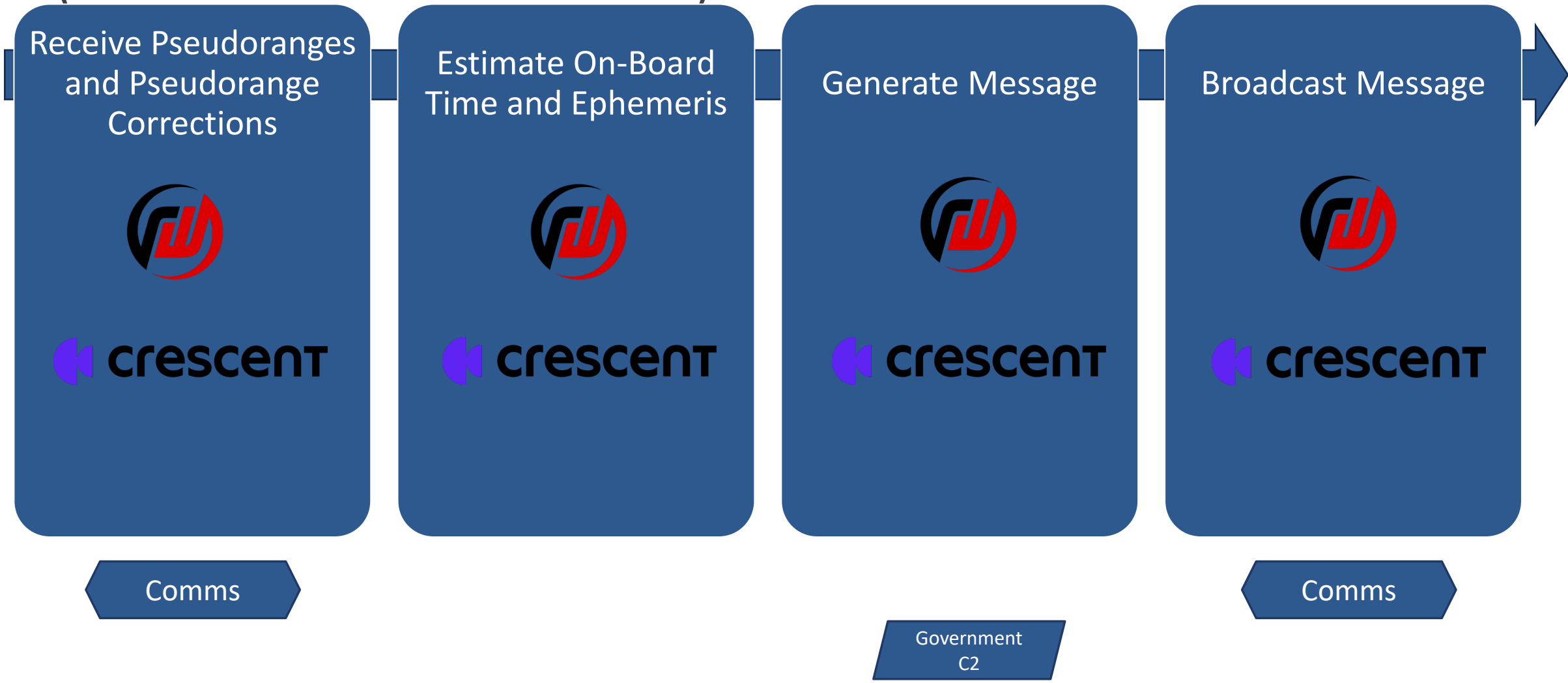
Foundation Phase (Years 3-6)

Position, Navigation, and Time Value Chain (Two-Way Ranging)



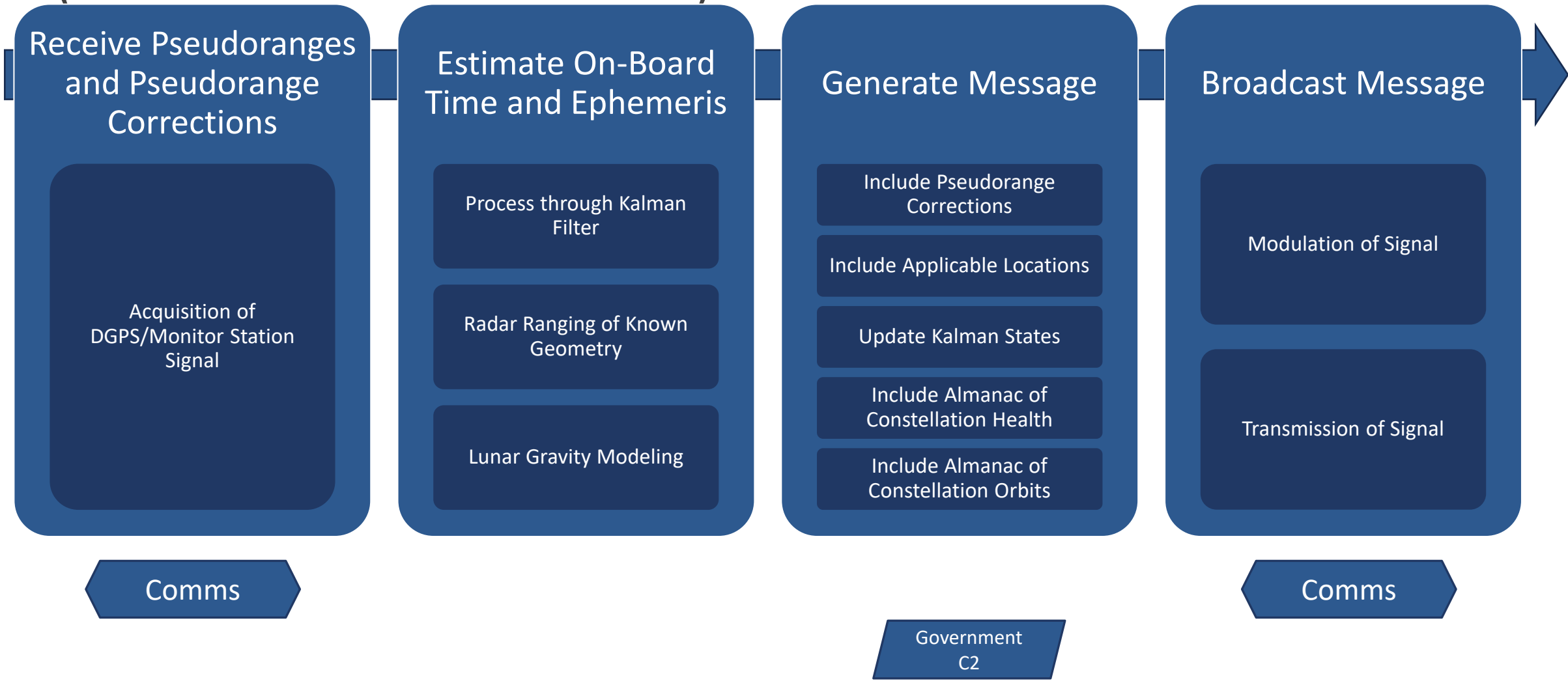
Industrial Phase (Years 6-10)

Position, Navigation, and Time Value Chain (Traditional – Provider)



Industrial Phase (Years 6-10)

Position, Navigation, and Time Value Chain (Traditional – Provider)

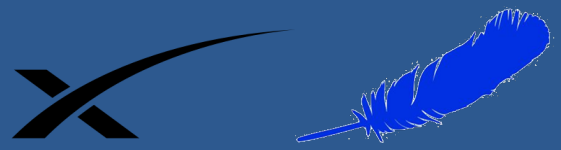


Industrial Phase (Years 6-10)

Position, Navigation, and Time Value Chain (Traditional – Monitoring Station)

Receive Message at Known Location

crescent

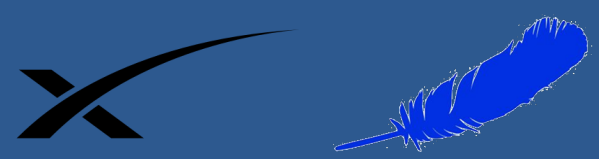


Comparison of Message to Known Position

crescent

Transmit Data Package to Satellites

crescent



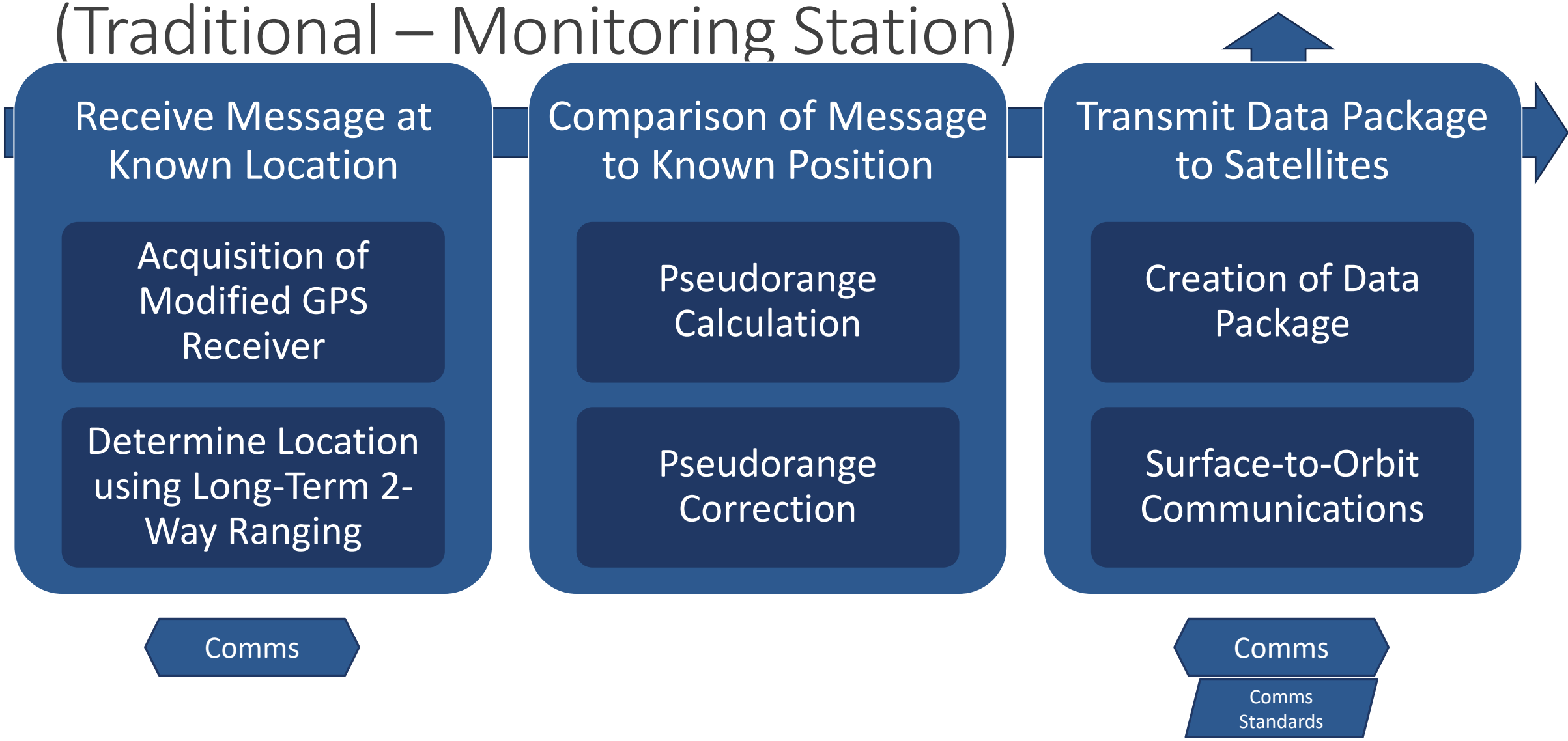
Comms

Comms

Comms Standards

Industrial Phase (Years 6-10)

Position, Navigation, and Time Value Chain (Traditional – Monitoring Station)



Industrial Phase (Years 6-10)

Position, Navigation, and Time Value Chain (Traditional – Receiver)

Receive Message (and Augmented Message)

Position Calculation & Timing Sync

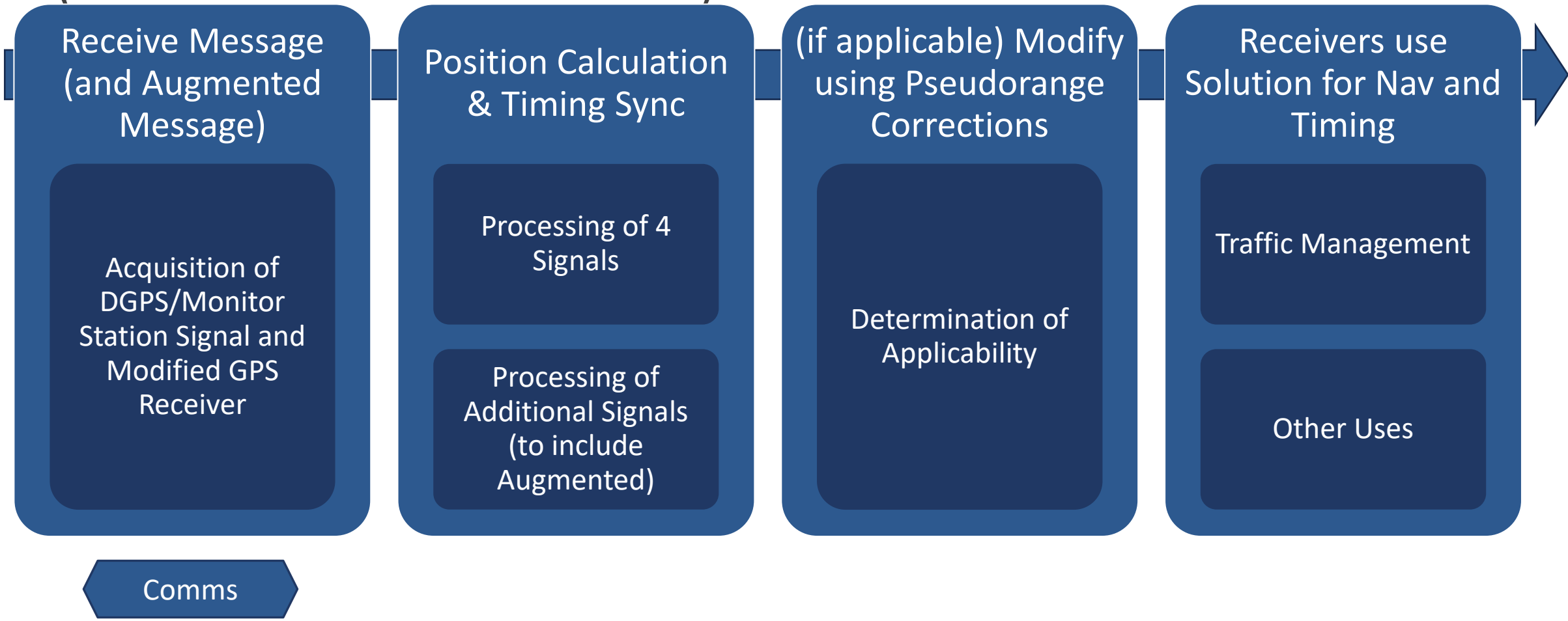
(if applicable) Modify using Pseudorange Corrections

Receivers use Solution for Nav and Timing

Comms

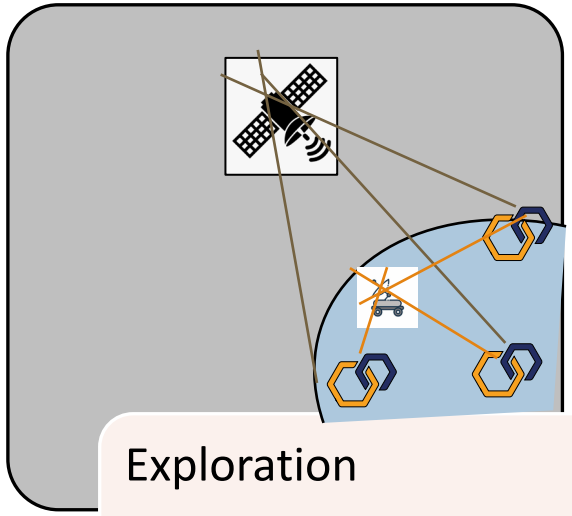
Industrial Phase (Years 6-10)

Position, Navigation, and Time Value Chain (Traditional – Receiver)



Through the Ages

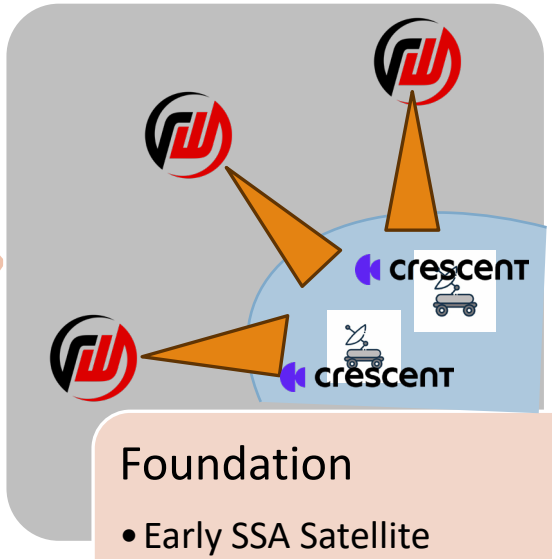
PNT: Lunar Surface & Space Traffic Management



Exploration

- Radio Direction Finder/ Automatic Direction Finder (RDF/ADF--Similar to Earliest Air Traffic Control)

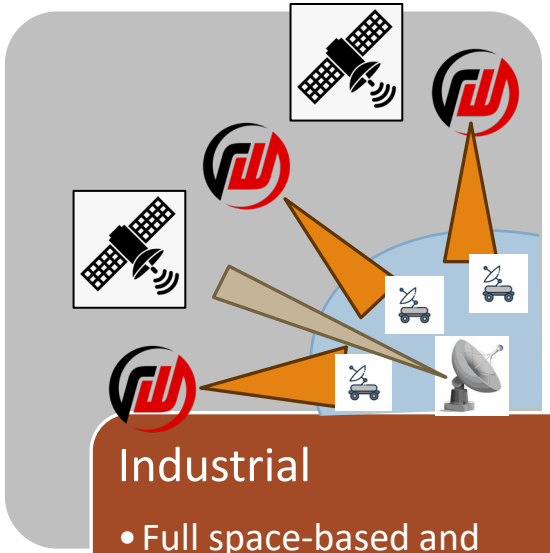
RDF/ADF Surface System



Foundation

- Early SSA Satellite constellation, surface mapping

Satellite Constellation



Industrial

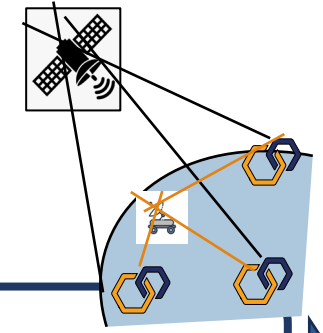
- Full space-based and ground-based sensor network providing PNT, Traffic Management service

Full Sensor Network

Traffic Management gov vs commercial

Exploration Phase (Years 0-3)

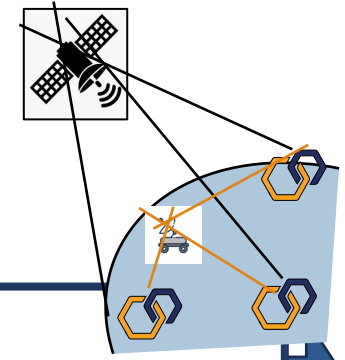
PNT Value Chain: Earliest Surface Traffic Management



Data Acquisition	Data Transmission	Data Analysis	Data Transformation	Data Storage	Data Use
+ RDF system	crescent				NORTHROP GRUMMAN SPACEX ICON GITAI
Comms	Comms				Comms Traffic Management gov vs commercial

Exploration Phase (Years 0-3)

PNT Value Chain: Earliest Surface Traffic Management



Data Acquisition

- ADF receiver connects to 3 RDFs for triangulation of position

Data Transmission

- ADF receiver on payload transmits position to Earth

Data Analysis

- Triangulation of signals to determine position
- Object Identification
- Event Processing

Data Transformation

- Data Validation
- Human Computation
- Data Curation

Data Storage

- Database
- Consistency, Availability, Scalability
- Security and Privacy
- Query Interfaces

Data Use

- Lunar Surface & Air Traffic Management (service?)
- O/O Decision Support
- Event Reconstruction (Insurance Purposes?)

Comms

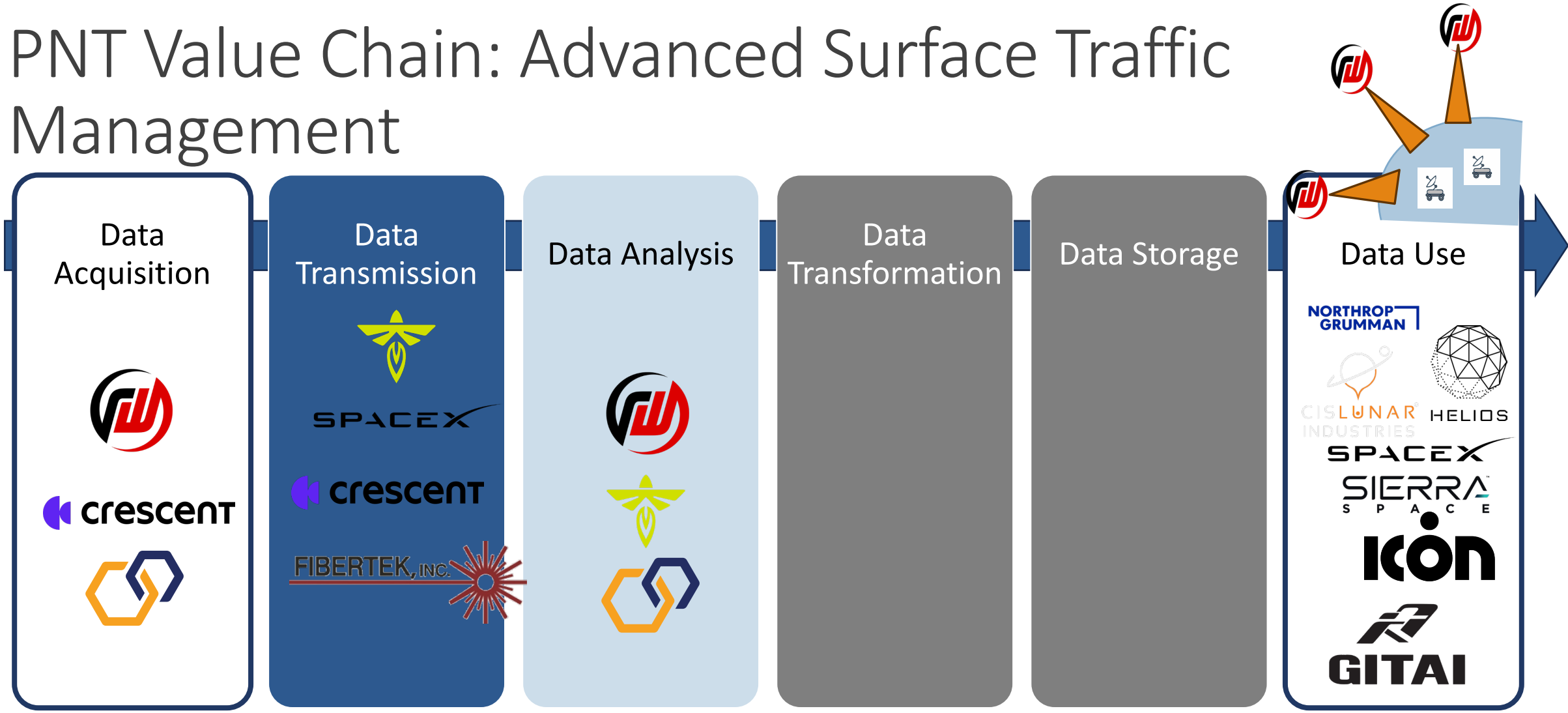
Comms

Comms

Traffic Management gov vs commercial

Foundation Phase (Years 3-6)

PNT Value Chain: Advanced Surface Traffic Management



Foundation Phase (Years 3-6)

PNT Value Chain: Advanced Surface Traffic Management

Data Acquisition

- Sensors (Space or Lunar Surface-based) collect raw observation data
- Sensors collect raw surface survey data

Data Transmission

- Raw spatial data formatted for transmission (ex. B3 ob file format)
- Obs File transmitted to Sensor Network (to Earth-based network? space-based network?)

Data Analysis

- Observations compiled in database
- Object Identification
- Event Processing

Data Transformation

- Sensor Calibration/quality control
- Data Validation
- Human Computation
- Data Curation

Data Storage

- Database
- Consistency, Availability, Scalability
- Security and Privacy
- Cloud Storage
- Query Interfaces

Data Use

- Surface & Air Traffic Management (service?)
- O/O Decision Support
- Event Reconstruction (Insurance Purposes?)
- Position data f/vehicle contact or recovery (PNT service?)
- Modeling/Prediction

Comms

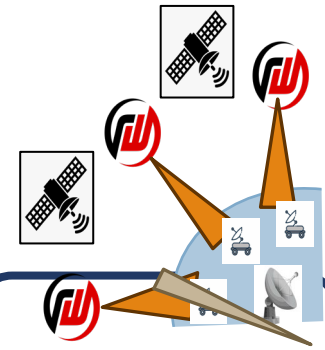
Comms

Comms

Traffic Management
gov vs commercial

Industrial Phase (Years 6-10)

PNT Value Chain: Space Traffic Management



Data Acquisition	Data Transmission	Data Analysis	Data Transformation	Data Storage	Data Use

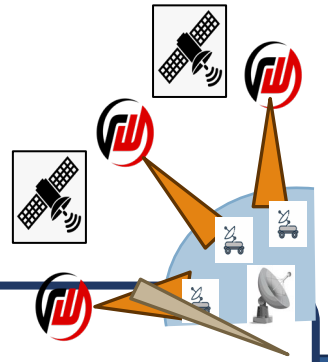
Comms

Comms

Traffic Management
gov vs commercial

Industrial Phase (Years 6-10)

PNT Value Chain: Space Traffic Management



Data Acquisition

- Sensors (Space or Lunar Surface-based) collect raw observation data
- Sensors collect raw surface survey data

Data Transmission

- Raw spatial data formatted for transmission (ex. B3 ob file format)
- Obs File transmitted to Sensor Network (to Earth-based network? space-based network?)

Data Analysis

- Observations compiled in database
- Object Identification
- Event Processing
- Orbit Determination
- Orbit Differential Correction

Data Transformation

- Sensor Calibration/quality control
- Data Validation
- Human Computation
- Data Curation
- Orbit Propagation

Data Storage

- Database
- Consistency, Availability, Scalability
- Security and Privacy
- Cloud Storage
- Query Interfaces

Data Use

- Space Traffic Management (service?)
- O/O Decision Support
- Event Reconstruction (Insurance Purposes?)
- ELSETS f/vehicle contact or recovery (PNT service?)
- Modeling/Prediction

Comms

Comms

Traffic Management gov vs commercial

Appendix 6 – Communications Value Chains

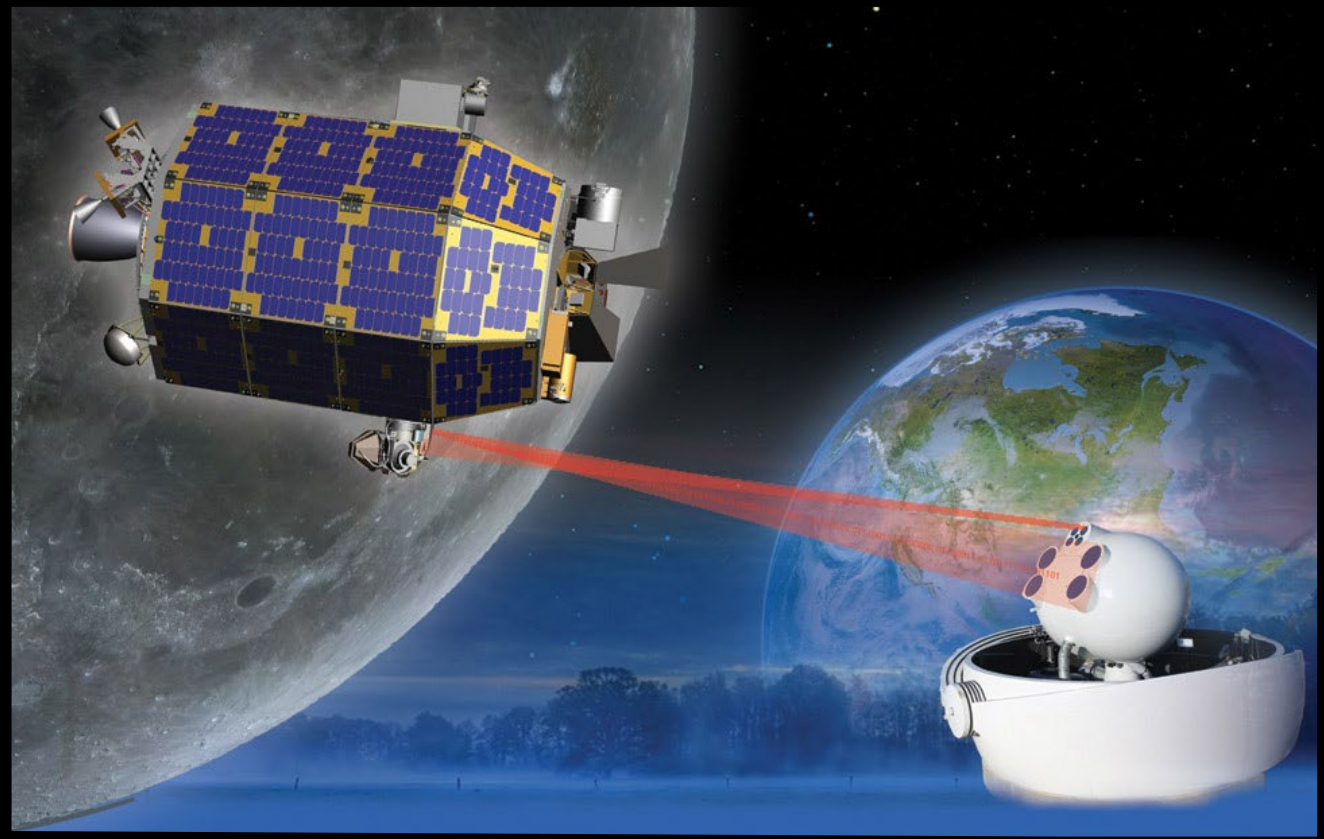
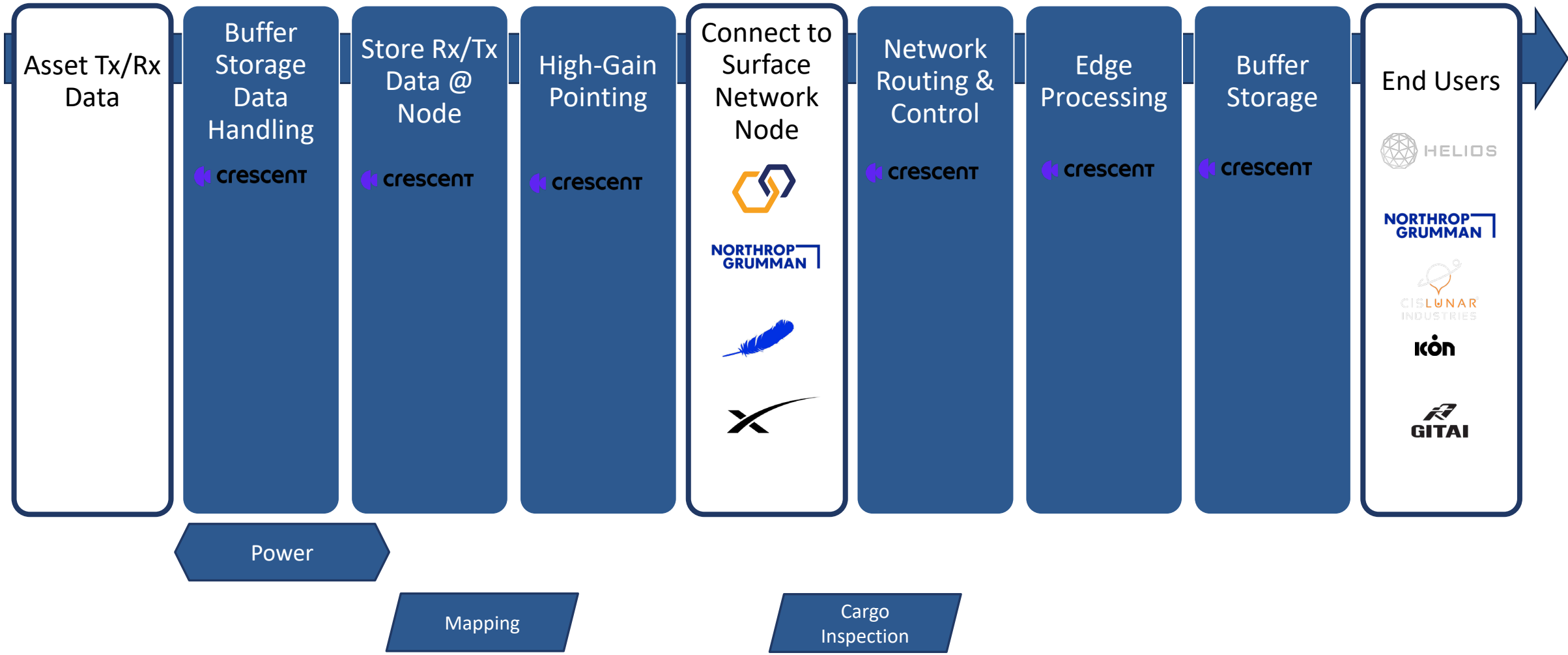


Image Credit: NASA

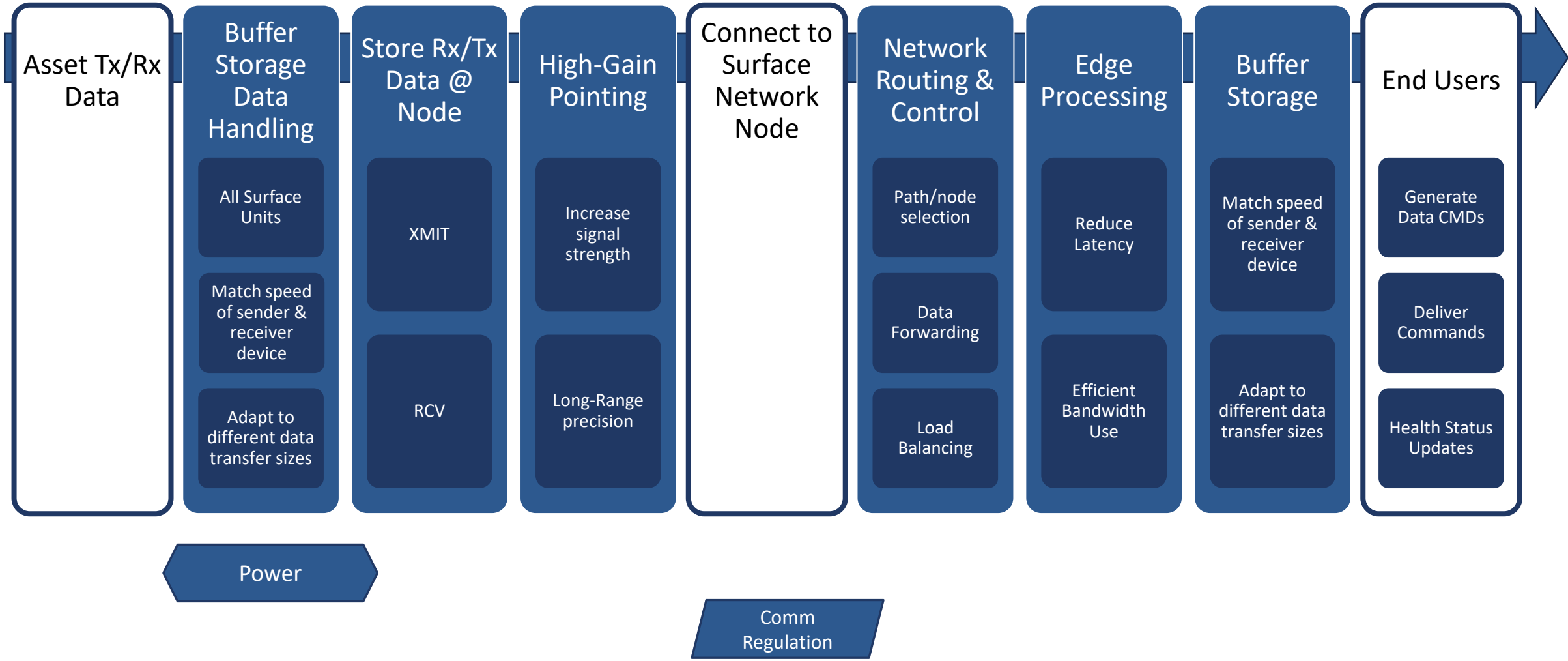
Exploration Phase (Years 0-3)

Communications Value Chain 1
Pioneer Comms (RF)



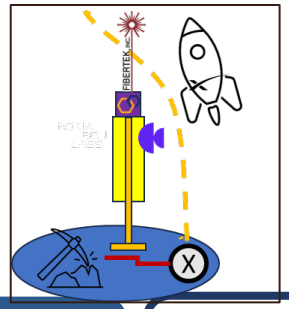
Exploration Phase (Years 0-3)

Communications Value Chain 1 Pioneer Comms (RF)



Foundation Phase (Years 3-6)

Communications Value Chain 1 Surface Comms (Optical)



Asset Tx/Rx Data	Buffer Storage Data Handling	Store Rx/Tx Data @ Node	Point the Rx	Connect to Surface Network Node	Network Routing & Control	Edge Processing	Buffer Storage	End Users
	FIBERTEK, INC.	FIBERTEK, INC.	FIBERTEK, INC.	NORTHROP GRUMMAN	crescent	crescent	crescent	HELIOS NORTHROP GRUMMAN CISLUNAR INDUSTRIES KÖN GITAI

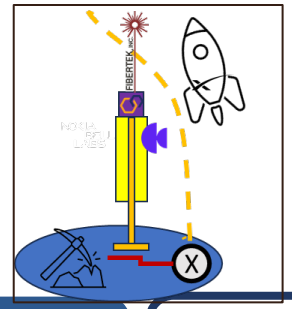
Power

Mapping

Cargo Inspection

Foundation Phase (Years 3-6)

Communications Value Chain 2 Surface Comms (Optical)



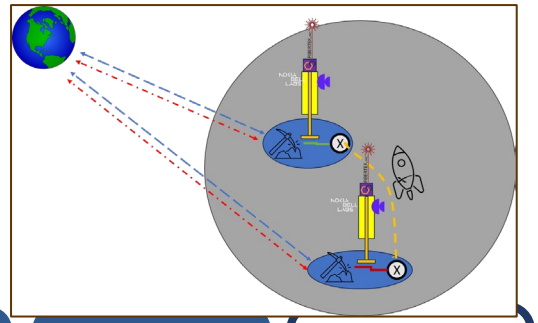
Asset Tx/Rx Data	Buffer Storage Data Handling	Store Rx/Tx Data @ Node	Point the Rx	Connect to Surface Network Node	Network Routing & Control	Edge Processing	Buffer Storage	End Users
	All Surface Units	XMIT	Lasers for long-range		Path/node selection	Reduce Latency	Match speed of sender & receiver device	Generate Data CMDs
	Match speed of sender & receiver device	RCV	High-speed communications		Data Forwarding	Efficient Bandwidth Use	Adapt to different data transfer sizes	Deliver Commands
	Adapt to different data transfer sizes				Load Balancing			Health Status Updates
								Sensing for Autonomous Rovers
								Remote Imaging
								Object Characterization

Power

Comm Regulation

Foundation Phase (Years 3-6)

Communications Value Chain 3 Surface to Earth (RF and/or Optical)



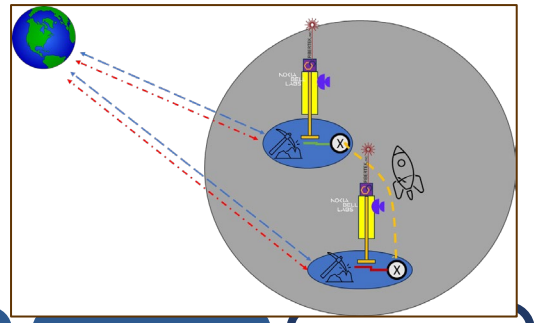
Asset Tx/Rx Data	Buffer Storage Data Handling	Store Rx/Tx Data @ End Pt	Point the Tx/Rx	Connect to Earth Comms	High-Gain Pointing	Store Rx/Tx Data @ End Pt	On-Orbit Buffer Storage	End Users
	FIBERTEK, INC.	FIBERTEK, INC.	SPACEX	NORTHROP GRUMMAN	FIBERTEK, INC.	FIBERTEK, INC.	SPACEX	HELIOS
					crescent	crescent	crescent	NORTHROP GRUMMAN
								CISLUNAR INDUSTRIES
								KÖN
								GITAI

Power

Comm Regulation

Foundation Phase (Years 3-6)

Communications Value Chain 3 Surface to Earth (RF and/or Optical)



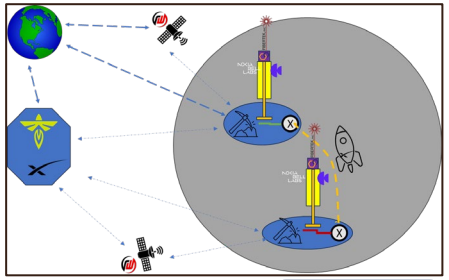
Asset Tx/Rx Data	Buffer Storage Data Handling	Store Rx/Tx Data @ End Pt	Point the Tx/Rx	Connect to Earth Comms	High-Gain Pointing	Store Rx/Tx Data @ End Pt	On-Orbit Buffer Storage	End Users (Orbit to Earth)
	All Surface Units	XMIT	Lasers for long-range		Increase signal strength	XMIT	Match speed of sender & receiver device	Generate Data CMDs
	Match speed of sender & receiver device	RCV	High-speed communications		Long-Range precision	RCV	Adapt to different data transfer sizes	Deliver Commands
	Adapt to different data transfer sizes							Health Status Updates
								Sensing for Autonomous Rovers
								Remote Imaging
								Object Characterization

Power

Comm Regulation

Industrial Phase (Years 6-10)

Communications Value Chain 4 Surface to Orbit (RF)



Asset Tx/Rx Data	Buffer Storage Data Handling	Store Rx/Tx Data @ End Pt	Point the Rx	Connect to Surface Network Node	Network Routing & Control	Edge Processing	Buffer Storage	Connect to Orbital Network Node	High-Gain Pointing	On-Orbit Buffer Storage Data Handling	End Users
	crescent	crescent	crescent	NORTHROP GRUMMAN	crescent	crescent	crescent	SPACEX	crescent	SPACEX	HELIOS, NORTHROP GRUMMAN, CISLUNAR INDUSTRIES, ICON, GITAI

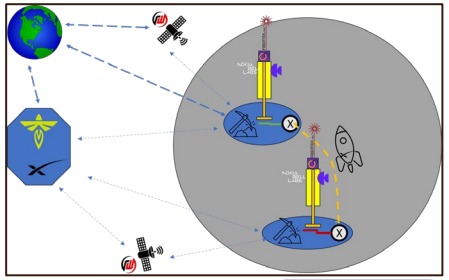
Power

Power

Comm Regulation

Industrial Phase (Years 6-10)

Communications Value Chain 4 Surface to Orbit (RF)



Asset Tx/Rx Data	Buffer Storage Data Handling	Store Rx/Tx Data @ End Pt	Point the Rx	Connect to Surface Network Node	Network Routing & Control	Edge Processing	Buffer Storage	Connect to Orbital Network Node	High-Gain Pointing	On-Orbit Buffer Storage Data Handling	End Users
	All Surface Units	XMIT	Lasers for long-range		Increase signal strength	XMIT	Match speed of sender & receiver device		Increase signal strength	Match speed of sender & receiver device	Generate Data CMDs
	Match speed of sender & receiver device	RCV	High-speed communications		Long-Range precision	RCV	Adapt to different data transfer sizes		Long-Range precision	Adapt to different data transfer sizes	Deliver Commands
	Adapt to different data transfer sizes										Sensing for Autonomous Rovers
											Remote Imaging
											Object Characterization

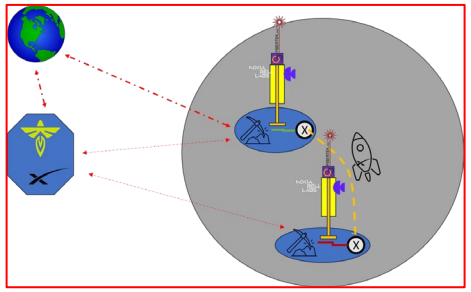
Power

Power

Comm Regulation

Industrial Phase (Years 6-10)

Communications Value Chain 5 Surface to Orbit (Optical)



Asset Tx/Rx Data

Buffer Storage Data Handling

FIBERTEK, INC.

Store Rx/Tx Data @ End Pt

FIBERTEK, INC.

SPACEX

Point the Rx

FIBERTEK, INC.

SPACEX

Connect to Surface Network Node

NORTHROP GRUMMAN

Network Routing & Control

crescent

Edge Processing

crescent

Buffer Storage

crescent

Point the Rx

FIBERTEK, INC.

SPACEX

Connect to Orbital Network Node

SPACEX

High-Gain Pointing

FIBERTEK, INC.

SPACEX

On-Orbit Buffer Storage Data Handling

SPACEX

End Users

HELIOS

NORTHROP GRUMMAN

CISLUNAR INDUSTRIES

KÖN

GITAI

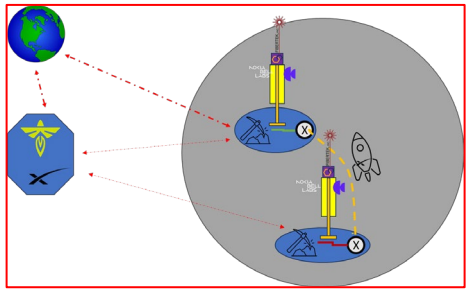
Power

Power

Comm Regulation

Industrial Phase (Years 6-10)

Communications Value Chain 5 Surface to Orbit (Optical)



Asset Tx/Rx Data	Buffer Storage Data Handling	Store Rx/Tx Data @ End Pt	Point the Rx	Connect to Surface Network Node	Network Routing & Control	Edge Processing	Buffer Storage	Point the Rx	Connect to Orbital Network Node	High-Gain Pointing	On-Orbit Buffer Storage Data Handling	End Users
	All Surface Units	XMIT	Lasers for long-range		Increase signal strength	XMIT	Match speed of sender & receiver device	Lasers for long-range		Increase signal strength	Match speed of sender & receiver device	Generate Data CMDs
	Match speed of sender & receiver device											Deliver Commands
	Adapt to different data transfer sizes	RCV	High-speed communications		Long-Range precision	RCV	Adapt to different data transfer sizes	High-speed communications		Long-Range precision	Adapt to different data transfer sizes	Sensing for Autonomous Rovers
												Remote Imaging
												Object Characterization

Power

Power

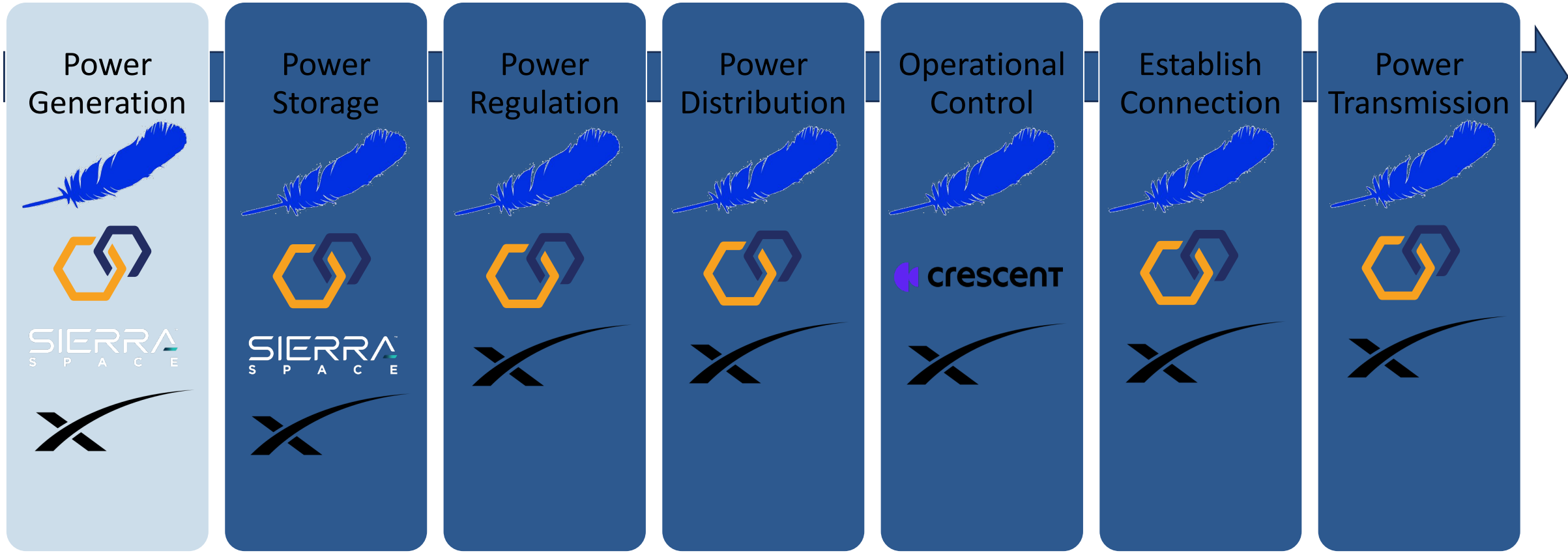
Comm Regulation

Appendix 6 – Power Value Chains

Image Credit: Honeybee Robotics

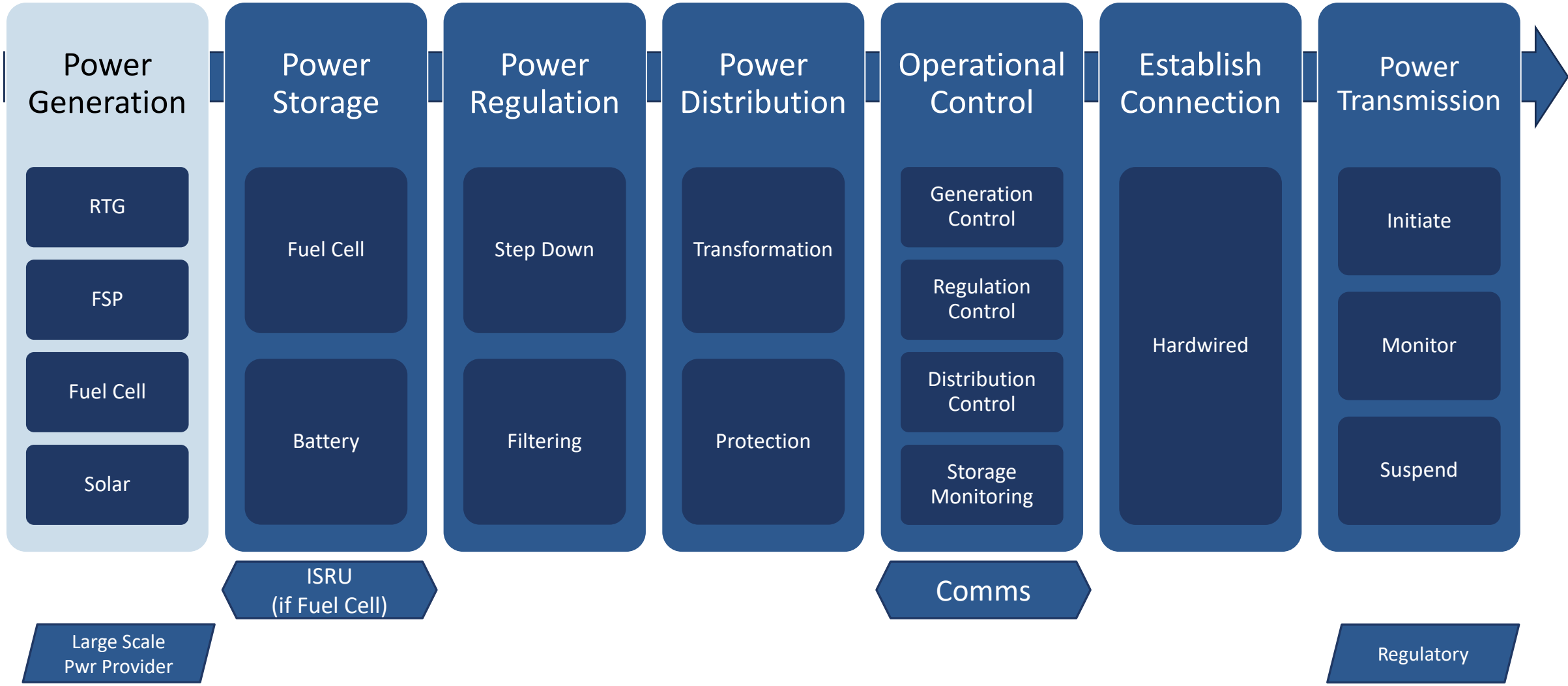
Exploration Phase (Years 0-3)

Power Value Chain 1
Wired, On-Facility Power (Provider)



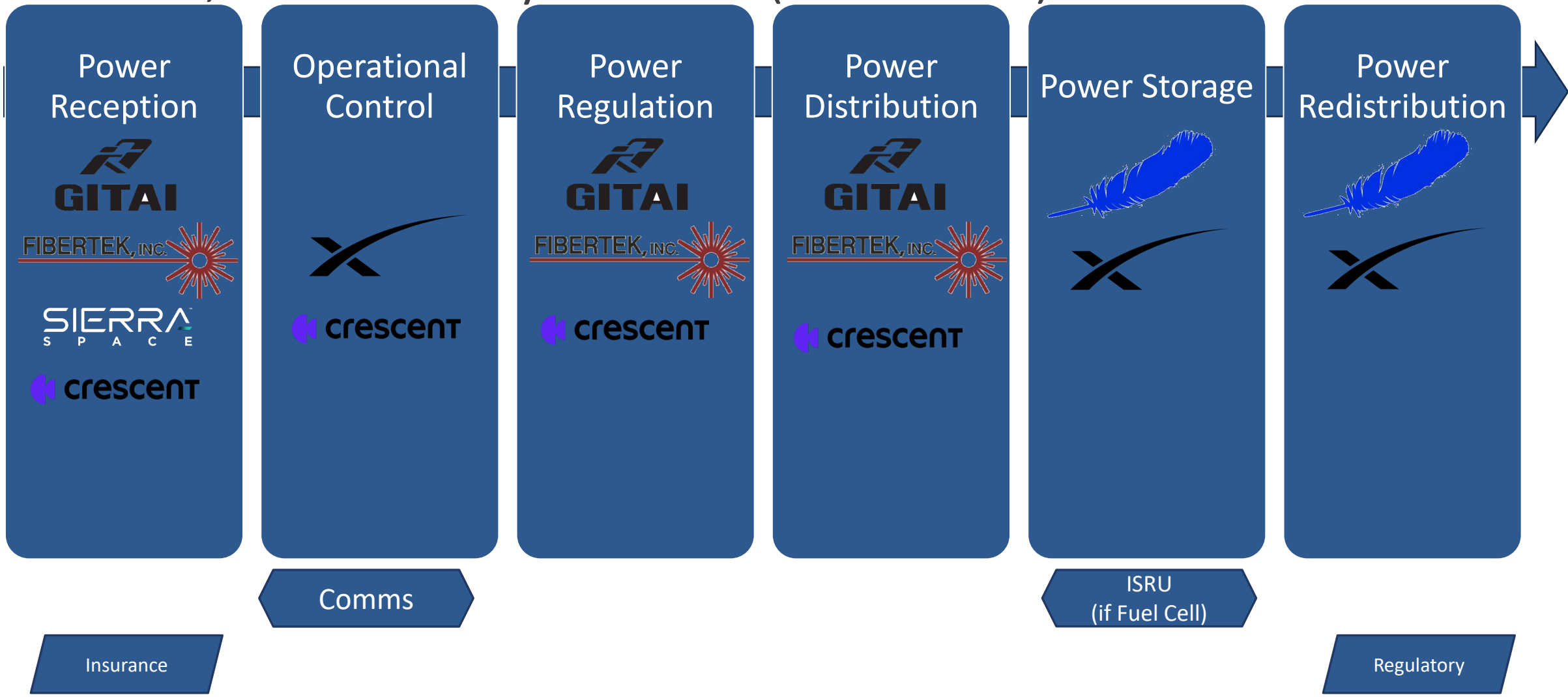
Exploration Phase (Years 0-3)

Power Value Chain 1
Wired, On-Facility Power (Provider)



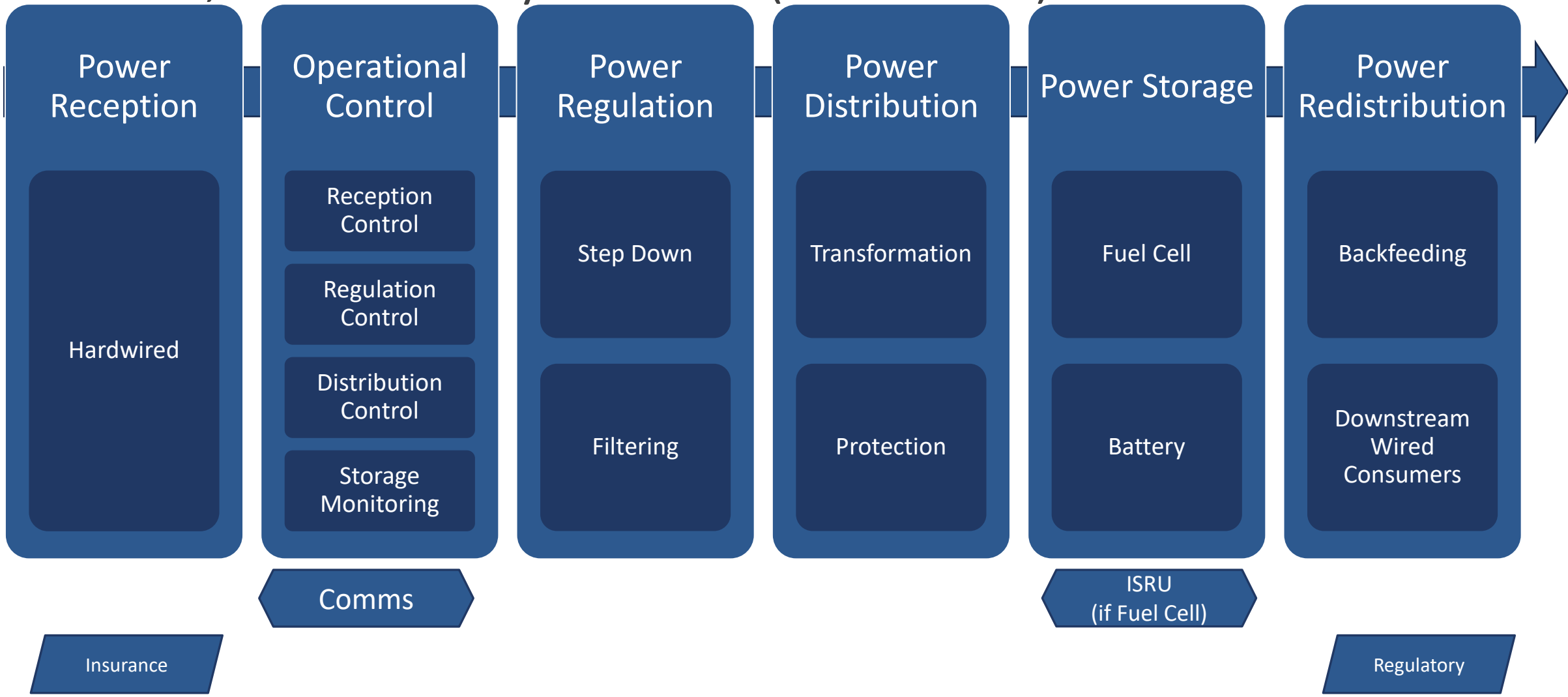
Exploration Phase (Years 0-3)

Power Value Chain 1
Wired, On-Facility Power (Receiver)



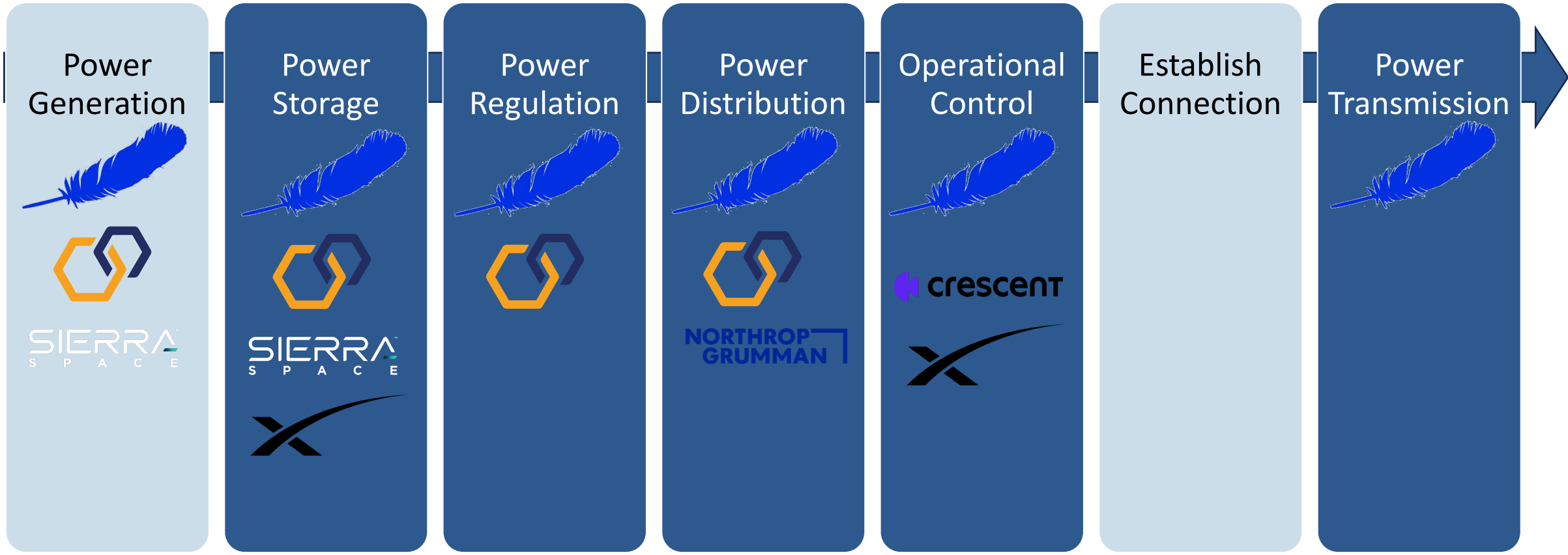
Exploration Phase (Years 0-3)

Power Value Chain 1
Wired, On-Facility Power (Receiver)



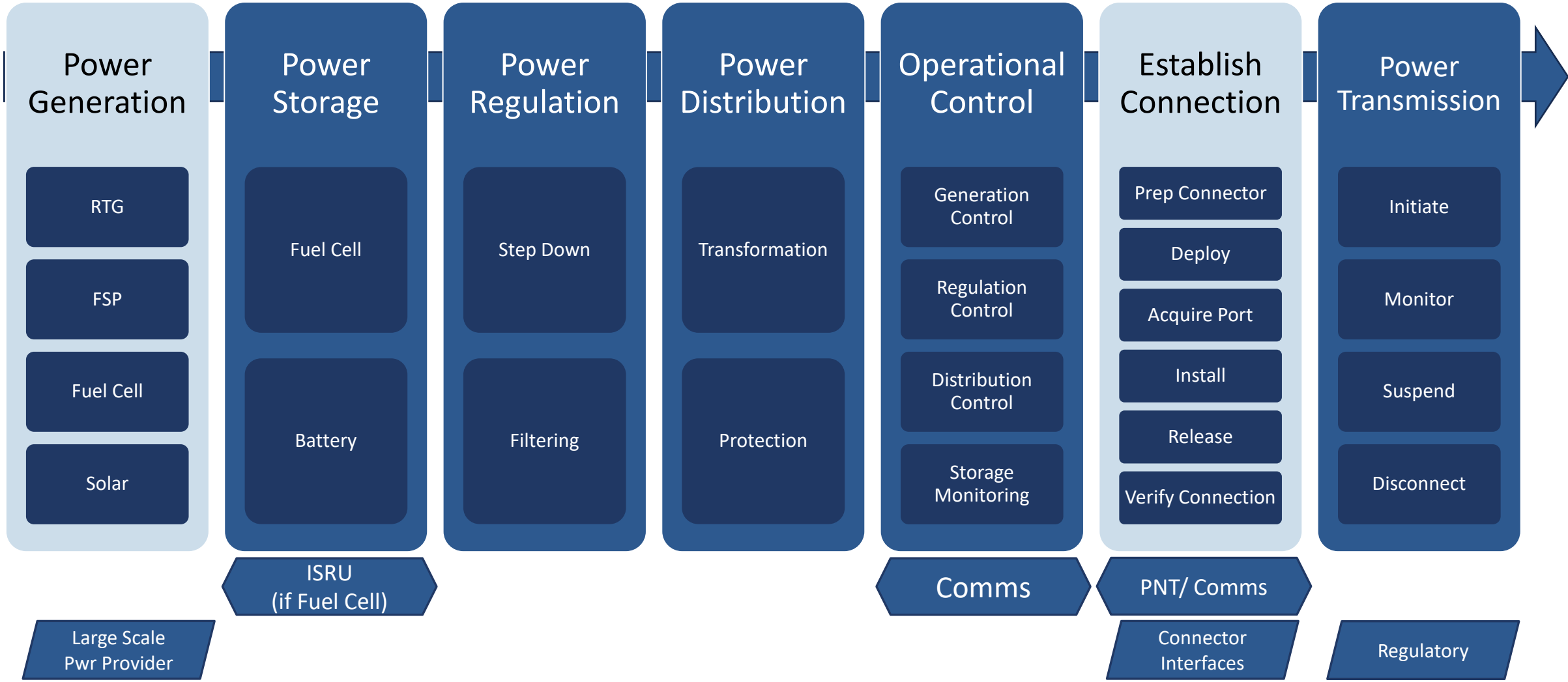
Foundation Phase (Years 3-6)

Power Value Chain 2
Wired, Remote Power (Provider)



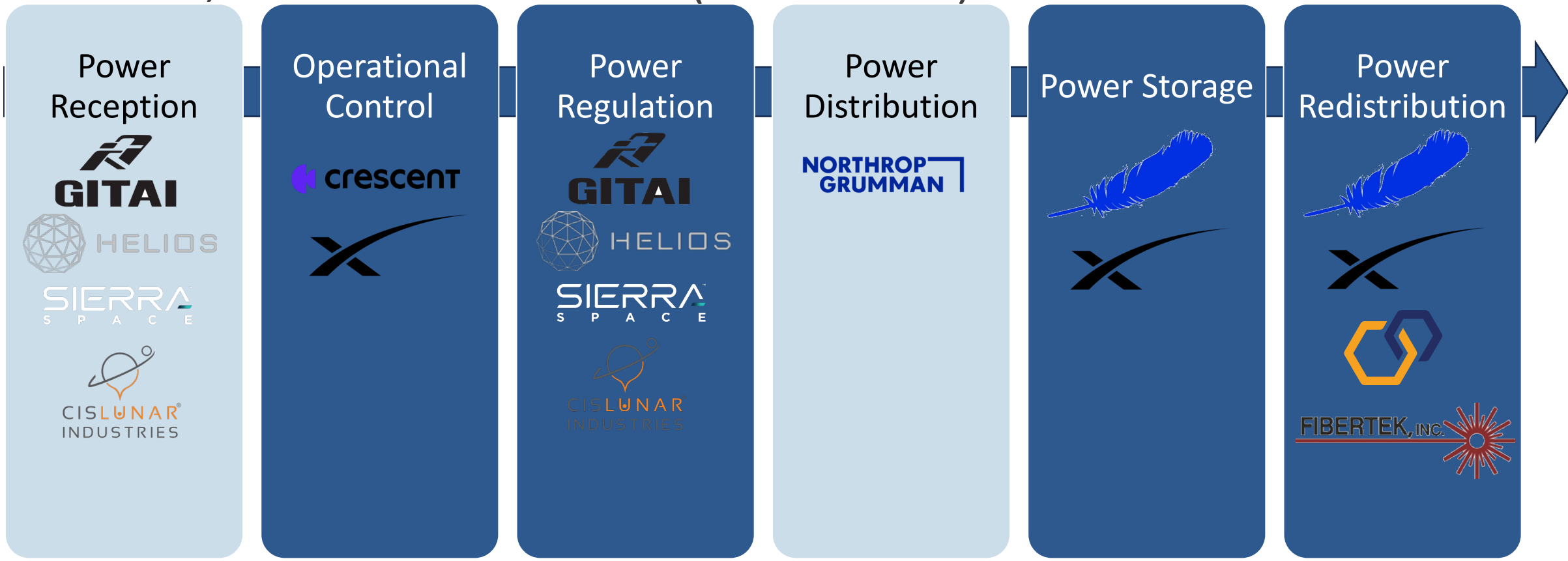
Foundation Phase (Years 3-6)

Power Value Chain 2
Wired, Remote Power (Provider)



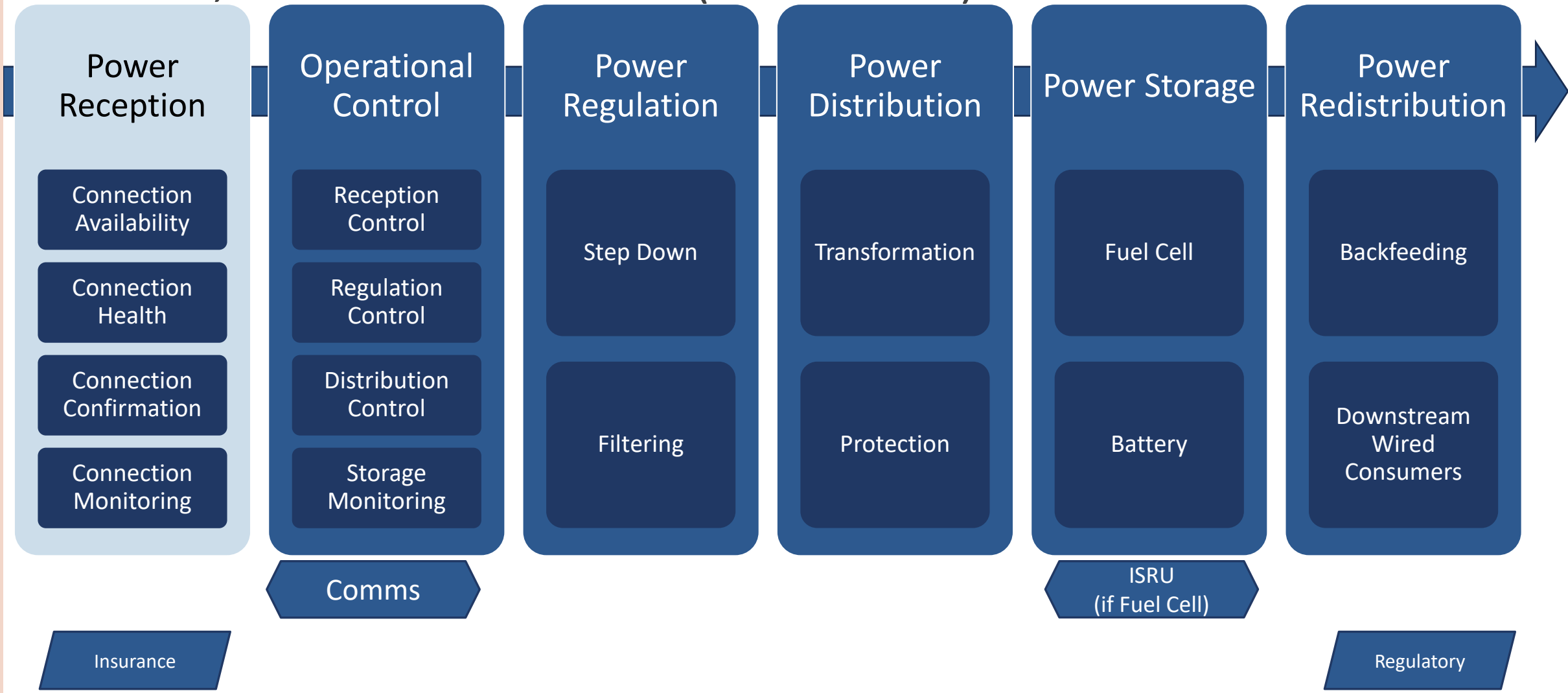
Foundation Phase (Years 3-6)

Power Value Chain 2
Wired, Remote Power (Receiver)



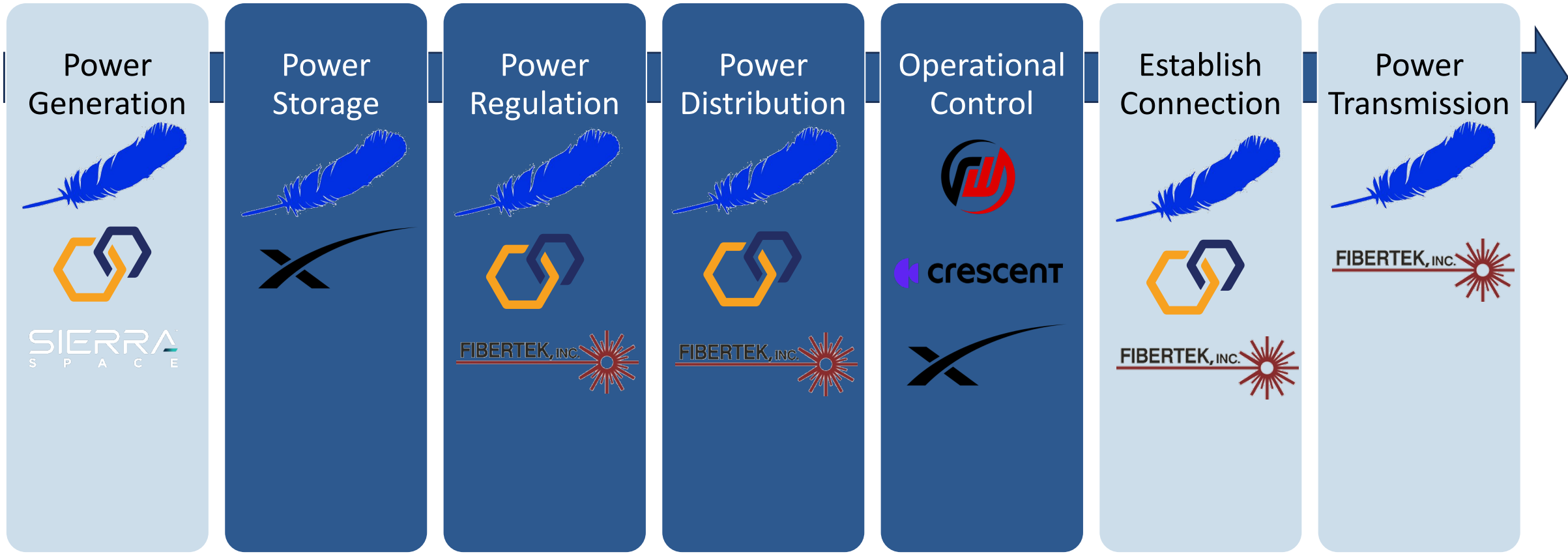
Foundation Phase (Years 3-6)

Power Value Chain 2
Wired, Remote Power (Receiver)



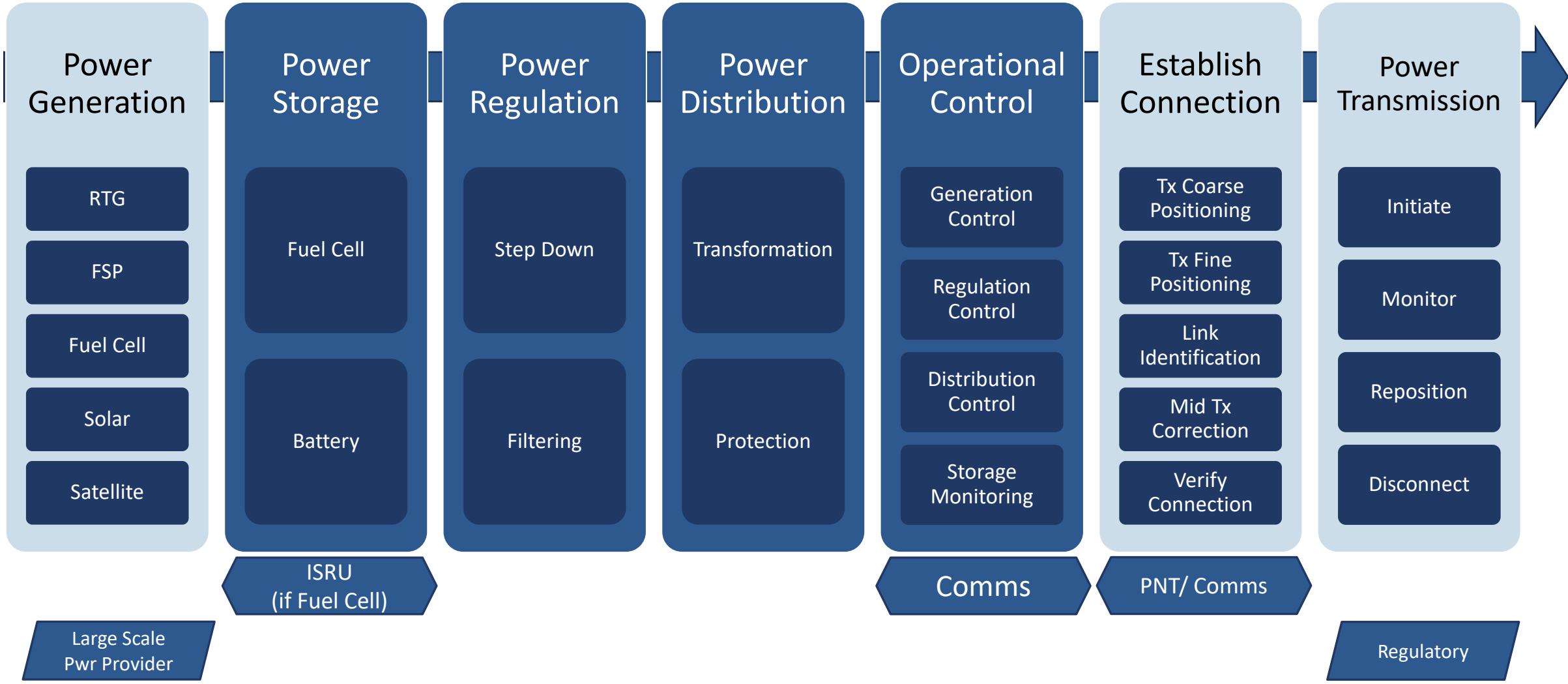
Industrial Phase (Years 6-10)

Power Value Chain 3
Wireless, Remote Power (Provider)



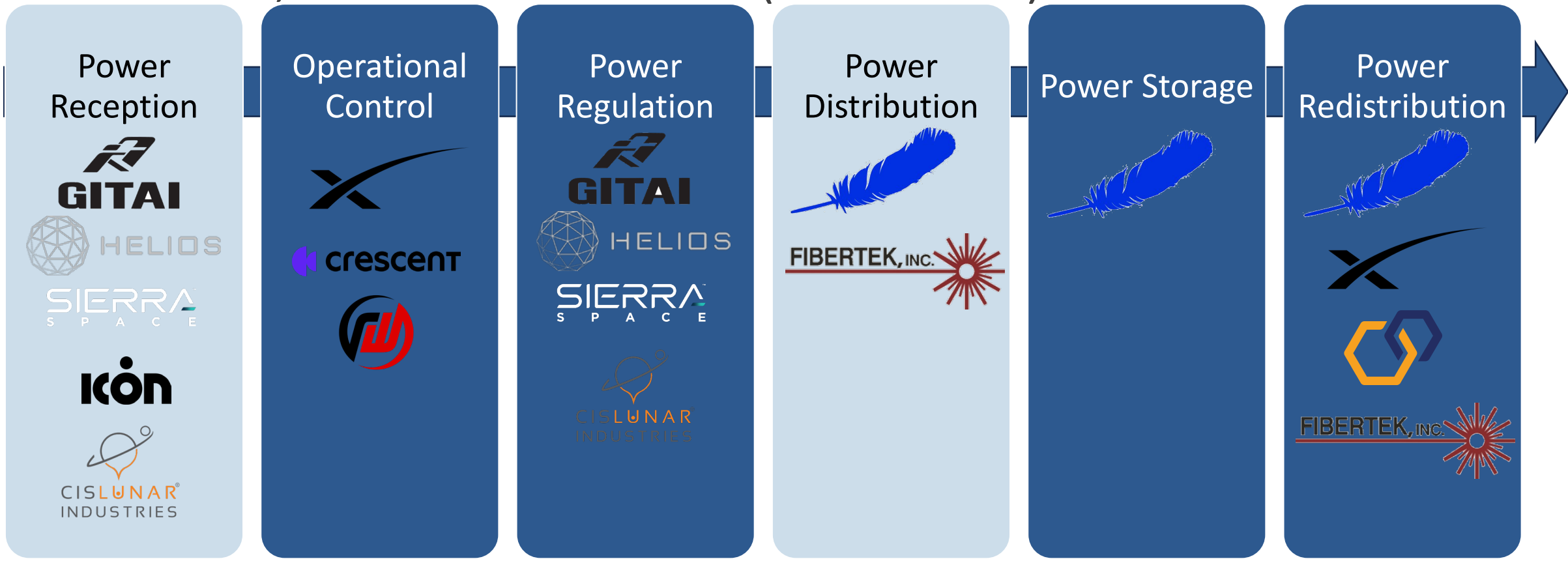
Industrial Phase (Years 6-10)

Power Value Chain 3
Wireless, Remote Power (Provider)



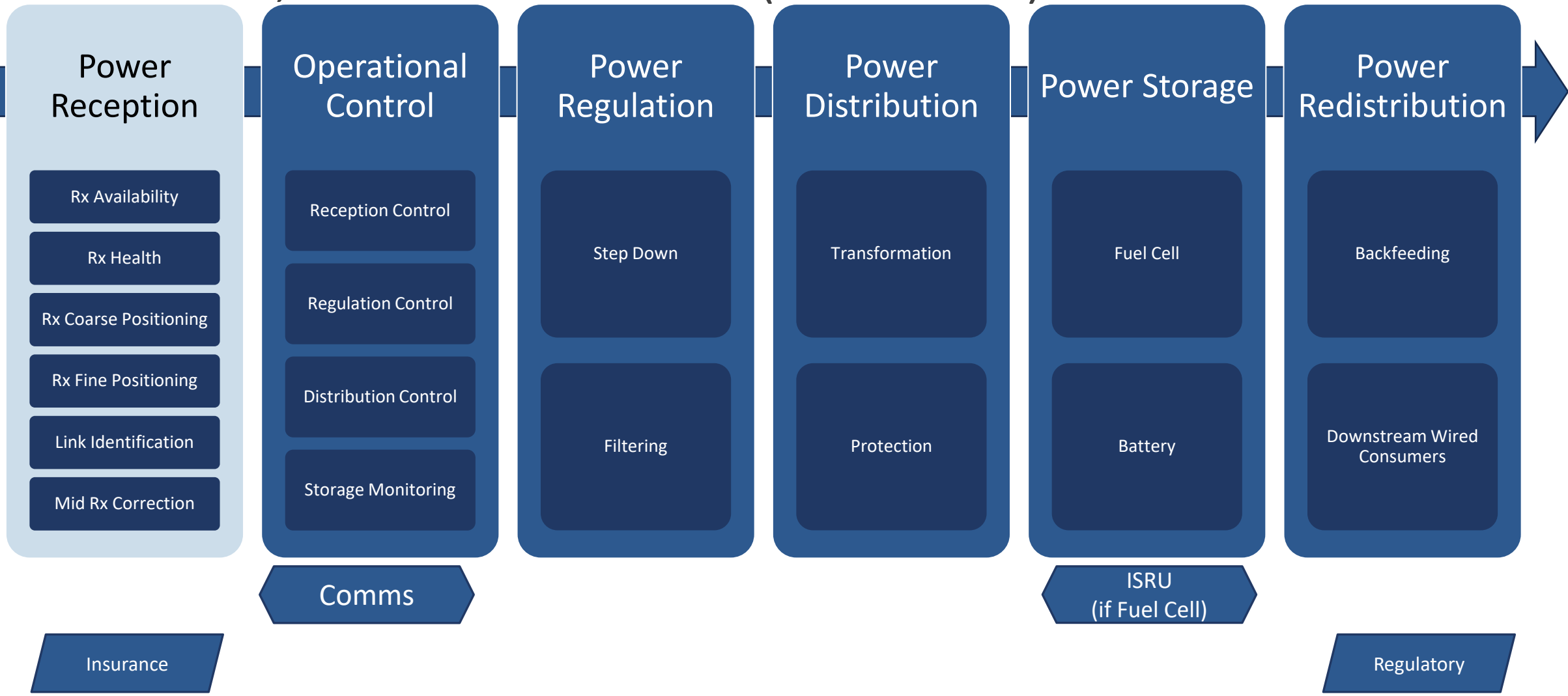
Industrial Phase (Years 6-10)

Power Value Chain 3
Wireless, Remote Power (Receiver)



Industrial Phase (Years 6-10)

Power Value Chain 3
Wireless, Remote Power (Receiver)



Appendix 7 – ISRU Value Chains

Image Credit: Sierra Space

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

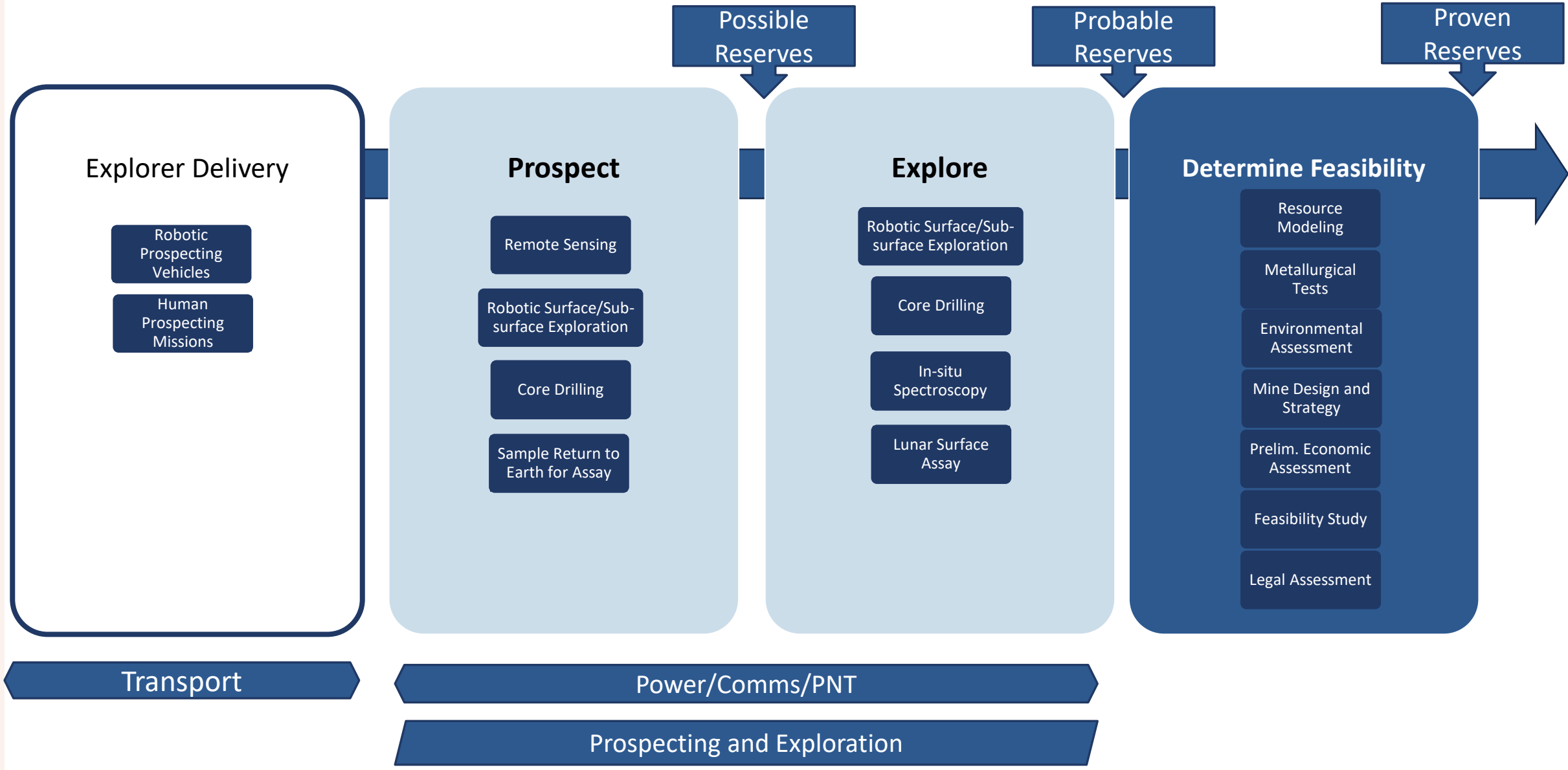
Transpo

Power/Comms/PNT

Prospecting and Exploration

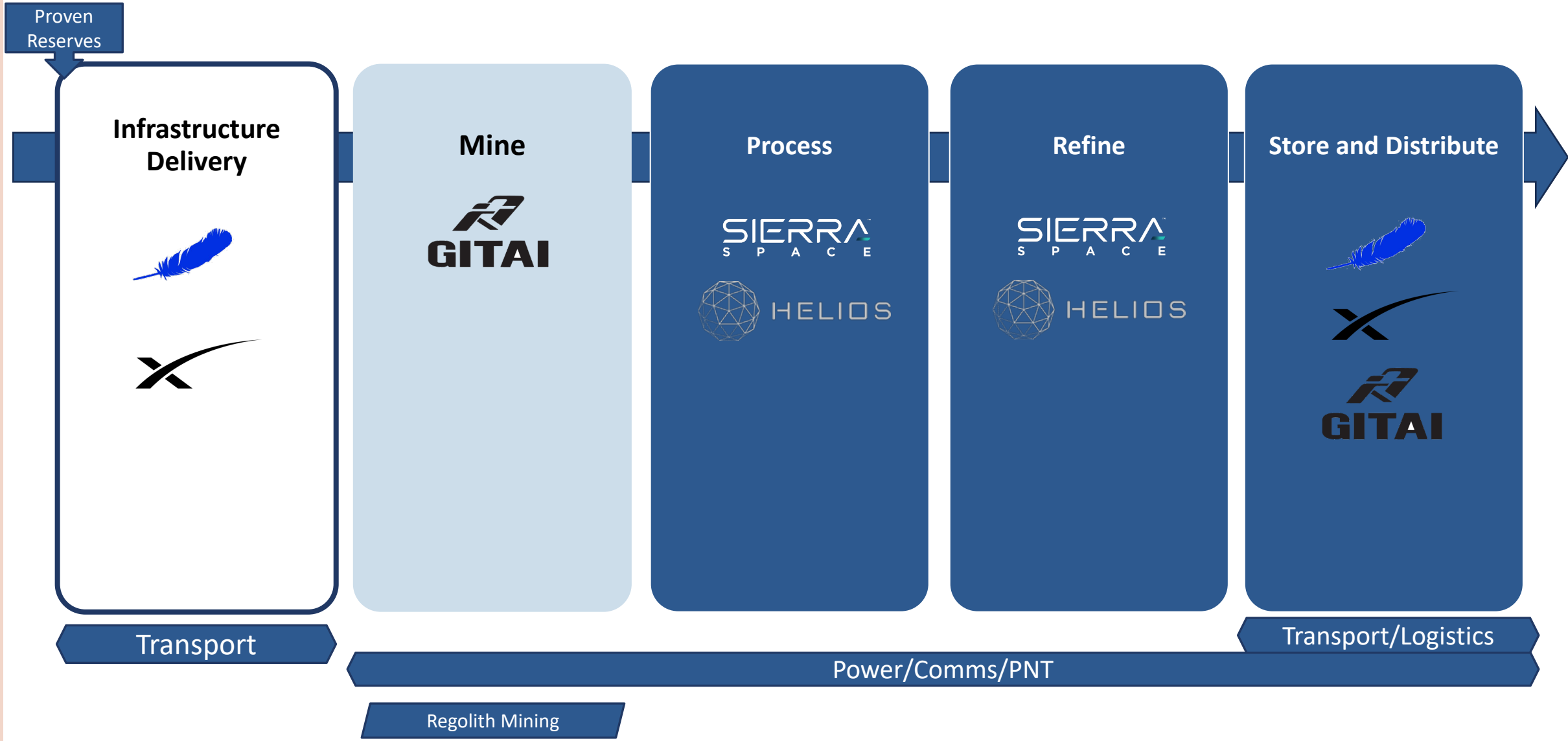
ISRU – REGOLITH DERIVED OXYGEN VC

Exploration Phase (Years 0-3)



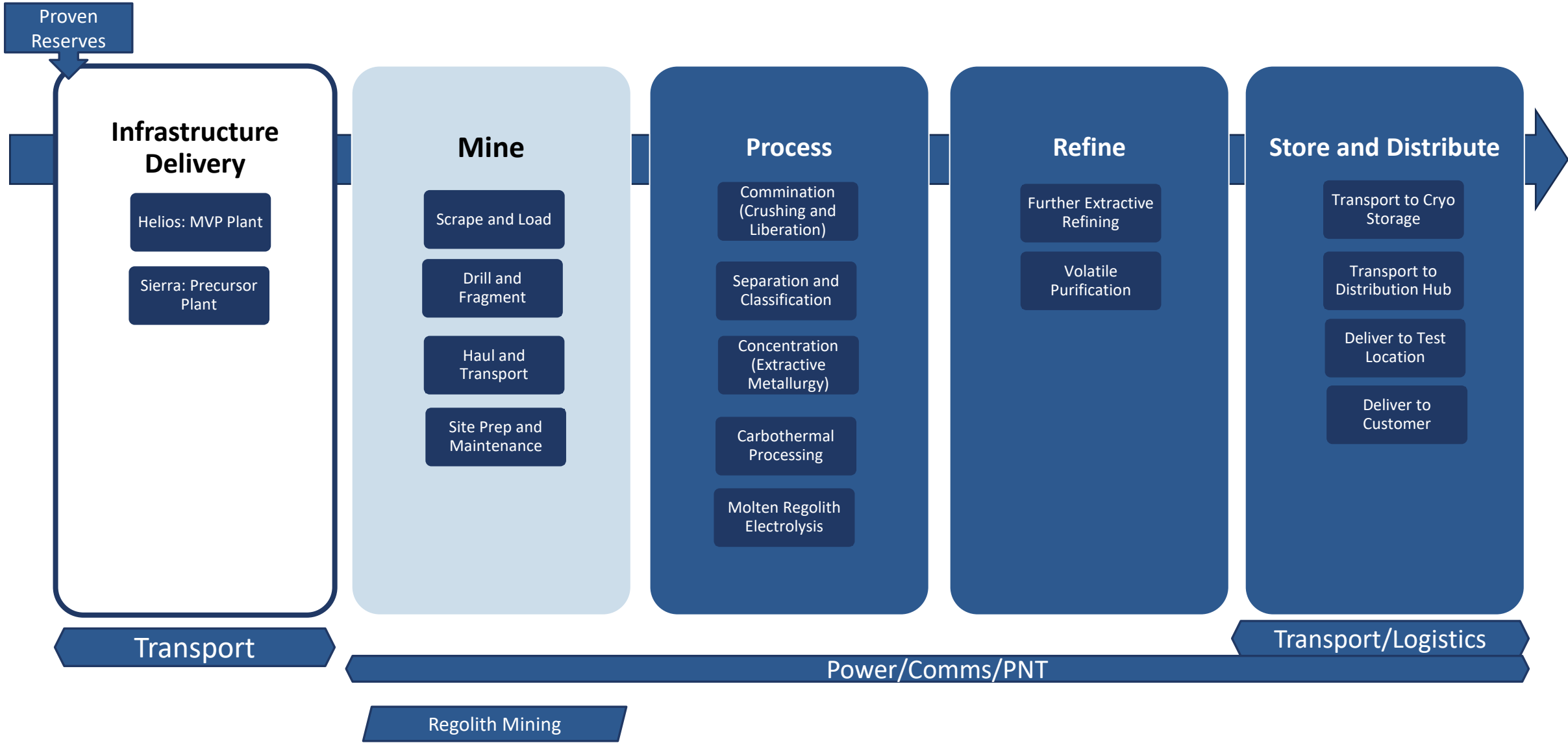
Foundation Phase (Years 3-6)

ISRU – REGOLITH DERIVED OXYGEN VC



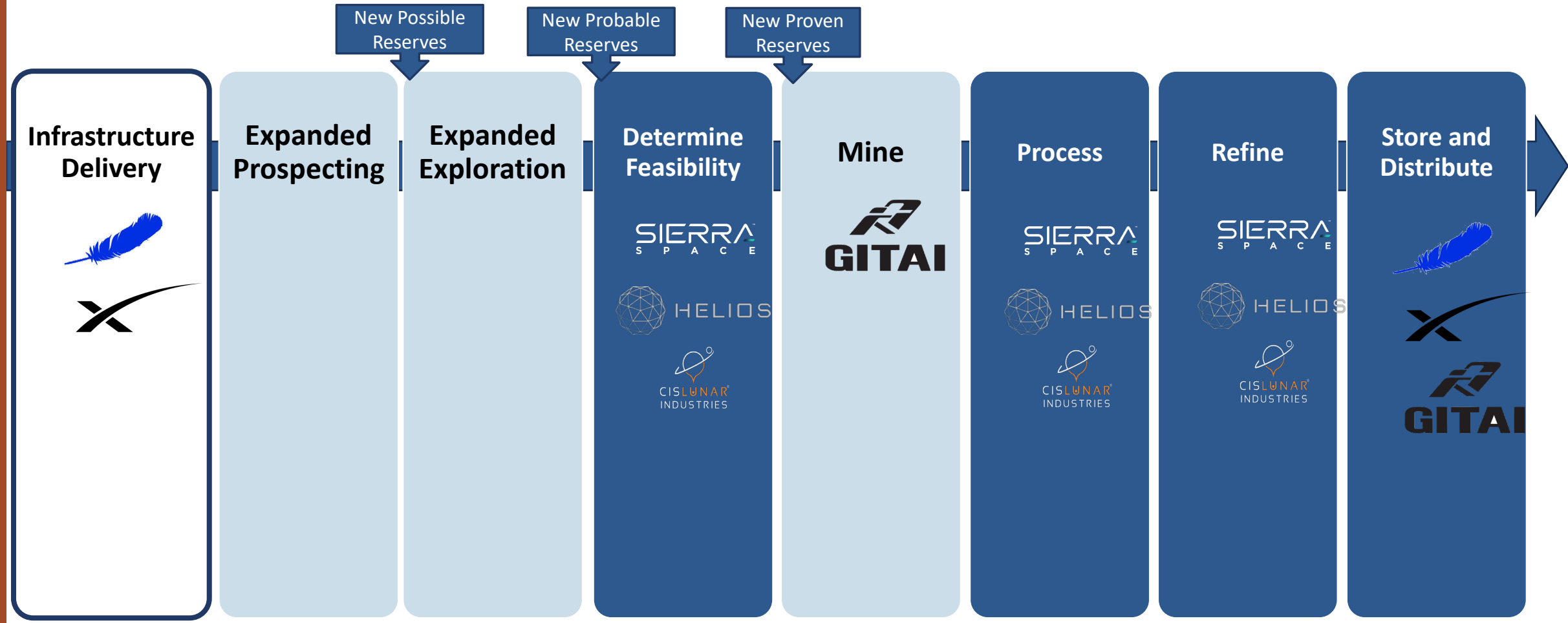
Foundation Phase (Years 3-6)

ISRU – REGOLITH DERIVED OXYGEN VC



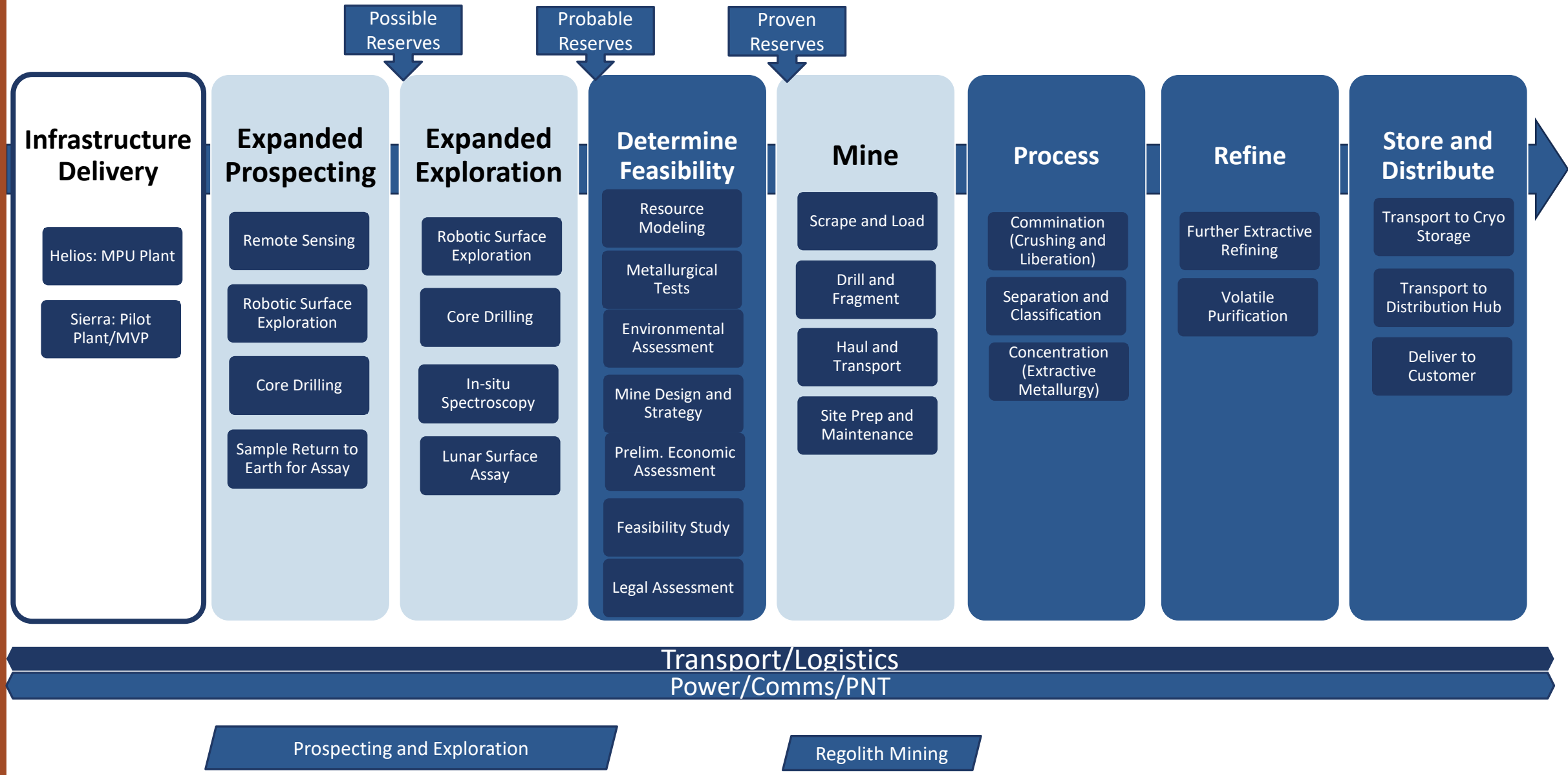
ISRU – REGOLITH DERIVED OXYGEN VC

Industrial Phase (Years 6-10)



ISRU – REGOLITH DERIVED OXYGEN VC

Industrial Phase (Years 6-10)

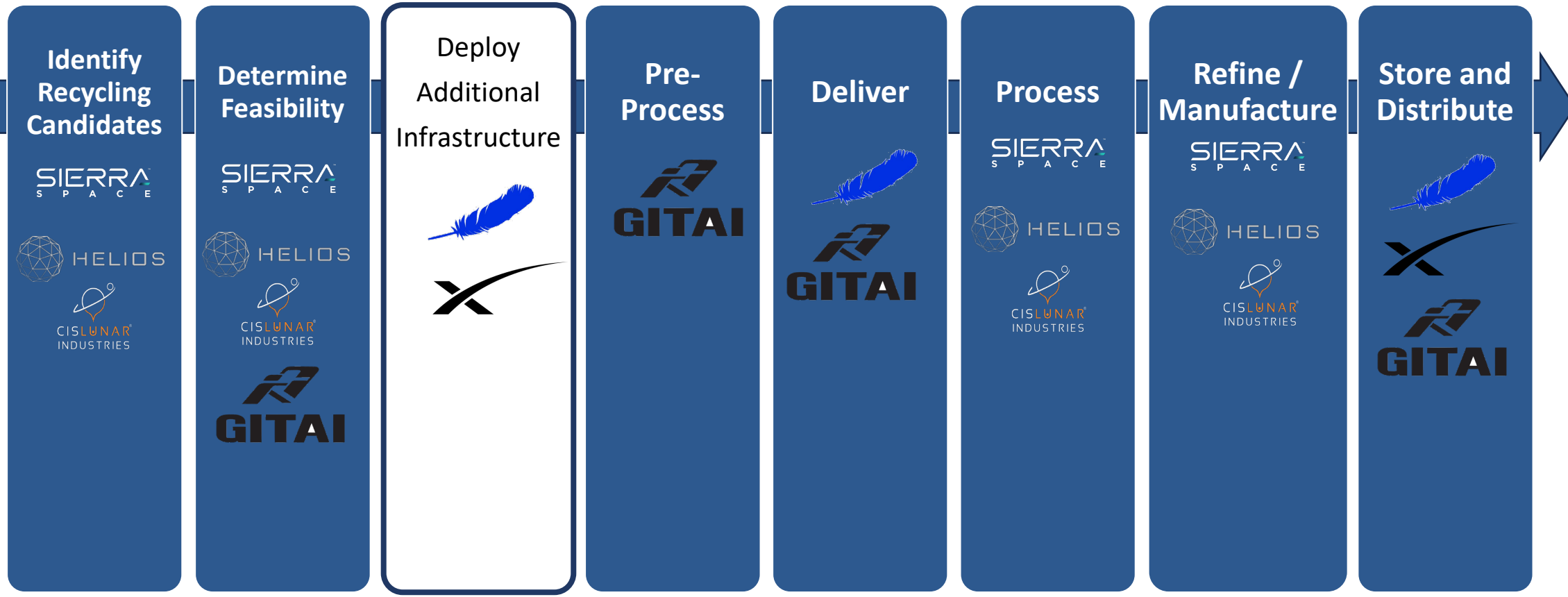


Foundation Phase (Years 3-6)

Industrial Phase (Years 6-10)

ISRU – MATERIAL RECYCLING

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

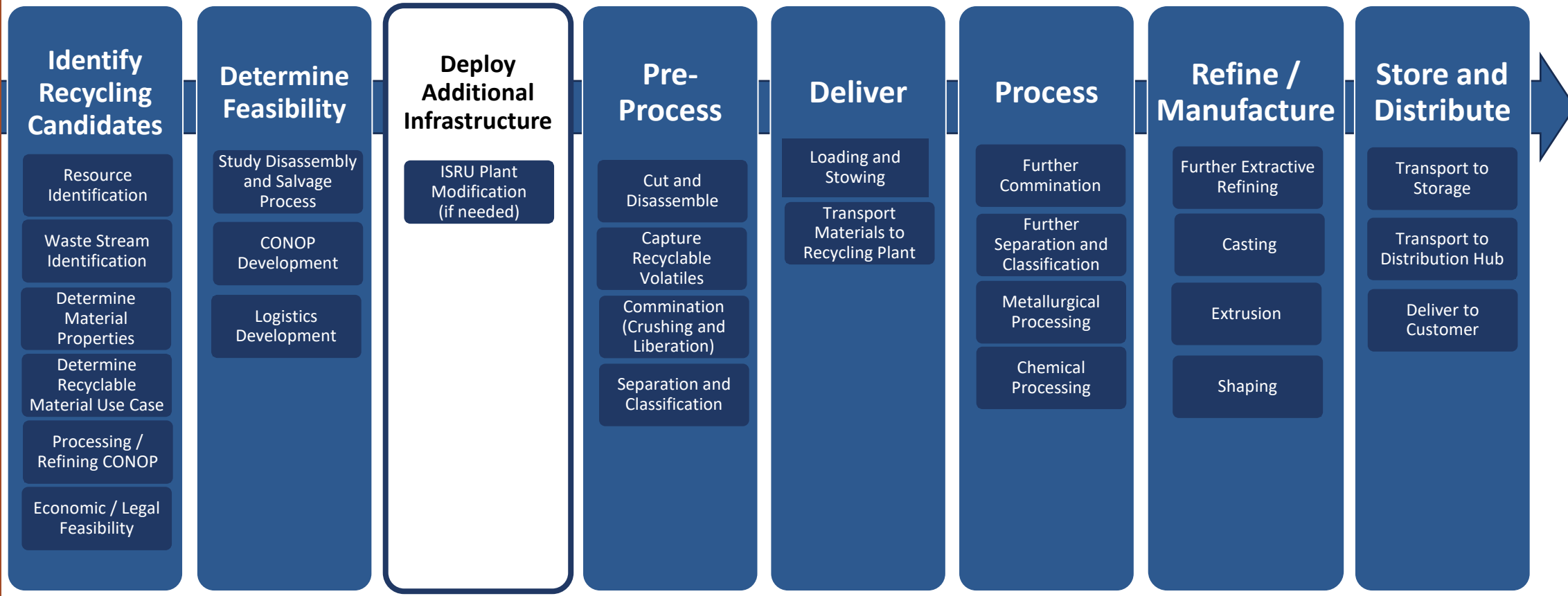


Foundation Phase (Years 3-6)

Industrial Phase (Years 6-10)

ISRU – MATERIAL RECYCLING

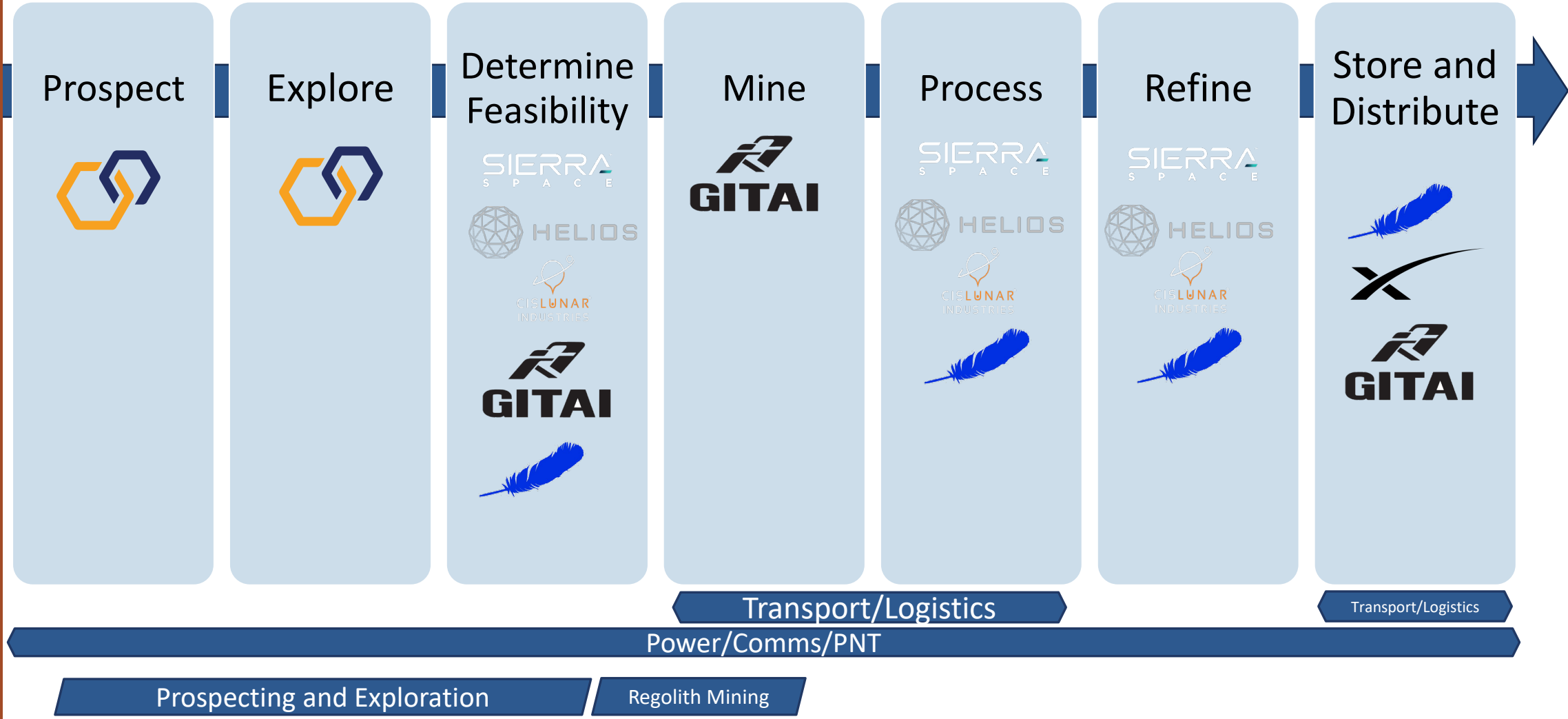
It is advantageous to design single-use/limited lifetime materials and ISRU processes for recycling!



Foundation Phase (Years 3-6)

Industrial Phase (Years 6-10)

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



Foundation Phase (Years 3-6)

Industrial Phase (Years 6-10)

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