Recycling the International Space Station White Paper

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Astroscale U.S.

CISLUNAR INDUSTRIES

Nanoracks

KALL MORRIS INC

NEUMANN SPACE

1 Opportunity

For more than twenty years, the International Space Station (ISS) has allowed for sustained human presence and research in low Earth orbit (LEO), yielding lasting returns on a wide array of scientific and technological efforts on Earth. Decades of scientific inquiry onboard the ISS have greatly expanded human understanding. Even though the ISS is unlikely to remain a human-rated spacecraft beyond its planned decommission in early 2031, the existing space architecture may continue to be of great scientific and technical value.

2 Solution

We propose repurposing the ISS at end of life to serve as the foundation of a non-habitable workspace for in-space logistics, servicing, and manufacturing, where individual components can be recycled into feedstock.

2.1 Solution Roadmap

The In-Space Servicing, Assembly, and Manufacturing (ISAM) National Strategy published in April 2022 outlines strategic national goals to address specific challenges currently impeding development of the ISAM industry. The decommissioning of the ISS offers an opportunity to repurpose existing space infrastructure as a resource for near-term ISAM initiatives. Given a new role as a non-habitable salvage yard and high-vacuum, microgravity workspace, the ISS can become a dynamic resource for ISAM technology and skills development. This will create jobs, help maintain US competitiveness, and set an inspiring example of sustainability and resourcefulness in space.

CisLunar Industries and its partners have laid out a preliminary roadmap to accomplish the ISAM national strategy and plan to develop a full mission strategy. Some key steps in the process for in-space repurposing of useful materials and components from the ISS are as follows:

- Create a master plan for what can be preserved, repurposed, and recycled.
- Obtain consent from owners to repurpose components and materials.
- Establish contracts and licensing for repurposing services and acquisition of requisite launch, spectrum use, and non-Earth imaging, as applicable.
- Launch servicer spacecraft and technologies.

2.2 Solution Overview Diagram

Exhibit 1 shows the solution overview for repurposing the ISS into usable in-space resources.

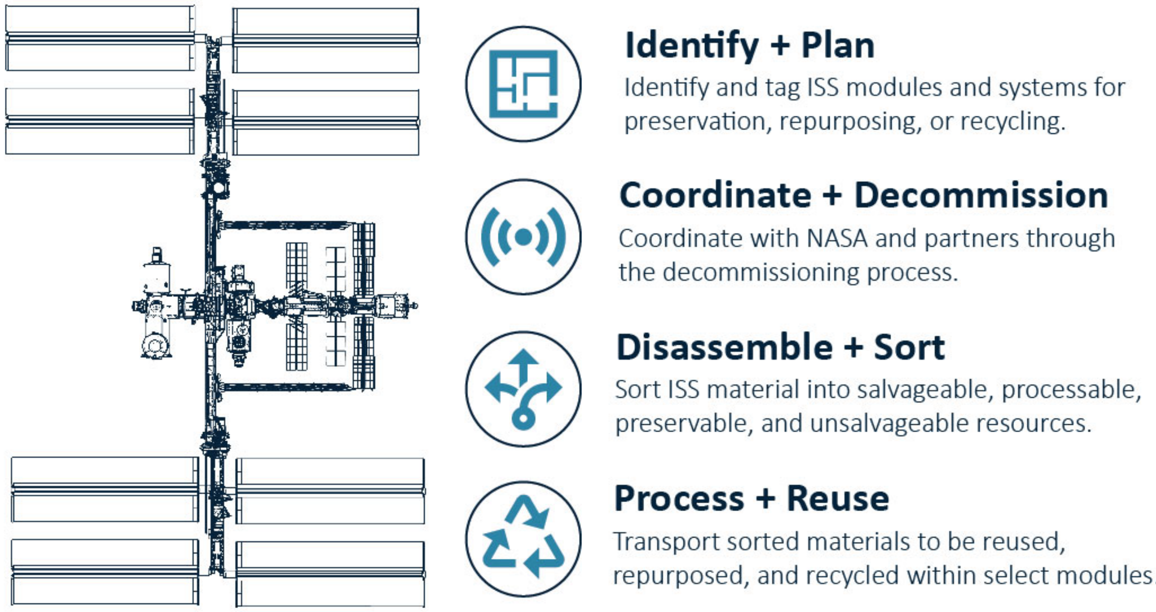

Exhibit 1. Solution Overview Diagram

2.3 On-Orbit Sequence

The following sequence details a conceptual approach to end-of-life operations at the ISS:

1. Identify and tag ISS modules for preservation, repurposing, or recycling.
    - Radiators, solar panels, batteries, and other power systems
    - Station-keeping systems
    - Modules for storage, staging, and semi-habitable spaces
    - Trusses for use in station reconfiguration and parking spots for large debris and vehicles
2. Coordinate with NASA through the decommissioning process.
    - Isolate modules that may still serve as semi-habitable spaces.
    - Reconfigure utility paths for station-keeping, communications, and other station critical support systems.
    - De-energize and disconnect power and pressurized systems.
3. Repurpose select ISS modules for staging and warehousing salvaged materials.
    - Build out salvage modules.
    - Use available crew, Canadarm, and modular servicing arms in initial repurposing.

4. Disassemble ISS modules selected for recycling.

- Use the Canadarm, and modular servicing arms.
- Use toolkit of end arm effectors including soft-capture system for securing unprepared, delicate, or unwieldy materials and debris-free cutters for controlled disassembly.
- Use free-flying servicing spacecraft operating servicing arms on station.

5. Sort material at ISS into salvageable, processable, preservable, and unsalvageable resources.

- Apply remote sensing technology to identify resources by material composition, quantity, and ability to separate from neighboring materials.

6. Consolidate sorted materials within the ISS.

- Store materials requiring further consolidation in repurposed modules to prevent creation of additional debris.
- Secure large materials on station structure.

7. Transport select, sorted materials to commercial space stations for further processing or use.

- Use servicing arms for securing and transferring prepared materials within station and new stations that may be attached via boom or tether.
- Use spacecraft for transport to commercial stations.

8. Process materials on commercial space stations.

- Triage materials and consolidate by material type utilizing remote sensing to guide robotic cutting and disassembly by material composition.
- Process metal materials with the Modular Space Foundry into propellant rods, wire, feedstock, and other basic metal construction materials.

9. Reuse, repurpose, and recycle items and implement ISAM initiatives.

- Apply metal propellant rods to electric propulsion systems, which could power spacecraft for orbital transfer and station-keeping.
- Transport metal propellant rods from ISS to space vehicles.
- Transfer metal propellant rods from service vehicle to client vehicle using robotic servicing arm.
- Transport unprepared objects (i.e., debris and derelict satellites) to the station for servicing or repurposing.

10. Separate unsalvageable components from the ISS and relocate the ISA-optimized ISS to a higher orbit for long-term stability.

- Segregate and relocate unsalvageable material.
- Relocate station to higher, long-term orbit.

3 Capabilities Leveraged

Astroscale, CisLunar Industries, Kall Morris Inc (KMI), Nanoracks, and Neumann Space are developing expertise and technologies to apply to a repurposing mission concept.

Astroscale has demonstrated rendezvous, proximity operations, and docking (RPOD) and maneuver technology in LEO for prepared objects and is developing technology to do the same with unprepared objects. KMI is developing separate technologies with a focus on rendezvous, retrieval, and relocating unprepared materials between locations in orbit, demonstrating aboard the ISS in 2023. Nanoracks is developing commercial space stations that can host space debris and materials processing centers. CisLunar Industries is developing in-space, metal-processing capabilities to melt down materials and reform them into useful products, like wire filament for 3D printing, manufacturing feedstock like sheet metal, and metal propellant rods. Neumann Space, an international partner, has developed a propulsion system that can run on metal rods recycled in space.

Exhibit 2 lists the capabilities of partner companies and technical contributors.

Exhibit 2. Partner Capabilities

Company	Capabilities
Astroscale U.S.	• RPOD with prepared and unprepared objects • Orbital transfer and maneuver • Inspection and characterization of objects • First commercial demonstration of RPOD technology in orbit
CisLunar Industries	• Foundry, metal processing, and industrial hardware for in-space assembly and manufacturing • Recycling of metal (including debris) into propellant rods and manufacturing feedstocks
Kall Morris Inc	• Analysis and capture of unprepared objects in orbit • Repeatable and releasable method to deliver objects to new orbits • Orbital material analysis and orbital dynamics
Nanoracks	• Development of a free-flying commercial space station • Operation of the Bishop Airlock and various other hardware on ISS • Development of upper stage repurposing technologies, including microgravity metal cutting capability • Satellite mission management and payload integration
Neumann Space	• In-space electric propulsion using solid metallic propellant rods (including in-space recycled metals)

4 Benefits

Recycling the ISS aligns with the strategic goals of the ISAM National Strategy:

- Advance ISAM research and development.
- Prioritize expanding scalable ISAM infrastructure.
- Accelerate the emerging ISAM commercial industry.
- Increase the industrial competitiveness of US private space companies.
- Extend the economic value of the ISS and return on investment on US taxpayers.
- Promote international collaboration and cooperation.
- Prioritize sustainability on Earth and in space.
- Inspire the future space workforce.

5 Next Steps

The US government should consider how to:

- Enact policy to capitalize on the substantial long-term investment in the ISS.
- Enable mechanisms for transfer of ownership, similar to decommissioned ships.
- Allow commercial entities to offer recycling as a service to NASA.
- Invest in ISAM with a clear signal to purchase materials derived and produced in space.
- Build a library of physical properties for materials produced in space.
- Identify demand for materials by tonnage, location, and timeframe.
- Establish a market price for materials produced in space.
- Provide incentive to use materials produced in space for ISAM.

Points of contact for this white paper:

- Astroscale U.S. Inc. Carolyn Belle c.belle@astroscale-us.com
- CisLunar Industries Joe Pawelski joe@cislunarindustries.com
- Kall Morris Inc Troy M. Morris troy@kallmorris.com
- Nanoracks David Marsh dmarsh@nanoracks.com
- Neumann Space Herve Astier herve.astier@neumannspace.com