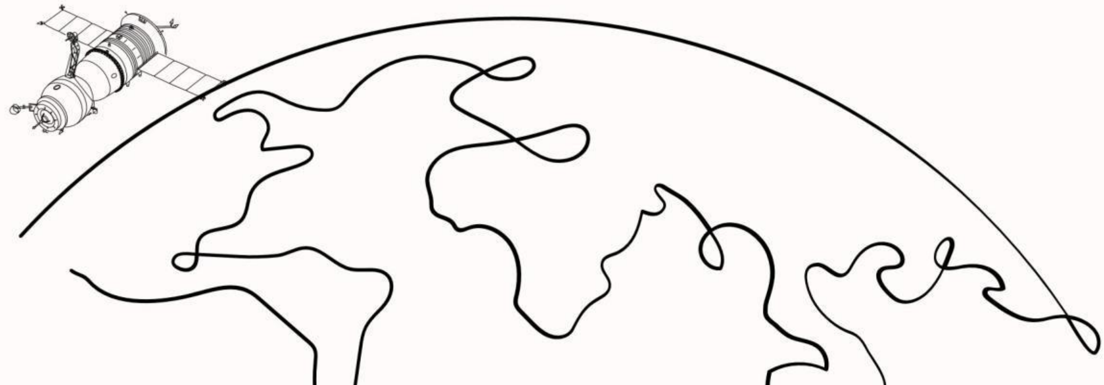
Turning Space Debris into Resources:

# The Space Debris Utilization Foundry (SDUF)



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# Abstract

Earth's orbit is becoming increasingly congested with defunct satellites, rocket bodies, and millions of fragments that pose risks to active missions and long-term space sustainability. Traditional debris removal concepts focus mainly on de-orbiting or destroying these objects, but this approach discards valuable materials already in space. The Space Debris Utilization Foundry (SDUF) presents a new pathway for capturing, processing, and repurposing orbital debris directly in orbit. By doing so, SDUF not only mitigates a critical safety threat but also pioneers in-space manufacturing that reduces reliance on costly Earth launches.

The concept is structured around a phased roadmap. First, a demonstrator in Low Earth Orbit (LEO) will prove debris capture, safe storage, and initial processing. Later, this system will evolve into a full orbital foundry capable of melting, reshaping, and 3Dprinting metals into useful components. The estimated cost for a demonstrator is between 80 and 150 million USD, comparable to existing debris-removal missions, but with the added benefit of material recovery and reuse.



**Keywords**: space debris, orbital sustainability, in-orbit recycling, in-situ resource utilization, orbital foundry, SDUF

# Introduction

Since the dawn of the Space Age, human activity has left behind thousands of objects in orbit. According to the European Space Agency (ESA) and NASA, there are over 54,000 pieces of trackable debris larger than 10 cm and millions of smaller fragments. These include an estimated 3,000 to 5,000 defunct satellites and more than 2,000 dead rocket bodies. Alongside these large objects are hundreds of thousands of smaller pieces between 1 and 10 cm, and millions more fragments as small as paint flecks. Each of these travels at orbital velocities, fast enough to disable or destroy an active spacecraft on impact.

This growing accumulation of debris shows how much of Earth’s orbital environment is cluttered with hardware no longer serving a purpose. The risk is compounded by the Kessler Syndrome, where collisions create cascading clouds of new debris, threatening to make certain orbits unusable.

A frequent question arises: Why not simply bring debris back to Earth and recycle it here? The answer lies in the immense cost and risk. Deorbiting requires large amounts of fuel or drag-enhancing devices, and re-entry often destroys much of the material. Bringing large pieces back safely would mean complex and expensive missions. It makes much more sense to recycle the debris in space, where the material is already needed.

The Space Debris Utilization Foundry (SDUF) addresses this challenge by combining debris mitigation with in-situ resource utilization. By capturing, crushing, melting, and re-shaping orbital debris into usable forms, SDUF will reduce hazards while creating the foundation for a circular economy in space.

## The Problem and the Opportunity

Earth’s orbital environment is both threatened and resource-rich. Defunct satellites, rocket bodies, and structural elements are composed of high-value materials such as aluminum, titanium, and composites. On Earth, these materials are abundant, but in orbit they are worth thousands of dollars per kilogram because of launch costs. Current missions expend enormous sums to launch hardware from Earth when a growing supply already exists overhead.

Thus, orbital debris should not be seen solely as a hazard. It represents an untapped resource. If reclaimed and repurposed, these materials could support construction of protective shielding, satellite components, reflectors, or even large-scale space infrastructure. Thus, SDUF is designed to unlock this opportunity.

## Our Solution: The Space Debris Utilization Foundry (SDUF)

The SDUF is envisioned as a modular orbital facility located in Low Earth Orbit at an altitude of 400 to 500 km. It will consist of a central processing hub equipped with solar furnaces, robotic manipulators, and storage bays. The hub will be accompanied by modular units that can expand capacity over time.

Key capabilities of SDUF include:

- Capturing large debris objects such as dead satellites or rocket stages.
- Crushing oversized debris into manageable fragments for storage and processing.
- Melting metallic debris using concentrated solar furnaces.
- Casting and 3D-printing molten material into panels, sheets, brackets, and other components, building on the in-orbit manufacturing experiments already demonstrated on the International Space Station (ISS).

The system is designed to evolve. In its initial stages, it will serve as a debris catcher and safe storage facility. In later stages, it will operate as a full foundry, recycling space junk into new tools, shields, and structures.

## Development Roadmap

### Phase 1: LEO Demonstrator

The first stage will launch a compact demonstrator weighing 16–18 tons, with robotic arms, a crushing mechanism, and storage bays. It will focus on capturing large, intact debris such as defunct satellites or spent rocket tanks. Captured debris will be compacted, sorted and stored safely, reducing collision risks while testing collection technologies.

### Phase 2: Orbital Foundry

The second stage will introduce solar concentrators capable of reaching 1,500–2,000°C, sufficient to melt aluminum, titanium, and steel. Robotic manipulators will feed crushed debris into seprate, pressurized chambers. Molten material will then be cast into ingots, sheets, or 3Dprinted components, similar to ISS printing but scaled for structural production. This capability will allow the direct manufacture of satellite shields, panels, and reflectors in space.

# System Design and Architecture

## Core Hub

The central cylindrical module will house solar furnace systems, robotic arms, and control units. Storage tanks will hold molten metals, and modular “garages” will provide debris containment. The size of each module will be comparable to existing ISS modules (about 4.5 meters in diameter and 7–8 meters in length), enabling compatibility with current launch vehicles while allowing incremental expansion.

## Energy Systems

Solar energy will be the primary power source, using deployable arrays and concentrators. During eclipses, batteries will provide backup. In the future, compact nuclear power systems may be considered for continuous high-energy operations.

## Capture and Crushing

Collection systems will use robotic arms with cameras and LIDAR, inspired by ESA’s ClearSpace-1 and Japan’s Astroscale missions. Nets or docking adapters will secure large objects. A crushing mechanism will compact bulky structures such as rocket stages, ensuring efficient storage and furnace compatibility.

## Processing and Manufacturing

Molten metals will be separated by type, aluminum for panels, titanium or steel for strong supports. Additive manufacturing units, modeled on ISS 3D-printing experiments, will turn raw molten material into finished components, reducing dependence on Earth-launched parts.

# Development Roadmap

SDUF provides four major advantages:

**Mission Safety**

By actively removing large debris, SDUF reduces the most immediate threat to commercial and governmental satellites, protecting billions in infrastructure.

**Economic Viability**

Recycling materials in orbit addresses high launch costs. Components manufactured in space can drastically reduce the price of future largescale missions.

**Sustainability**

As a circular economy model for space, SDUF keeps orbits usable for future generations, preventing cascading debris events.

**Foundational Infrastructure**

SDUF is more than cleanup. It is the cornerstone of a long-term in-space manufacturing ecosystem, enabling construction of habitats, stations, and interplanetary vehicles.

# Risks and Mitigation

## Technical Risk

Capturing and processing uncontrolled, tumbling debris is complex. This is mitigated by beginning with stable, intact targets and building on proven robotics.

## Economic Risk

The market for in-orbit recycled material is still emerging. This risk is reduced by targeting early partnerships with government agencies and commercial satellite operators.

## Regulatory Risk

Ownership and salvage rights for orbital debris remain under debate. SDUF will coordinate with international bodies to ensure compliance and begin with cooperative partners.

## Operational Risk

The SDUF must also protect itself from debris. Shielding, safe operations, and later the use of recycled material for reinforcement can keep it safe.

## Economic Outlook

The first demonstrator mission is projected to cost between 80 and 100 million USD, comparable to ESA's ClearSpace-1 mission, which is budgeted at around a $104 million. Unlike ClearSpace-1, which only deorbits debris, the SDUF demonstrator validates in-situ material processing, establishing a long-term economic case for orbital recycling. A full-scale operational foundry would cost more but could eventually offset its expense through reduced launch requirements and partnerships with space agencies and industry.

## Conclusion

The Space Debris Utilization Foundry represents a turning point in how humanity engages with the orbital environment. Instead of treating debris solely as waste to be discarded, SDUF treats it as a resource to be harvested and reused. By starting with a small demonstrator and scaling to a full foundry, the project reduces risks while laying the foundation for a sustainable in-space economy. Just as the International Space Station became a symbol of global cooperation and technological achievement, SDUF has the potential to stand as the next major milestone, a facility that turns orbital hazards into the building blocks of future exploration.

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