Enabling a Space Circular Economy by 2050

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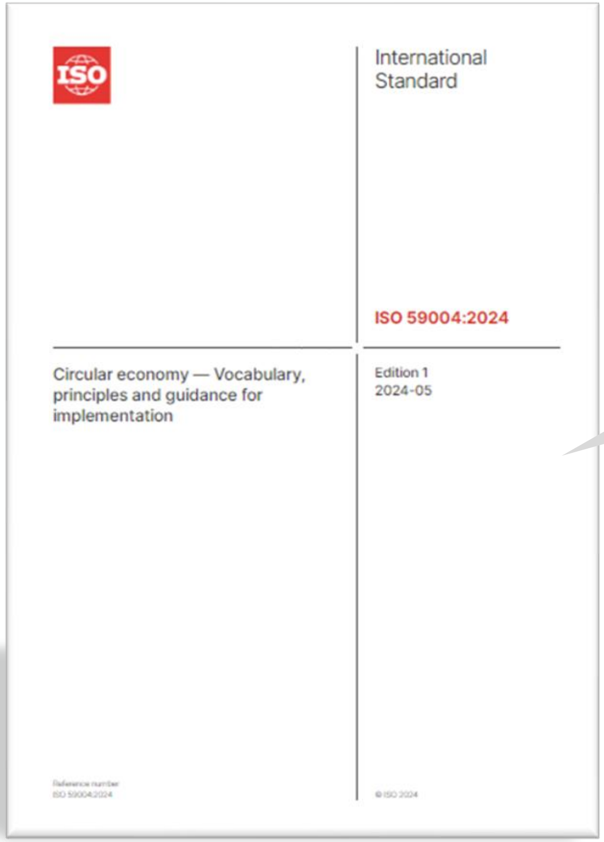
Talk Outline

1. What is the Space Circular Economy?
2. What are the Challenges?
3. What are the Enablers?
4. Space Circular Economy at ESA

What is the Space Circular Economy?

Defining a Circular Economy: ISO 59004


International Standard

ISO 59004:2024

Circular economy — Vocabulary, principles and guidance for implementation

Edition 1
2024-05

Circular Economy

An economic system that uses a systemic approach to maintain a circular flow of resources by recovering, retaining or adding to their value, while contributing to sustainable development

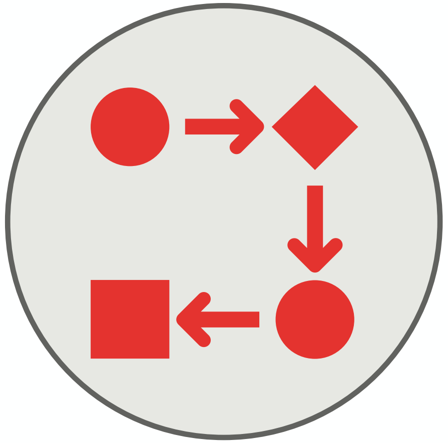
Three key parts of this definition:

- Systematic Approach
- Circular Flow of Resources
- Contributing to sustainable development

Systematic Approach and Circular Flow of Resources

Systematic Approach

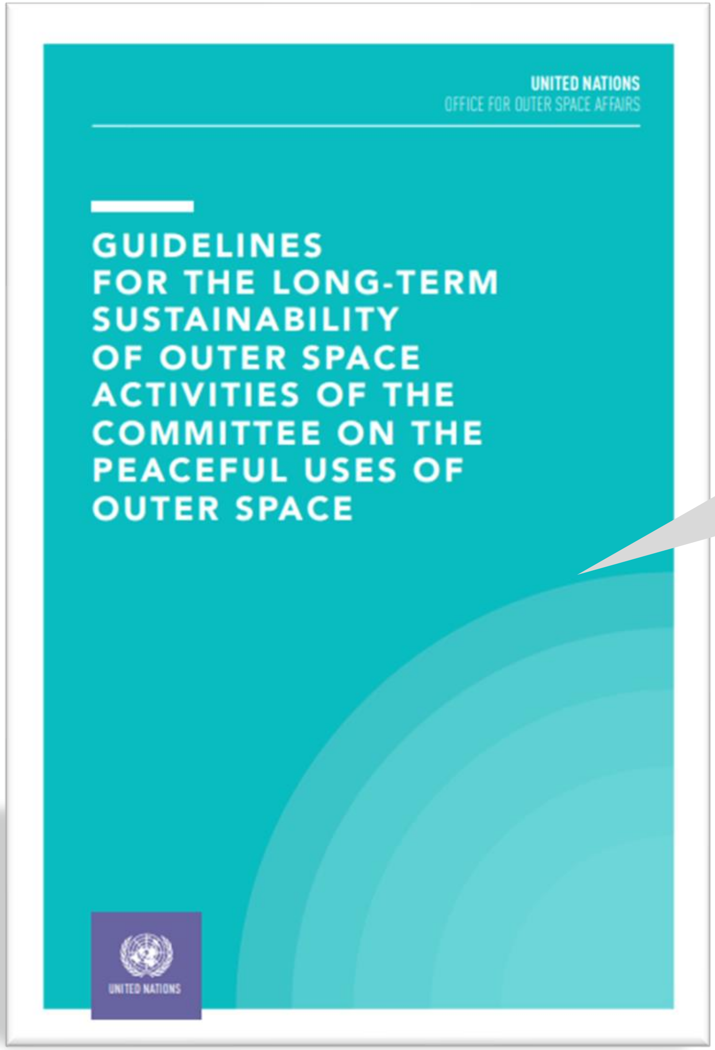
a systemic approach will take the form of new methods to design, develop, and manage complex space systems, with associated processes, methodologies, and tools.



Circular Flow of Resources

Reducing launch mass and re-using systems, sub-systems, components, and materials already in orbit. This will require advance in-orbit servicing technologies and missions capable of refurbishing existing systems, manufacturing and assembling new ones, and in the future recycling components

Defining a Circular Economy: Sustainable Development



Sustainability of Outer Space Activities

the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations

Working Definition of a Circular Economy

Combining the three definitions above gives the following working definition:

> *A space economy in which novel methods of design and managing space systems allows systems, subsystems, components, and materials to remain in orbit and be refurbished or re-used using an ecosystem of advanced in-orbit servicing techniques. This approach will preserve the space environment for future generations while meeting current economic needs.*

This is not proposed as a definition beyond the scope of this presentation but presented to clarify what is referred the following sections.

What are the Challenges?

Space Circular Economy Challenges

Business Cases
This a fundamental challenge, as economic viability will ultimately decide whether a circular approach will ultimately be adopted in space.

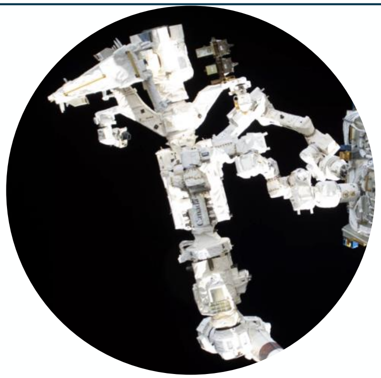
Regulatory Framework
A regulatory framework is required that can support and licence novel new activities while addressing difficult questions of oversight and liability.

Availability of Funding
The development of space circular economy technologies and missions will likely require support –at least at first—from space agencies and other funding bodies

Innovative Mission Concepts and Architectures
The space circular economy relies on an ecosystem of advanced in-orbit servicing techniques, which will require innovative mission concepts to demonstrate and eventually deliver services.

What are the Enablers?

Space Circular Economy Enabling Technologies

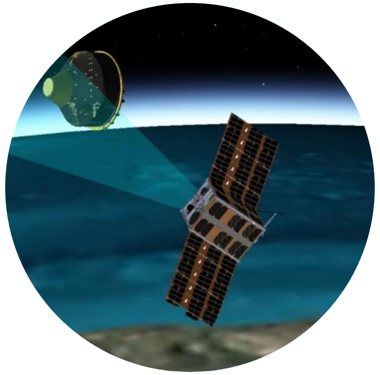


Advanced Space Robotics

In-Orbit Servicing missions rely on robotic capabilities to capture, manipulate, and service space objects.

Modular Spacecraft

Refurbishing and upgrading spacecraft will require new modular architectures with containerised subsystems or payloads



In-Orbit Verification

The creation of structures and satellites in orbit will require new approaches to verification and testing.

Standardised Interfaces

Standardised interfaces between subsystems and between payloads and platforms will be required to achieve modular spacecraft and reduce the complexity of services

Space Circular Economy Enablers I

Identify Use Cases
The use cases for in-orbit assembly, manufacturing, and recycling - including timeframe, cost, and return on investment (e.g., break-even point) will be defined.

Incentives and Regulation
It will be necessary to investigate potential incentive and regulatory schemes to foster an in-orbit assembly, manufacturing, and recycling ecosystem.

Technology Roadmaps
A variety of enabling technologies are required for the space circular economy. To mature and develop these technologies, it is necessary to first establish their TLRs and map necessary developments.

Cost Benefit Analysis
Cost-benefit analysis of the development and deployment of in-orbit assembly, manufacturing, and recycling compared to existing solutions

Space Circular Economy Enablers II

Design Principles for Circularity

Containerised, modular satellites architectures will be achieved by first developing design principles for circular space systems.

Ensure Long-term Reliability of Space Robotics

Persistent platforms in the space circular economy will have to reliably work for extended periods, and robotic subsystems in particular will be vital to in-orbit servicing missions.

Characterise Effects of the Space Environment

The long-term impact of the space environment on components which are re-used and re-purposed across several missions will have to be assessed before

Assess Environmental Impacts

Manufacturing and recycling on orbit risks the creation of debris or small fragments, and the creation of large structures could pose problems for ground-based astronomy.

Space Circular Economy Activities at ESA

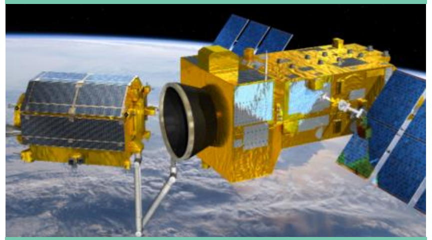
ESA activities - 5 Elements of IOS

Mission Implementation

Purpose: To implement Near Term IOS Opportunities:

- ADR and IOS Missions
- In-Space Transportations Missions

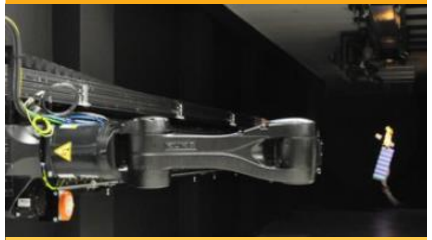
In-Orbit Servicing System Studies



Purpose: To Define Long-Term In-Orbit Servicing Missions:

- Assembly
- Manufacturing
- Refurbishment
- Recycling
- Refueling

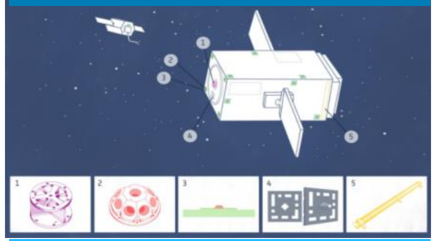
Technology Developments



Purpose: To prepare technologies for future IOS mission concepts:

- Capture systems
- Rendezvous and close-proximity equipment
- Test Facilities

Standardized Servicing Interfaces for Future Platforms



Purpose: To prepare future ESA missions:

- Capture interfaces
- Rendezvous markers
- System requirements
- Refueling interfaces

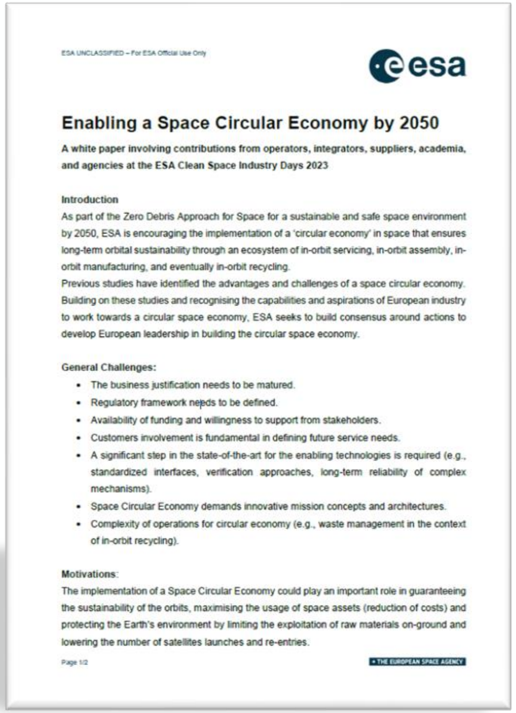
Safe Close Proximity Operations

Purpose: To derive a methodology for ensuring sustainable close-proximity operations:

- Guidelines
- Handbook
- Verification Tools

Circular Economy Workshops and White Paper

ESA has held a series of workshops with industry, operators, academia, and regulators to define an approach to the Space Circular Economy and published a White Paper on enabling activities.



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Enabling a Space Circular Economy by 2050

A white paper involving contributions from operators, integrators, suppliers, academia, and agencies at the ESA Clean Space Industry Days 2023

Introduction

As part of the Zero Debris Approach for Space for a sustainable and safe space environment by 2050, ESA is encouraging the implementation of a 'circular economy' in space that ensures long-term orbital sustainability through an ecosystem of in-orbit servicing, in-orbit assembly, in-orbit manufacturing, and eventually in-orbit recycling.

Previous studies have identified the advantages and challenges of a space circular economy. Building on these studies and recognising the capabilities and aspirations of European industry to work towards a circular space economy, ESA seeks to build consensus around actions to develop European leadership in building the circular space economy.

General Challenges:

- The business justification needs to be matured.
- Regulatory framework needs to be defined.
- Availability of funding and willingness to support from stakeholders.
- Customers involvement is fundamental in defining future service needs.
- A significant step in the state-of-the-art for the enabling technologies is required (e.g., standardized interfaces, verification approaches, long-term reliability of complex mechanisms).
- Space Circular Economy demands innovative mission concepts and architectures.
- Complexity of operations for circular economy (e.g., waste management in the context of in-orbit recycling).

Motivations:

The implementation of a Space Circular Economy could play an important role in guaranteeing the sustainability of the orbits, maximising the usage of space assets (reduction of costs) and protecting the Earth's environment by limiting the exploitation of raw materials on-ground and lowering the number of satellites launches and re-entries.

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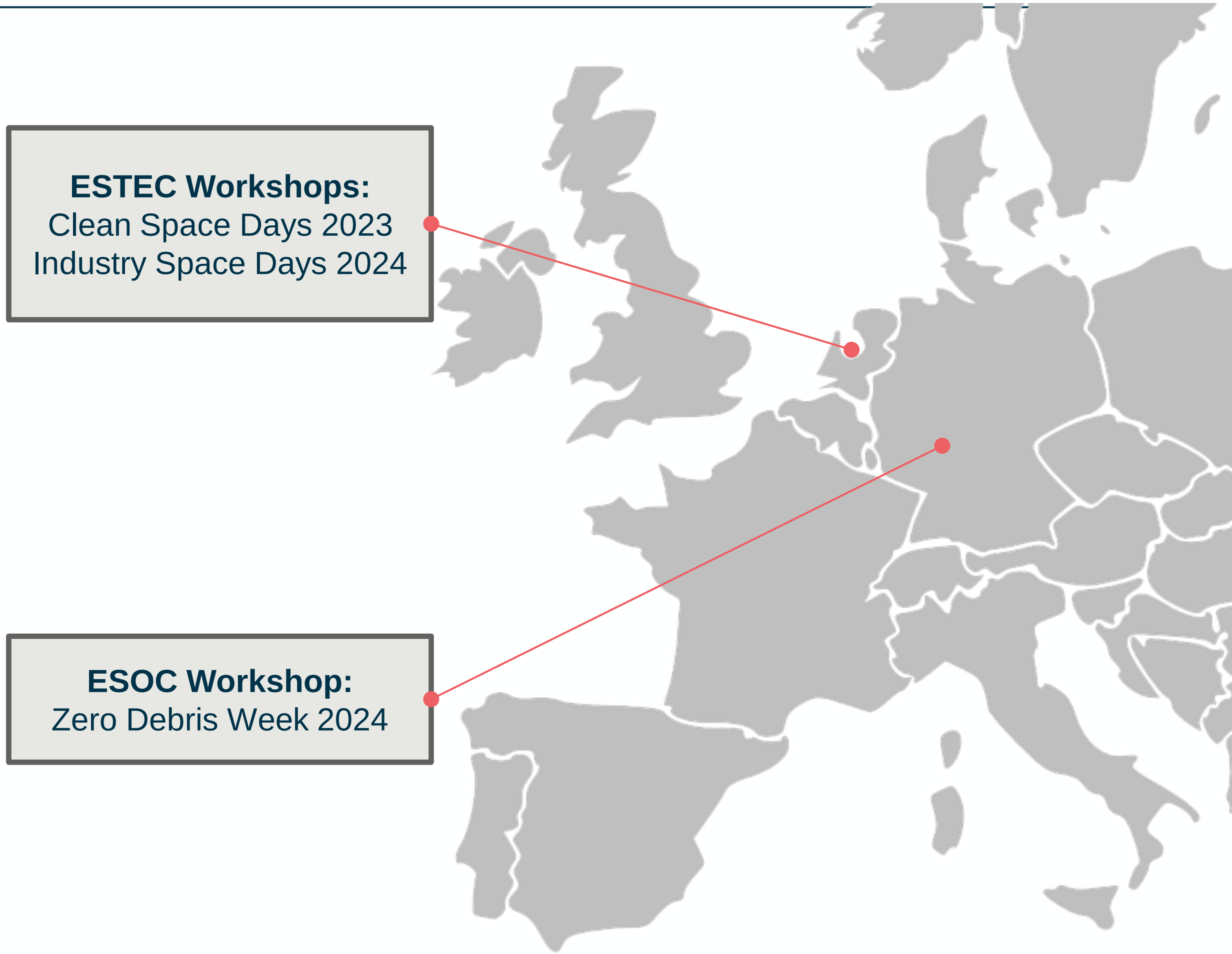
→ THE EUROPEAN SPACE AGENCY



Read the White Paper here: https://tinyurl.com/k5mkhrdx

Current Studies: Space Circular Economy

ESA is funding 5 new 100 k€ studies to investigate mission concepts for future circular economy space systems capable of providing **on-orbit refurbishment, manufacturing, and recycling** in Earth orbit. A campaign to gather proposals was launched on the OSIP platform in January this year.

Refurbishment is the servicing of an existing satellite by replacing current aged or non-functional parts by new equivalent ones.

Manufacturing is the manufacture of s/c parts on-orbit starting from raw material and/or basic components coming from Earth and/or from on-orbit recycling.

Recycling is the capacity to process materials/parts already in space, from old spacecraft or space debris, into usable raw material for the manufacturing of new equipment/parts

Selection Criteria

- **Relevance for circular economy in space**
- **Novelty and disruptive potential**
- **Technical and programmatic feasibility**

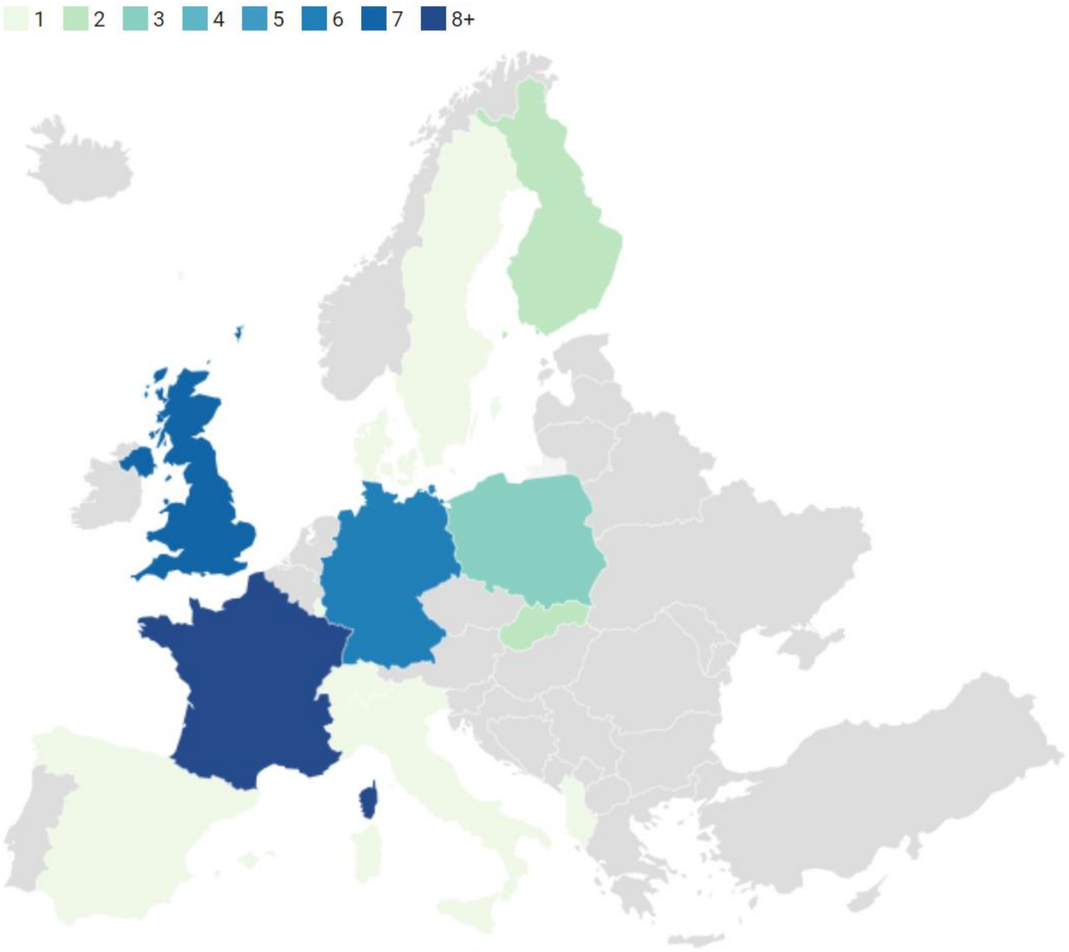
Proposed Ideas for the Space Circular Economy

- **36 ideas received** from 13-member, cooperating, or associate states
- **10 proposals** requested for the second round
- **5 proposal** accepted for industrial contracts

OSIP Campaign Summary	
Member or Contributing State	Number
Poland	3
Slovakia	2
United Kingdom	7
France	9
Finland	2
Germany	6
Italy	1
Canada	1
Spain	1
Sweden	1
Switzerland	1
Denmark	1
Luxembourg	1

Number of Ideas Submitted

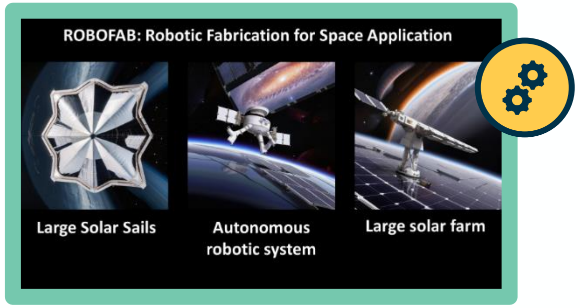
Ideas submitted to ESA's System Studies for the Circular Economy in Space OSIP campaign.



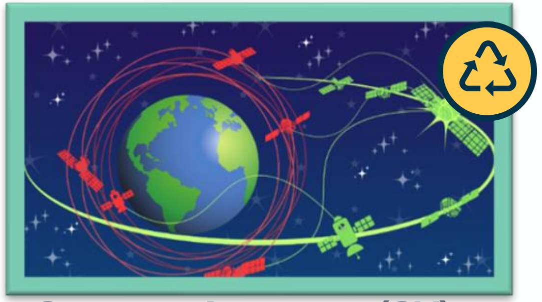
Current Activities on the Space Circular Economy

Selected proposals: 5 activities started in September and October 2024.

Astroscale (UK)
Satellite Refurbishment and Upgrading Services for Orbital Sustainability



KINETIK Space (DE)
Robotic Fabrication for Space Applications



Space scAvengers (SV)
Managed Recycling Orbit operated as a Multi-Agent System

Growbotics (UK)
LOOP: commercial refurbishment mission of a spacecraft in GEO

Thales Alenia Space (FR)
Recycling Space Plant

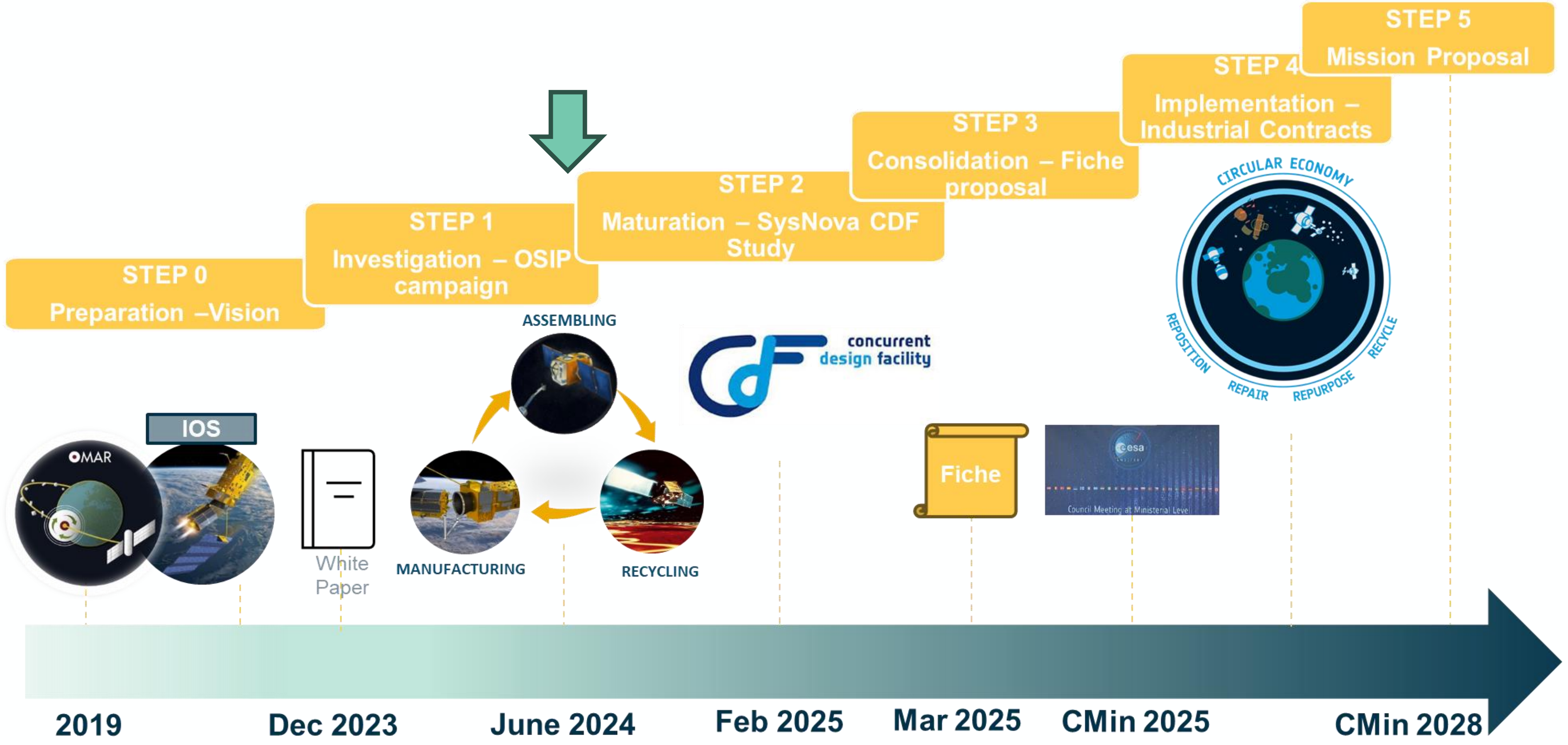
Activities Objective

Motivation

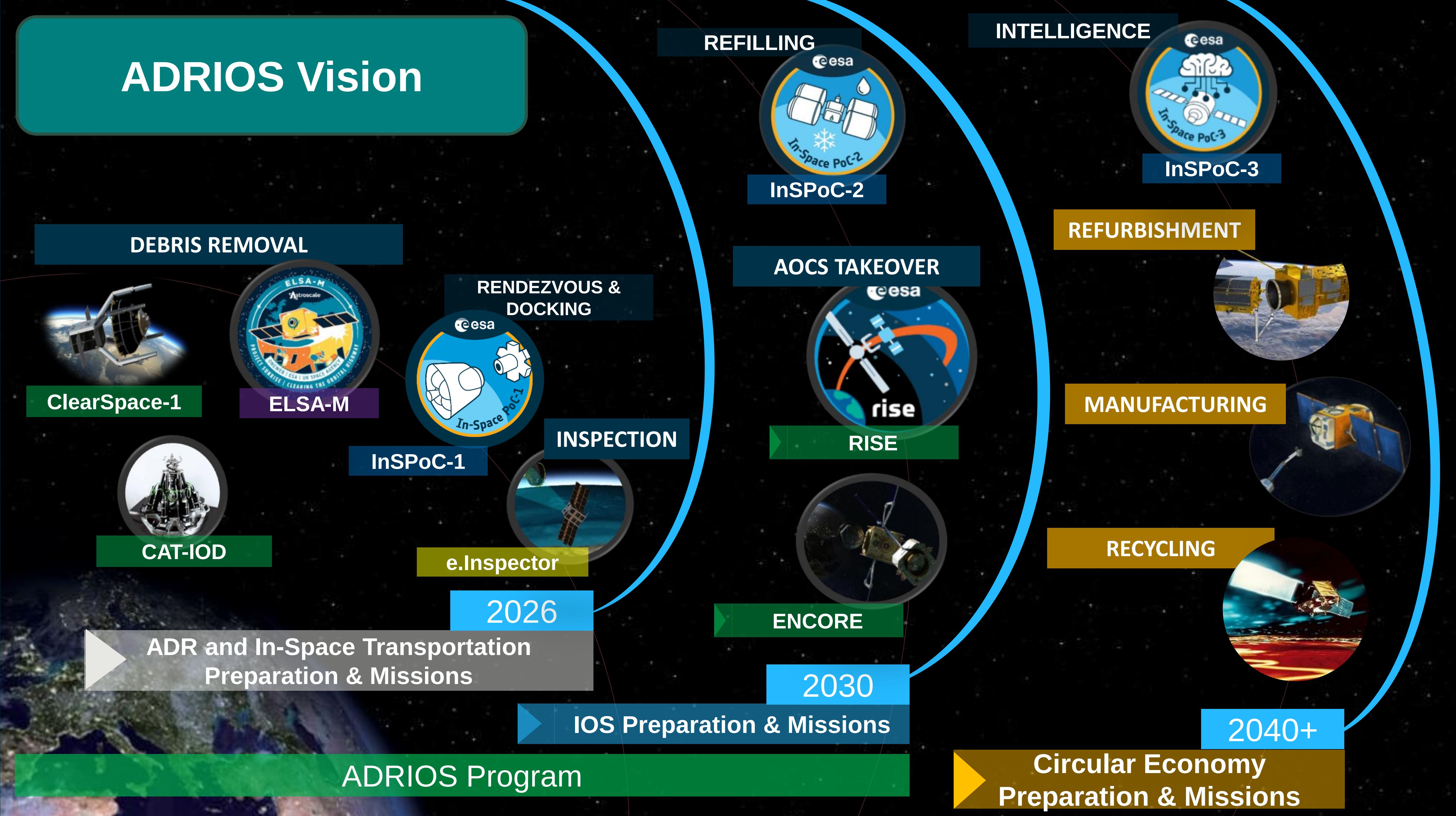
- Build consensus for priorities on circular economy activities in the short-medium term
- Objective is to build case for procuring future activities

- Build consortiums and lobbying
- Prepare proposal for the next Cmin25

Way forward: Space Circular Economy at CMin25



CM25 : options as 2 phase A/B1 follow-up mission study + technology maturation – 2 x 10M€
CM28 : phase B2 - E mission proposal



ADRIOS Vision
DEBRIS REMOVAL
ClearSpace-1
ELSA-M
CAT-IOD
RENDEZVOUS & DOCKING
esa
In-Space PoC-1
InSPoC-1
INSPECTION
e.Inspector
2026
ADR and In-Space Transportation Preparation & Missions
REFILLING
esa
In-Space PoC-2
InSPoC-2
AOCS TAKEOVER
esa
rise
RISE
ENCORE
2030
IOS Preparation & Missions
ADRIOS Program
INTELLIGENCE
esa
In-Space PoC-3
InSPoC-3
REFURBISHMENT
MANUFACTURING
RECYCLING
2040+
Circular Economy Preparation & Missions

Thank you for your attention

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