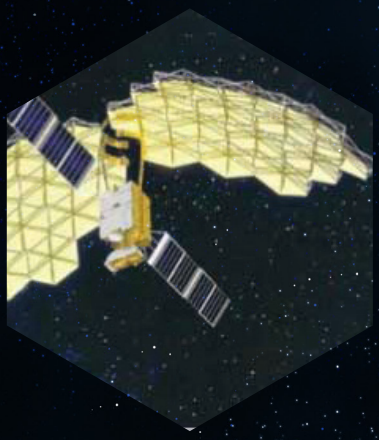
UK IN-ORBIT SERVICING CAPABILITY

A Platform for Growth



Astroscale

FAIR-SPACE

CATAPULT Satellite Applications

Contents

1.0 Executive Summary

Space is now a vital component of the infrastructure that impacts the daily lives of all society. However, as global space activity grows, the proliferation of space debris has become one of the principal threats to satellites and the sustainability of the Critical National space Infrastructure upon which the UK depends.

The UK has the capability, opportunity, and need to take a leadership position in ensuring space sustainability and can use this position as a platform for longer-term opportunities. Building capabilities for satellite servicing and debris removal opens up bigger, more strategic, and longer-term markets linked to assembly and manufacturing in space as an in-orbit economy develops.

Benefits to the UK

- Access to Clean Space
- Strengthen the UK Supply Chain
- Grow new services & UK Space Industry
- Foster International Partnerships
- Protect National Security
- UK Leadership drives Inward Investment

Opportunity and Benefits to the UK

The UK should invest in relevant space system technologies and we should target becoming a dominant space player globally in the In-Orbit Services and Manufacturing (IOSM) market with the objective of capturing $1Bn of the global market by 2030. The Space Growth Partnership (2018) identified the IOSM market as one of the key growth areas of the UK space industry and a cumulative overall global market size for IOSM of greater than US$4.4 billion is projected by the end of this decade. Emergent in-orbit services services such as Active Debris Removal (ADR) and End of Life Services (EOL) will actively contribute to the sustainable use of space and safeguard the space environment whilst life extension maximises the use of expensive assets in a sustainable manner.

> **"We will promote a 'whole-of-life' offer from R&D through finance to satellite operations, launch capability data applications and end-of-life services."**
>
> *Global Britain in a Competitive Age. The Integrated Review of Security, Defence, Development and Foreign Policy. March 2021*

Importantly, the technologies and skills developed through In-Orbit Servicing (IOS), including debris removal, unlock wider business opportunities based on assembly and in-orbit manufacturing that have the potential to deliver massive benefits to society, with revenues worth £10Bns to the UK. IOSM concepts enable the next generation of services based on constructing large infrastructure in space. From connectivity that can be truly ubiquitous by beaming direct to mobile equipment or enabling lower cost handsets, to space-based solar power which can deliver continuous green energy and contribute towards net zero commitments.

There are political, sustainability, and future national security imperatives as well as innovation and longer-term economic growth drivers that make it important to shape this market opportunity and create a strong UK position. A sustainable space environment is essential for all future ambitions in space and a strong opportunity for UK political leadership.

UK Position and Approach

The UK has the necessary technical, commercial and legal capabilities to conduct a range of IOSM missions. While many nations are engaged in space robotics research, so far, no country is the "go-to" for usable products. There are at least four UK based companies that could deliver a complex, commercial, IOSM mission. There is also a unique UK ecosystem covering various levels of assurance from lower cost solutions to large prime capabilities. The UK can also leverage its regulatory leadership as a market creation tool to build capability quicker.

The UK is ahead of the curve in important areas like close proximity operations (CPO) as demonstrated by the ELSA-d mission but is lagging behind in other areas such as robotics where countries including Japan, Canada, the USA and Europe are investing heavily and fast. The UK needs a strong robotics R&D programme (leveraging UK non-space robotics capability and technology transfer from international companies with a UK presence). We also need to invest in end-to-end mission simulation. With the level of investment from other countries, many investing more than $2Bn each year into space, we cannot compete through government funding alone. **Through our leadership in regulation and a commercial approach that is joined-up between industry and government we can position the UK for success.**

Recommended Actions

With significant strategic opportunities ahead, the UK needs to be a shaper of this evolving opportunity and must act now. In all segments, barriers to entry are high and with limited customers and national interests, it will not be possible to play a fast-follower role. To be successful, by 2025, we need to be in a position to capitalise on capability developed over the next few years and to take advantage of the most promising opportunities that can be implemented by 2030.

The UK should embrace leadership on space sustainability and progress at pace. There is an urgent need to develop IOS capabilities for national security and economic growth. A critical first step in unlocking future opportunities is an **ambitious UK active debris removal (ADR) mission.** The UK should **progress with regulatory advances and key Phase A mission feasibility studies now,** starting with an ambitious UK ADR mission and then follow-on missions, including a Space Bench for broad capability development around robotics and close proximity operations. The following recommendations (see next page) summarise activities the UK could undertake to meet these goals.

- Act on UK Sustainability Priorities to remove two UK space objects in low Earth orbit
- Multi-Target mission drives more economical debris removal solutions
- A cost-effective UK mission will drive the commercial viability of future IOS applications
- Demonstrate additional capabilities, for example in-situ SSA
- Design with future servicing in mind to lead international standards for satellite servicing interfaces and further enable future IOS market segments.

Strengths of an Ambitious Active Debris Removal mission

By taking leadership in space sustainability, the UK can drive regulatory advances and capability development. The UK can capture $1Bn of the global IOS market by 2030 to enable commercially funded IOSM capability development that can be applied to many future opportunities. This broad area is also a fantastic platform to strengthen international space partnerships with major strategic partners including the US, Japan, Canada, Europe, and India.

A multi-target ADR mission will be a visible marker of UK intentions to deliver on space sustainability commitments. Importantly, a UK ADR mission can accelerate regulatory and policy interventions, as well as capability development that will both enable this mission and other opportunities based on close-proximity operations in space. An ambitious ADR mission will position the UK as a global leader in orbital operations.

Development of a UK Space Bench enables IOSM, R&D, capability and capacity building at scale. The Space Bench will link with the ADR platform, feature robotic arms, and can be built incrementally. Digital twinning, of facilities in-space and on the ground, allows the UK space community to continually, and rapidly, test innovative solutions and applications such as Rendezvous Proximity Operations (RPO), assembly techniques or Close Proximity Operations (CPO) to trial Space Based Solar Power. Initial, lower cost concepts can enable the UK to move quickly and form initial elements of the Space Bench.

Parallel enabling actions are key to position the UK for success, including regulations, standards, demand creation, and finance to support scaled investment in businesses and space infrastructure. This will enable the UK to take a commercial approach that focusses on delivering benefits to society, from sustainable space to protect existing space services, to next generation connectivity, to green energy, and many high value jobs. Coordinated government action is needed, with strong industry support. The rewards are potentially huge. Working together, the UK can drive sector growth that delivers resilient national space capabilities, national prosperity, projects UK influence globally, and amplifies all the benefits that space can deliver from sustainability to productivity to well-being. **We have a golden opportunity to secure a leadership role in these important sectors, and with it, a bright, sustainable future for the space and satellite applications industry that delivers benefits for all.**

	Recommendations
Immediate (< 1 Yr.)	Phase A Study for initial UK multi-target ADR mission
	Implement market enabling regulatory regime for space sustainability and proximity operations.
	Leverage IOS capability development and missions to strengthen international partnerships.
Short Term (2-4 Yrs.)	Co-fund (with industry) UK ADR mission
	Phase A study for future IOSM capability development (servicing and Space Bench)
Medium Term (5yrs+)	Co-fund (with industry) further IOSM mission (servicing and Space Bench)

2.0 Background

Space is now a vital component of the infrastructure that impacts the daily lives of all society. Over the past 20 years the UK space sector has built one of the most innovative, highly skilled sectors in the whole UK economy. We must, however, go further. Space is only growing in importance globally, as is the value of the space economy worldwide. With decisive Government action, the British space industry could more than double to £40 billion by 2030.

Key Findings

1. There is a worthwhile market developing for in-orbit serving and debris removal (IOS), of which the UK can target approximately $1Bn by 2030.
2. An ADR mission would demonstrate visible leadership for space sustainability, and can be part of wider, capability building platform in space to support IOSM ambitions.
3. The bigger prize is the commercial opportunities around assembly and manufacture which IOS builds capability for. These are strategically significant as an in-orbit economy develops from the perspectives of security and for benefits from connectivity to clean energy.
4. The UK is a leader in regulation and close proximity operations and has a diverse ecosystem that is capable of delivering both IOS and IOSM opportunities.
5. While other countries are investing heavily, the UK can take a more commercial approach to deliver success.
6. Barriers to entry are very high and the UK needs to be a part of the developing landscape now.
7. A range of enabling interventions from regulation to finance and demand creation can position the UK for future opportunities.
8. Decisions are needed on the UK position for sustainability, IOSM and the in-orbit economy.

The space sector is now transforming, along with the benefits it can deliver to lives on Earth. Space is becoming a general-purpose infrastructure with a transformative impact on people and policy, and with an increasing reach into the foundations of our daily lives. Advances in Robotics and AI will help to further widen the horizon of space economic development, fuelling more audacious missions such as active debris removal, satellite servicing, large aperture modular space telescopes and antennas; power generation and servers in space; materials and medicines manufactured in orbit; sustainable lunar development; and ultimately an in-orbit economy. We are moving into an era of space infrastructure where the size of what can be fitted into a rocket is no longer a constraint on what can operate in space. All of this is enabled by close proximity robotic operations in space and UK leadership in this area will accelerate new commercial services from space.

However, as global space activity grows, the proliferation of space debris has become one of the principal threats to satellites and the sustainability of the Critical National space Infrastructure upon which the UK depends. There are an estimated 900,000 debris objects larger than 1 cm in Earth orbit[ii], any of which can damage operational satellites. After launch and deployment into orbit, space debris is often the next highest risk to a mission. Addressing space debris delivers benefits related to space sustainability but also develops capabilities that open up longer-term opportunities.

By driving leadership in space sustainability and in-orbit servicing (IOS), the UK can also create the capability building blocks to enable longer-term commercial opportunities based on assembly and manufacture (IOSM). All of this is enabled by close proximity robotic operations in space and UK leadership in this area will accelerate new commercial services from space.

Image: ESA

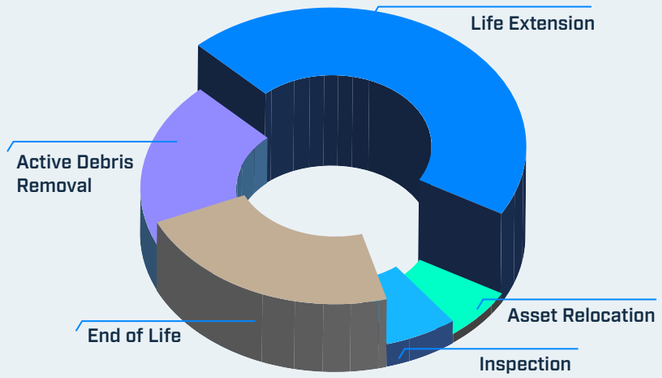
3.0 Market Opportunity

3.1. In-Orbit Servicing (IOS)

The market opportunity for debris removal and in-orbit servicing (IOS) is developing and will become a multi-billion-dollar market by the end of the decade. It is conservatively predicted to be valued at ~$4.4Bn in cumulative revenues (within a range of $2.3-7.2Bn) by 2030, of which the UK is capable of capturing ~$1Bn[iii]. The global IOS market over the next decade will be led by GEO life extension, LEO debris removal services (both active debris removal and end of life servicing), and broader asset relocation. Furthermore, debris removal services protect the entire LEO ecosystem and the space assets as part of the UK's critical national infrastructure (including defence assets) on which essential services depend. The UK is well placed to capture 20-30% of the global IOS Market. The key segments that the UK should target are end of life, active debris removal, and life extension in the nearer term. 60% of this global market opportunity will be from commercial customers and 40% from government.

The UK is well placed to capture a substantial share of the global In-Orbit Servicing market.

_$4.4BN GLOBAL IOS MARKET



> **"We have to be responsible space participants and we can't create debris out there."**
>
> *Sunil Bharti Mittal — Executive Chairman, One Web*

IOS Segment	2030 Global Market *Cumulative*	Time to Market	Market Uncertainty
Life Extension	$1 – 3.1Bn	**Maturing:** Commercial Servicer 2019 (MEV-1), MEV-2 launched 2020, further missions (2023)	Market Proven
End of Life	$450M – 1.7Bn	**Emerging:** ELSA-d demo 2021, Commercial ~2024/25 Mature by 2030	Developing
Active Debris Re-moval	$600M – 1.5Bn	**Emerging,** first missions 2025 (ESA, JAXA) **Mature** by 2030	Developing
Asset Relocation	$160 - 400M	**Emerging** wider applications to mature by 2030	Developing
Inspection	$110 - 540M	**Emerging:** Mature by 2030	Developing
Refuelling	Emerging by 2030	**Nascent:** Emerging by 2030	Uncertain
Repair / Upgrade	Emerging by 2030	**Nascent:** Emerging by 2030	Uncertain

3.2. IOS enabling In-Orbit Services and Manufacture (IOSM)

Leadership in IOS builds a strong position toward future IOSM opportunities and an in-orbit economy.

Although there are clear commercial opportunities for IOS in the near term, it is the technologies and skills being developed for longer term IOSM that have the potential to enable a dynamic and sustainable in-orbit ecosystem. This will provide huge benefits to Earth, and the building blocks for new space industries such as manufacturing of unique products and assembly of large constructs that will generate revenues in the £10s of billions. Scaling up IOS capabilities will unlock wider applications based on assembly, and in-orbit manufacturing such as very large antennas or telescopes that are too large to launch assembled and will require scheduled servicing and upgrade as part of the design. These concepts can deliver connectivity that can be truly ubiquitous by beaming direct to mobile or enabling significantly lower cost terminals, space based solar power to deliver continuous green power to meet our net zero demands, development of transformational new materials in microgravity, or new observation systems that can help us understand our planet and our universe with greater fidelity. These will be assembled in orbit and will also require regular maintenance and servicing. In turn, this all builds capabilities that will enable a cis-lunar economy. Significant spill over benefits are also expected from technology developments such as deployable optics.

"Ignoring space safety would not unleash NewSpace innovation — it will kill it." [...] "The FCC rules are a critical, positive step forward. But they represent a first step toward effective management of space.

Mark Dankberg - co-founder, Viasat

In-orbit Servicing and Manufacture [IOSM]					
Segment	**System Cost**	**Operator Revenue**	**IOSM Revenue**	**Time to Market**	**Market Uncertainty**
Advanced Comms – Very Large Antenna	£2bn	£300m-£600m p.a. (Comms operator per system)	£400m	2030 (Concept for consumer mobile, commercial viability unproven. Potential for specialist customers with lower revenue.)	Concept Strong demand for low cost satcom
Space Based Solar Power	£20-£40bn (first system then £5Bn)	£2bn-£4bn p.a. (energy company per system)	£3bn-£6bn (+£100m ops p.a.)	2030-2040 (BEIS reviewing technical / commercial viability)	Concept (interest growing re Net Zero)
Large In-Orbit Telescopes	£5Bn	Govt. Science Budget	£1.0bn	2027-35 (Dependent on Govt. budget and science expression of need, more cost effective than JWST)	Concept Institutional demand, needs budget
Advanced Earth Observation Platform	£280m-£1bn	Govt. Science Budget	£80mn (+£10mn p.a.)	2026 (Capability available, requires support from EO community)	Concept Institutional demand, needs budget
Fractionated Satellites	£600m	£150mn p.a. per system (comms operator)	£10-15m	2025 (DARPA, JAXA concepts mainly for high resilience)	Concept (demand unknown)
In-Space Manufacture (Earth App)	Various	£60mn - £1.4bn p.a.(2028) (IOSM company)	£60mn - £1.4bn (contract from product marketeer)	2028 (depends on rate of success of applications devt)	Concept (tech proven, market unproven)
In-Space Manufacture (Components and Tools)	£5-15m	£10-30mn (IOSM company)	£10-30mn (contracted by service company)	2026 (Applying lessons learnt from ISS if commercially viable)	Concept (market unknown)

For IOSM elements of the table above, system cost is cost of single system development unless specified, operator revenue is the expected revenue that the operator of a system is expected to realise, IOSM revenue is the amount of a system development or ongoing operational costs that could be realised by IOSM businesses[iv].

The market for IOSM will begin to emerge by 2030, building on initial IOS offerings and developments in robotics and autonomy via dedicated missions. Furthermore, the capability to build the larger structures in space will also energize the IOS market, by enabling further demand for foundational in-orbit-servicing capabilities.

3.3. Timing for Growth

Opportunities are expected to accelerate around 2025.

Accelerated opportunity which the UK needs to be ready for is expected from a confluence of factors around 2025. The likely trigger points for accelerated IOS market growth are around global policy and regulation for space sustainability, along with growth of LEO constellations and standards maturing. This timing also aligns with when concepts for larger infrastructure opportunities in space are expected to begin development from 2025-30. **There are a range of other demand side triggers that could see longer-term opportunities accelerate such as the demand for greater mobile connectivity or net zero energy generation needs.**

4.0 UK Position and Approach

4.1. The UK IOS Ecosystem

The UK has the key elements for a world leading IOSM sector.

Figure 1: In-orbit servicing supply chain

The IOS supply chain is complex with stakeholders from industries as diverse as satellite bus design, mission operations, insurance and potentially broadcast TV companies. The previous diagram above shows a simplified IOS value chain including stakeholders such as regulators, Assembly, Integration and Test facilities and an IOS service provider. The UK has strength in all areas.

The UK has existing or developing offerings for all key services and capabilities for both IOS and IOSM. Key services linked to IOSM have been presented in Section 3 and the UK has developing offerings in all areas. Key capabilities for IOSM are defined below.

Table 1: Key IOSM capabilities.

Capability	Definition
Uncooperative Search & Approach	Finding the client satellite without having a communication with it, identifying it and then approaching it.
Client Diagnosis	Determining the physical condition of the client satellite to evaluate if anything is damaged or missing. This includes capturing photos and sending them back to Earth to analyze.
Advanced Client Examination	More accurate determination of client satellite physical conditions. May include using robotic arm with a mounted camera to come closer to certain areas of the client satellite.
Close Proximity Operations	Close proximity operations include any type of activities between the servicing satellite and the client satellite in a relatively close distance (the two satellites are within a few kilometers or less from each other).
Unprepared Servicing	Servicing a client satellite that is not prepared to be serviced: it has no marker or reflectors that can be used for navigation and no interfaces to be captured.
Cooperative Docking	Docking in which the client satellite is controlled and there is communication between the servicing satellite and client.
Uncooperative Docking	Docking in which the client satellite is not controlled and there is no communication between the servicing satellite and the target satellite.
De-orbiting	Capturing a client satellite and accelerates its reentry to atmosphere.
Robotic Manipulation	Robotic manipulation includes any operation done by one or more robotic arms such as: capturing, replacing modules etc.
Fine Propulsion for CPO	Lower thrust chemical propulsion for CPO.
Propulsion for Orbital Transfers	Electric propulsion for orbital maneuvering.
Mission End to End Simulation	Using a high-fidelity simulator to demonstrate on ground the approach and the capturing of the target satellite. It includes the ground segment, the simulation of both the space segment and the communication.
Ground Segment	The facility that offers different mission capabilities such as: mission planning, mission control system, image processing.
SSA (Space Situational Awareness)	Satellite tracking capabilities are essential in locating defunct debris which are unable to provide their own position.
Satellite Manufacturing	The ability of designing and manufacturing a satellite.

The most important technical capabilities and technologies to be addressed by the UK are:

- **Close Proximity Operations** – this capability effectively gives way to unlocking most of the IOS market segments. Based on missions such as ELSA-d and UK investments in ESA, the UK is ahead of the curve in this area, but this area needs much more development in the UK in order to enable more advanced services.
- **Robotic Manipulation** – in order to unlock most IOSM market segments, commercially driven space robotics research and development is required. Whilst there is much robotics work in the UK in non-space sectors, our capabilities with respect to IOS robotics lag other countries in Europe, Canada, US, and Japan. The UK needs a strong R&D programme in this area. The UK has good options either through inward investment or accelerated national developments, including robotics developments in adjacent sectors such as automotive and nuclear.
- **Mission End to End Simulation** – the complexity of such IOS missions means they must be well simulated / tested in advance of launch. Simulators enable missions to be well designed, to be robustly designed to accommodate for a range of in-orbit cases and help operators train for these complex missions. They are key infrastructure which should be developed. The UK has not yet invested heavily in this area, but development of digital twins or other hardware testbeds would propel us to be a leader in this area.

Importantly, while many nations are engaged in space robotics development, so far no-one is the "go-to" for usable products. There are at least four UK based companies that could deliver a complex, commercial, IOSM mission, and a supply chain covering both low and high levels of assurance. The UK has the necessary technical, commercial and legal components to conduct a range of IOSM missions. We have a great mix of large, ambitious primes and smaller dynamic new entrants. The UK has led the world in the small satellite revolution and has learnt how to build spacecraft to fit the requirements of commercially astute customers. **This presents a unique ecosystem through which the UK can leverage "new-space" commercial-off-the-shelf (COTS) satellite capabilities as well as large prime mission capabilities.**

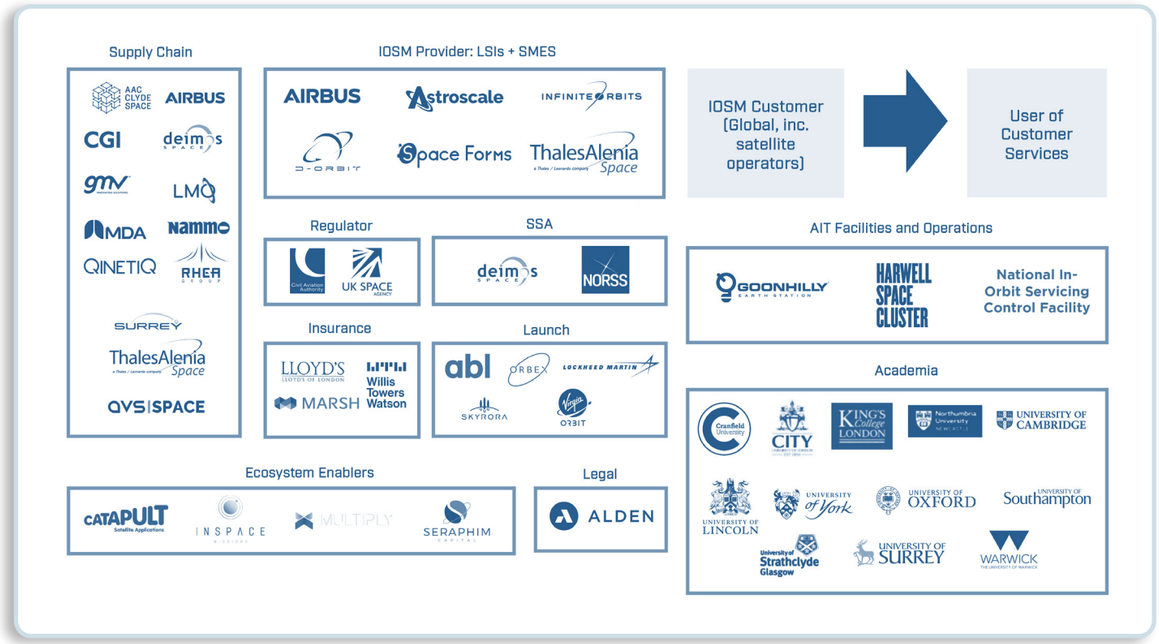


Figure 2: UK IOSM Ecosystem.

Academic R&D relevant to IOSM takes place in over twenty UK universities. The FAIR-SPACE technology hub has provided a focus for recent advances and ten universities are part of the SPAN (Space Academic Network) SPARC (Space Robotics) hub.

The UK has very strong advanced engineering sectors that can cross-pollinate capabilities toward IOSM to create the sector needed for tomorrow, particularly robotics and motorsport / aerospace / advanced manufacturing. If we can engage these sectors and bring them toward opportunities for IOSM we have the opportunity to move ahead by developing opportunities that open new markets. The UK has also created many technology transfer hubs bringing together capabilities from academia and industry, across disciplines such as robotics, artificial intelligence, digital twins and computer vision, all vital for a successful IOSM sector. These include such centres as the Catapult network and the Robotics hubs including Robotics AI for Nuclear (RAIN), Offshore Robotics for Certification of Assets (ORCA) and National Centre for Nuclear Robotics (NCNR) as well as facilities at the various High Value Manufacturing Catapult centres.

Regulation is a key lever, and the UK is also a regulatory leader with organisations such as UK Space Agency, CAA, Ofcom and others respected globally. The UK's current regulatory framework under the Outer Space Act 1986 (OSA) is regarded internationally as a credible and thought-leading licensing regime with a longstanding international reputation[v]. UK launch and operations licences are seen to be a "stamp of approval" for the licence holder and its technology[vi]. There is also a strong set of organisations in the legal sector such as Alden, FieldFisher and others. Coordination of industry needs and views is provided by the UKSpace Regulatory Advisory Group (RAG). As an indication that the UK is seen as having a good regulatory and legal ecosystem, countries that are interested in operating IOS regimes have approached the UK consultants and regulators to discuss drafting of their own national policies and regulations. The space regulatory framework in which IOSM operates is international by nature and currently immature. However, the UK has an outline space regulatory framework developed over a number of years by UK Space Agency and legal advisors such as Alden.

Financial services required by the IOSM sector and large space infrastructure is another area the UK can lead the world. The City of London is world renowned for finance and provides investment for some of the most expensive and complex projects in the world. Mechanisms to support long-term space infrastructure developments would enable significant growth and benefits to **Earth.** Venture Capital funds such as Seraphim are well established in London to help space SMEs grow, and there are now hundreds of space knowledgeable investors thanks to the Satellite Finance Network (SFN), Catapult, KTN, UK Space Agency and others. However, there is still a shortage of patient, high value funding for long term space businesses in the UK that the future unicorns from the IOSM sector will need. The UK is also good at financing high value industries with significant decommissioning requirements, such as nuclear, oil and gas. Learnings from these sectors could be transferred to benefit developments for debris removal and servicing[vii].

4.2. International Perspectives

The UK is internationally competitive, leading in regulation and Close Proximity Operations. IOS and IOSM offer opportunities for strategic international partnerships.

International co-operation is vital for development of regulations for space sustainability and there are strong opportunities for partnership linked to IOSM. The development of IOSM has multi-national aspects because of the international nature of space regulations, the potential global impact of space debris and the cross-border ownership of the major companies in the sector.

There are a small number of key players and the UK is well placed to engage with most of them. The leading countries in the development of IOSM solutions are currently USA, Japan, China, Russia, Canada, the EU states (especially Germany, France, Italy, Switzerland via ESA) and the UK. A recent report published by The Institute for Defence Analyses (IDA)[viii] claims the United States has the widest range of On-Orbit Servicing, Assembly and Manufacturing (OSAM) activities, closely followed by Russia and China. The report found that China and Russia are closest to the United States with respect to not just technology maturity of component technologies, but also current IOSM capabilities; both countries could have similar future competencies to the United States if they continue to pursue OSAM at their current levels of effort. Canada and Japan are also very strong from a robotics perspective. Government space budgets are a key indicator of both current and future capability. Based on 2018 figures, the US leads the way at $40Bnpa+, followed by China ($6Bn), Russia ($4Bn), France ($3Bn), Japan ($3Bn), and Germany ($2Bn)[x]. The UK was around $900M but the scope of a more substantial national programme is being considered.

European countries often via the European Space Agency (ESA) and the EU PERASPERA programme have a large number of cross border collaborations, and both Japan and the United States appear well integrated into IOSM partnerships internationally. While China and Russia are not as integrated into international IOSM partnerships, both have made international collaborations. In addition, there are countries on the fringe of the IOSM landscape such as Canada, Australia, Algeria, Egypt, Greece, India, and the United Arab Emirates.

UK capabilities in robotics lag other countries and the rest of the world is investing heavily. Countries like Canada, US, China, and Japan are ahead with respect to robotic operations and capability is evolving quickly. We are currently punching above our weight compared to others, but other key countries are developing their industry base and aiming towards 2025 and beyond (see below, and IOS missions include removeDebris (UK), Clearspace (ESA), ELSA-d (Japan, UK Operations), JAXA-CRD2 (Japan), MEV-1 (USA), MEV-2 (USA), NASA OSAM (USA), DARPA RSGS (USA), EROSS+ (EU)).

This broad area of IOSM is a fantastic platform to strengthen international space partnerships with major strategic partners including the US, Japan, Canada, Europe, and India.

By acting as thought leaders, the UK can establish internationally accepted common standards and operating models leading to an enabling regulatory environment for UK space organizations. It will be necessary for the UK to maintain international recognition of the current and evolving space regulatory regime by actively engaging with bodies such as ITU and the UN. Industry believe it would be beneficial for the UK Space Agency to continue its work within international forums such as IADC, UNCOPUOS and ISO to lead discussion on the implementation measures for space sustainability and to ensure their widespread application by operators in other jurisdictions.

The UK in the Global Landscape

- The UK is world leading in its streamlined regulatory process and Orbital Missions frameworks.
- The UK is expected to have capabilities ready for 2025 in all areas of IOS except Repair/Replace.
- The UK ranks 4th globally in terms of the level of advancement of core IOS technologies, behind USA, China, Germany. However, we are behind in the following areas: GNC, Automation, Computer Vision & Robotics.
- The UK led the first ever EU ADR demonstration with the RemoveDEBRIS mission. The UK will be involved in 3 of the 9 ADR/IOS missions scheduled up to 2026 including the world's 1st commercial orbital active debris removal mission and the world's 1st mission to remove an item of debris from orbit.

4.3. Benefits to the UK

Championing IOS and Clean Space will protect critical national infrastructure and enable a leadership position in the growing space economy.

There are political, sustainability and future national security, innovation, and longer-term economic growth drivers that make it important to shape this market opportunity and create a strong UK position. Sustainable space is essential for all future ambitions in space and a strong opportunity for UK political leadership. Maturation of the IOS market contributes to protecting £300Bn of wider UK GDP that is supported by satellite services through maintaining clean space[x, xi]. IOSM will open up an in-orbit economy and furthermore, cis-lunar space is considered extremely important from a security perspective. This is all underpinned by robotic operations in space and assembly and manufacture. With the lift capabilities of UK launch, assembly of infrastructure in space may also be needed for completely sovereign missions.

Benefits to the UK

- Access to Clean Space
- Strengthen the UK Supply Chain
- Grow new services & UK Space Industry
- Foster International Partnerships
- Protect National Security
- UK Leadership drives inward investment

The bigger prize is assembly and manufacturing opportunities and the services they enable from next generation observation and communication to power from space. We have the opportunity to put the UK at the centre of a sustainable and commercial in-orbit economy that drives massive benefits to Earth. As illustrated in the figure below, the market opportunities within debris removal services (EOL and ADR) and Life Extension are developing the key capabilities and technologies to enable future growth. All services that require docking to be performed (which include debris removal, in-space assembly, in-space manufacturing, refuelling), require Close Proximity Operations (CPO). CPO capability is the key to unlock all these market segments. **Fundamentally, this is a transformational opportunity and one that the UK needs to be a part of.**

Capability / Technologies	IOS Segment						Wider IOSM	
	Refuelling	Inspection	Asset Relocation / Life Extension	Repairing / Upgrading	EOL	ADR	Assembly	Manufacture
Uncooperative Search and Approach		✓			✓	✓		
Client Diagnosis		✓		✓	✓	✓	✓	✓
Advanced Client Examination		✓				✓	✓	
Close Proximity Operations	✓	✓	✓	✓	✓	✓	✓	✓
Chemical Propulsion	✓	✓	✓	✓	✓	✓	✓	✓
Capture Mechanism	✓		✓	✓	✓	✓	✓	✓
Docking Plate (Capture Only)					✓			
Servicing Interface	✓		✓	✓			✓	✓
Unprepared Servicing						✓		
Cooperative Docking	✓		✓	✓			✓	✓
Uncooperative Docking					✓	✓		
Electric Propulsion			✓		✓	✓	✓	✓
Client de-orbiting					✓	✓		

Figure 3: IOSM segments and the capabilities they enable.

4.4. Creating Advantage

The UK needs to act now as the barriers to entry are too high for a fast follower.

In all segments the barriers to entry are high and with national interests and high value first customers it will be hard to play a fast follower role. There is not expected to be significant first mover advantage in its traditional sense, beyond providing a greater ability to influence regulations, as technology is expected to move quickly, and national interests will mean IOS is unlikely to be a winner takes all market from a national perspective. However, in all areas, and particularly, wider IOSM capabilities, knowledge and financial barriers are too high to enter later. Opportunities for commercial development will be significantly reduced, increasing the need for government investment and support longer term, if the UK is not an early mover.

4.5. UK Approach

A "UK Approach" can enable commercial developments that support benefits to Earth and global exports.

By 2025, the UK can capitalise on market opportunities in LEO debris removal (both EOL and ADR), whilst also developing core capabilities that enable pursuit of larger, longer-term opportunities for IOSM (including assembly and manufacture).

With significant strategic, but uncertain, opportunities ahead, the UK needs to be a shaper of this evolving opportunity. To be successful, by 2025, we need to be in a position to capitalise on capability developed and to pursue the most promising options to be implemented by 2030. The roadmap for the UK comprises of developing capability and building demand to 2025, capturing initial IOS markets and strengthening capability from 2025 to 2030, and delivering future concepts (assembly and manufacture) from 2030.

The recommended approach for the UK is as follows:

1. **Build a world class ecosystem of Close Proximity Operations (CPO) capabilities and technologies** for wider IOSM services and capacity building across the UK IOSM value chain. This capability can then be applied in a range of future directions.
2. **Use leadership in space sustainability as a vehicle to drive regulatory advances and capability development.** Aim to capture $1Bn of the ~$4.4Bn global IOS market by 2030 to enable commercially funded IOSM capability development and UK leadership for space sustainability.
3. **Proactively build future demand and demonstrate technologies for future assembly and manufacturing opportunities** (e.g. connectivity, space based solar power). This opens up commercial options for the future that leverages this capability, delivers services that benefit Earth, and creates commercial opportunities that enable global export and offset of government investment.
4. **Enable regulatory leadership as a market creation tool.** If we can enable UK companies to do new things in space ahead of others, it will allow us to build capability quicker, along with an ecosystem of organisations looking to develop opportunities to capitalise.

The UK can create durable difference and advantage through intelligent use of no-regrets moves and options[xiii], alongside creation of a 'hard to imitate' ecosystem. This builds UK capability and interest whilst also keeping options open so that bigger bets can be made at a later stage.

With the level of investment from other countries, some investing more than $2Bn[xiii] per annum into space, we cannot compete through government funding alone but through our leadership in regulation and an intelligent, commercial approach that is joined up between industry and government we can position the UK for success.

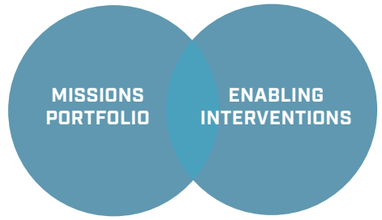
5.0 Recommended Interventions

5.1. Missions Portfolio

The UK has the capability, opportunity and need to take a leadership position toward space sustainability. This provides an opportunity for international leadership, to enable clean space and to build capabilities that open up bigger, more strategic, and longer-term opportunities linked to assembly and manufacturing toward an in-orbit economy.

Long-run aligned purpose and investment between government and industry is required. The UK Government needs to make swift, bold decisions about its future role in the space sector and to implement parallel developments that build opportunities and capabilities linked to IOSM.

A range of actions are recommended to develop the capability needed for the UK to be in a position to capitalise on IOSM opportunities by 2025. A coordinated portfolio of interventions is needed including both mission, and wider enabling interventions.



A portfolio of mission and space infrastructure development opportunities can demonstrate leadership for space sustainability and build capacity.

A portfolio of mission and space infrastructure development opportunities can build distributed UK capability. It is important to enable two or more UK-based companies / consortia to lead IOSM missions with support from the broader supply chain to create sufficient innovation in the ecosystem.

The opportunity to take a global lead for space sustainability is time limited, and a "no-regrets move", as other international space organisations gear up to exploit IOS. The UK will have to act quickly. A critical first step is an **ambitious UK active debris removal (ADR) mission**. Importantly, the mission can also accelerate regulatory and policy interventions, and capability development that will both enable this mission and other opportunities based on close-proximity operations in space. However, to really build critical capability for the future, the mission would also be designed to become part of a future UK testbed in space for broad capability and capacity building around robotics and proximity operations – the **Space Bench**.

1. **An ambitious ADR mission.** Such a mission will be a visible marker of UK intentions towards space sustainability. Importantly, the mission must accelerate regulatory and policy interventions, and capability development that will both enable this mission and other opportunities based on close-proximity operations in space. Suitable non-operational targets have been identified that are in the same inclination and similar altitudes which reduces the amount of fuel required for the mission, are gravity gradient stabilised which means the targets would not be tumbling, would be completely destroyed upon re-entry, and will otherwise remain on orbit for up to a hundred years to before passively decaying, presenting collision risks for many decades to come. The UK ADR mission proposed would enable the UK to strongly differentiate itself from other ADR missions and position the UK as a future leader in orbital operations. A UK ADR mission would yield additional long-term benefits or opportunities through subsequent servicing missions, laying the foundation for the Space Bench concept.

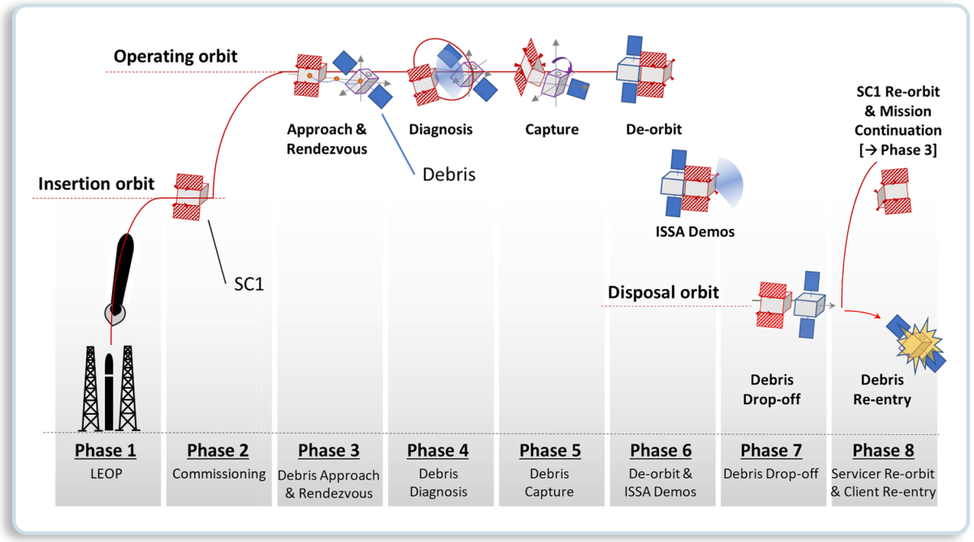


Figure 5: An ambitious ADR mission

The UK ADR mission proposed would enable the UK to strongly differentiate itself from other ADR missions and position the UK as a future leader in orbital operations in the following ways:

- **Multi-target:** The ability to remove more than one object from orbit with a single servicer is a substantial development required for future debris removal missions. Multi-use capability is critical for the economic viability of debris removal operations. Current ADR missions are planning to remove a single piece of debris with one service; this 'one-up-one-down' approach is not economically efficient in addressing the space debris problem.
- **Cost Effective:** The proposed multi-target ADR mission could leverage existing UK capabilities and technologies and offer an ambitious ADR service at substantially lower cost to currently proposed missions. The development of UK cost-effective ADR services drives the commercial viability of future applications (both EOL, ADR, and other IOS).
- **Risk-Reduction:** The proposed ADR mission will remove two risky UK space objects in low Earth orbit. This ADR mission aligns with the UK's space sustainability priorities and shows leadership in reducing the UK's risk profile in orbit, whilst also strengthening the UK's IOS capabilities for future services.
- **Demonstrate Additional Capabilities:** The ADR servicing spacecraft, SC1, can also be equipped with a Space Situational Awareness (SSA) experiment which could be demonstrated in noncritical phases of the mission, for example, while the spacecraft transitions to drop off the captured target assets in the disposal orbit.
- **Prepared for Future Servicing:** The ADR servicing spacecraft, SC1, can be designed with future servicing in mind, with the integration of a refuelling port and docking plate. This will help the UK to lead on international standards for satellite servicing interfaces and further enable future IOS market segments.

2. **Development of a Space Bench** that links with the ADR platform, features robotic arms, can be built incrementally, and enables capability building at scale. Digital twinning with the above, effectively creates the facilities in-space and on the ground to allow the UK space community to continually and rapidly test innovative solutions and applications such as CPO, assembly techniques or developing novel solar collectors to trial Space Based Solar Power. The recommendation is to develop a substantial Space Bench that enables steps toward, and continued capacity building around, major IOSM capabilities. As part of this, initial lower cost concepts can enable us to move quickly and form initial elements of the Space Bench. If the concept can have attractive enough features such as power sources, it can become an experimental zone in space that is continually developed over time. Its utility will be amplified if a special regulatory zone can be created around it to enable trial, and also learnings that can support regulatory and insurance advances.

Enabling UK IOSM Leadership through Space Bench

- **Builds depth in fundamental RPO capability.**
- **Capabilities enable protection of assets and skills for new commercial opportunities.**
- **Provides an attractive kernel to support ongoing modular development.**
- **Creates a playground in space for rapid evolution of capabilities, technologies and regulation.**
- **Development leverages strengths of both large primes and lower cost, rapid approaches.**

Options: Building blocks for SBSP. Power for microgravity products.

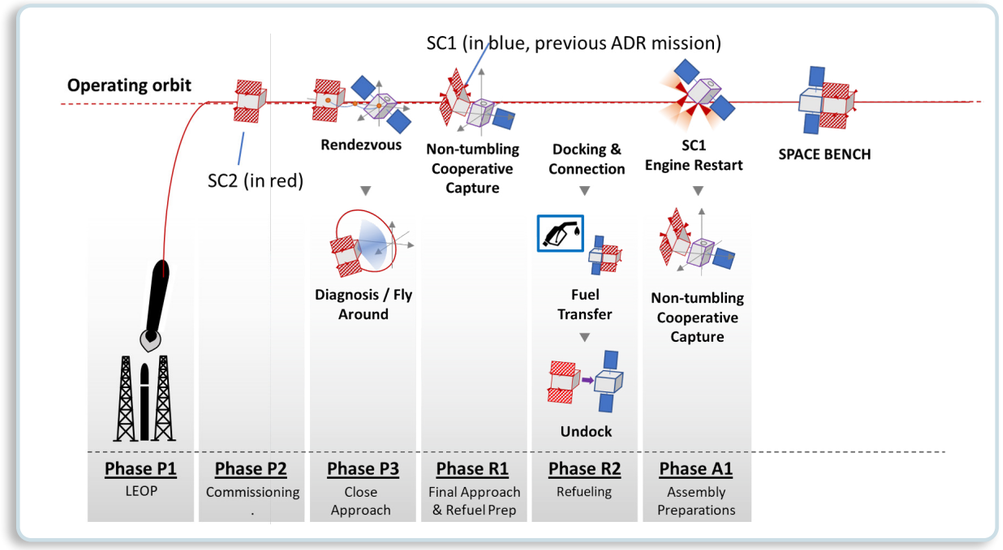


Figure 5: Refuelling, and creating a SpaceBench for rapid capability development through SC2.

5.2. Enabling Actions

A range of parallel enabling actions can provide a foundation for success.

Broader enabling actions can provide a foundation for success in terms of regulation being an attractor and enabler, finance to support scaled investment in businesses and infrastructure, and demand creation to enable the UK to take a commercial approach that focusses on delivering benefits to Earth. These do not require significant investment, rather policy implementation, international stakeholder engagement, and financial innovation.

1. **Co-develop a long-run plan for IOSM and the in-orbit economy between government industry and academia** – the aim should be included in the National Space Strategy.
2. **Drive regulatory leadership** – Developing regulations both for space sustainability and new licencing regimes that move beyond single mission profiles will enable UK companies to advance. The proposed "NATS for Space" developments would be an important enabler for this.
3. **Lead in demand-side innovation and commercial innovation** - We need to develop a range of longer-term commercial opportunities in parallel with capability development, starting to build demand from today.
4. **Unlock the UK finance sector to support investment in infrastructure in space** – This includes, creating a patient capital fund for infrastructure in space (min £500M[xv]) and enabling long-term investment in space infrastructure through long-term space infrastructure bonds.
5. **Develop international partnerships** – From sustainability to space robotics to a Space Bench to IOSM to Space Based Solar Power, to plans toward an in-orbit economy, these developments present fantastic opportunities for international partnership but they should be selected carefully based on long-term UK aims.
6. **Engage adjacent sectors** - Supporting UK initiatives that engage non-space sector players are important. We need capability and capacity building in robotic operations, energy / propulsion and SSA and other sectors in the UK such as robotics, manufacturing and motorsport have leading capabilities that can help.

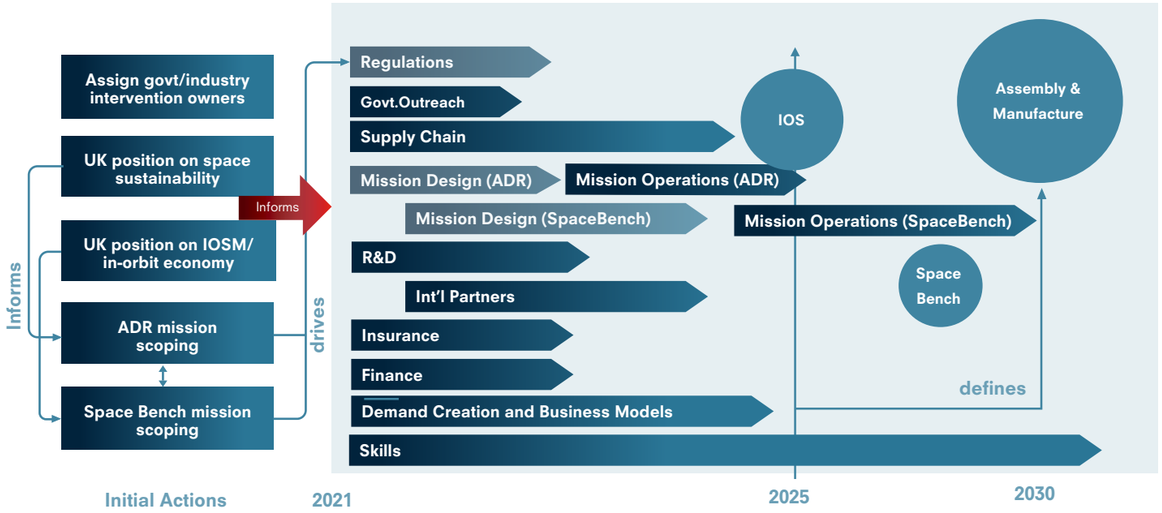
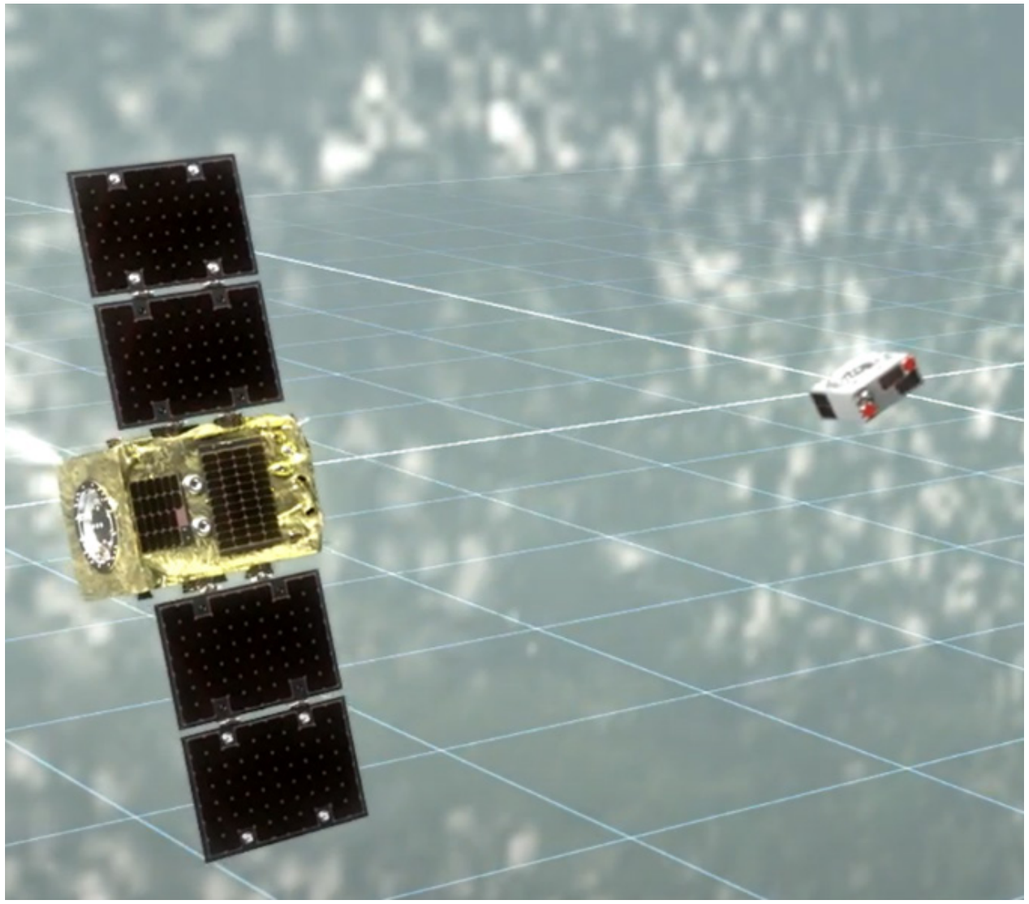


Figure 7: Timeline of interventions.
Note: Most interventions are for the long-term. The arrows show where intensity is expected to be highest.

5.3. Priorities and Next Steps

The UK should embrace UK leadership on space sustainability and progress at pace. Investment in visible action for space sustainability is needed now through an ADR mission alongside regulatory developments. There is an urgent need to develop IOS capabilities for security and economic growth. The UK should **progress with regulatory advances and key Phase A mission feasibility studies now**. Starting with an ambitious UK ADR mission and then follow-on missions, including a Space Bench for broad capability development.

	Recommendations
Immediate (< 1 Yr.)	Phase A Study for initial UK multi-target ADR mission
	Implement market enabling regulatory regime for space sustainability and proximity operations.
	Leverage IOS capability development and missions to strengthen international partnerships.
Short Term (2-4 Yrs.)	Co-fund (with industry) UK ADR mission
	Phase A study for future IOSM capability development (servicing and Space Bench)
Medium Term (5yrs+)	Co-fund (with industry) further IOSM mission (servicing and Space Bench)



5.4. Summary: A Platform for Growth

There is a "UK path" that drives leadership in sustainability and enables commercial developments that support benefits to Earth (connectivity, space solar power) but it is essential for the UK government and industry to establish an agreed vision and joint investment profile. This needs to be done in partnership, bringing government, industry and the finance sector together to envision and then enact a bright, bold and ambitious future that benefits many.

The UK can succeed if it focuses on creating a non-imitable ecosystem, strengthening regulatory leadership, awakening the potential of the UK financial sector, taking a strategic UK value-driven approach to international partnership, and a commercially focussed application-driven approach that builds capability and knowledge more quickly than others can through, innovative and incremental developments. If we can kickstart the development of missions immediately that trigger regulatory advances and build capacity, while at the same time building demand for future concepts and enabling large scale space infrastructure financing, we will be setting up UK companies with a strong chance to be leaders in this developing area. Starting now is essential if future options are to be realised. Achievements by 2025 are important but primarily through the capability that is built which is increasingly fundamental to large-scale endeavours in space from 2030 to 2050 and beyond[xvi]. The UK needs to be a part of this.

With the creation of the National Space Council, and National Space Strategy, we can confidently set an ambitious vision that is not just about the next few years, but about driving the UK to where it needs to be in 15 years' time. The opportunity ahead is huge, but only if we look beyond a traditional view of the satellite sector. The space industry is just emerging from its shell and other nations are investing with priority and purpose. Working together, the UK can drive sector growth that delivers resilient national space capabilities, national prosperity, projects UK influence globally, and amplifies all the benefits that space can deliver from sustainability to productivity to well-being. **We have a golden opportunity to secure a leadership role in these important sectors, and with it, a bright, sustainable future for the space and satellite applications industry that delivers benefits for all.**

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References

[i] Space structures bigger than today's satellites require some form of assembly and ensuring a fully sustainable use of space will require capture, disassembly and/or removal of structures including constellation of satellites. Agile and intelligent spacecraft that can perform these complex missions will further enable activities such as in-orbit manufacture.

[ii] https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers

[iii] Further analysis and justification for UK market capture is contained in the full report.

[iv] Assumptions for the costs of longer-term projects listed in the table include discussions with a leading space manufacturer for the Large Antenna, pre-publication information from "Space Based Power Report" by Frazer Nash, The Larger in-Orbit telescope is a comparison with the James Web Space Telescope, whilst the costs of Advanced EO and Fractionated satellites are estimates based on projects of a similar scale and function. The in-space manufacturing ROM estimates are dependent on what is being manufactured and are from sources including "New Space vol 5 No3 2017 – Exotic Optical Fibres and Glasses" (I Cozmuta & D Rasky), as well as confidential discussions with on-orbit manufacturing SMEs.

[v] The UK Space Agency is internationally recognised for its innovative regulatory approach to industry developments such as the small satellite sector and the importance of constellations and wider policy initiatives such as the current work on implementation of the new Space Industry Act to facilitate the development of the UK's launch sector potential. The UK's responsible approach to regulation and its collaboration with international bodies (such as the UNCOPUOS and UNOOSA, the IADC and the ITU) and other national space agencies and regulators is respected in international fora where the UK Space Agency has a strong voice and influence and is regularly requested to share its in-depth licensing experience.

[vi] This is evident where market access in certain countries (including the US) is often conditional on obtaining a UK launch and operations licence.

[vii] See https://astroscale.com/wp-content/uploads/2021/02/Astroscale-Decommissioning-Report-DPS-online-version-Feb-18-21.pdf

[viii] IDA - Global Trends in On Orbit Servicing, Assembly and Manufacturing (OSAM), 2020 https://www.ida.org/-

/media/feature/publications/g/gl/global-trends-in-on-orbit-servicing-assembly-and-manufacturing-osam/d-13161.ashx

[ix] https://spacenews.com/op-ed-global-government-space-budgets-continues-multiyear-rebound/

[x] The risk from debris is forecast to rise; so much of the value is in prevention not cure. We need to be more purposeful on ensuring debris doesn't get worse while figuring out how to remove what's there already.

[xi] Key market drivers for IOS over the next decade include the growth of LEO and GEO commercial activity, space sustainability in a congested LEO environment, and opportunities for greater value generation from more complex in-orbit activity. Commercial drivers for continued access to clean space, spacecraft flexibility and optimisation, and moving beyond 'single-use' spacecraft are also driving satellite operators to explore opportunities for the full range of IOSAM possibilities.

[xii] Shapers aim to drive their industries toward a new structure of their own devising. Their strategies are about creating new opportunities in a market—either by shaking up relatively stable level 1 industries or by trying to control the direction of the market in industries with higher levels of uncertainty.

[xiii] No-regrets: Strategic decisions that have positive payoffs in in any scenario.

Options: Decisions that yield a significant positive payoff in some outcomes and a (small) negative effect in others.

[xiv] https://spacenews.com/op-ed-global-government-space-budgets-continues-multiyear-rebound/

[xv] Further consideration required and may need to be larger.

[xvi] Small example of super-extended satellite lifetimes via refuelling/repositioning or incremental assembly & upgrade; big example of space solar power being a permanent contributor to global energy demands.

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