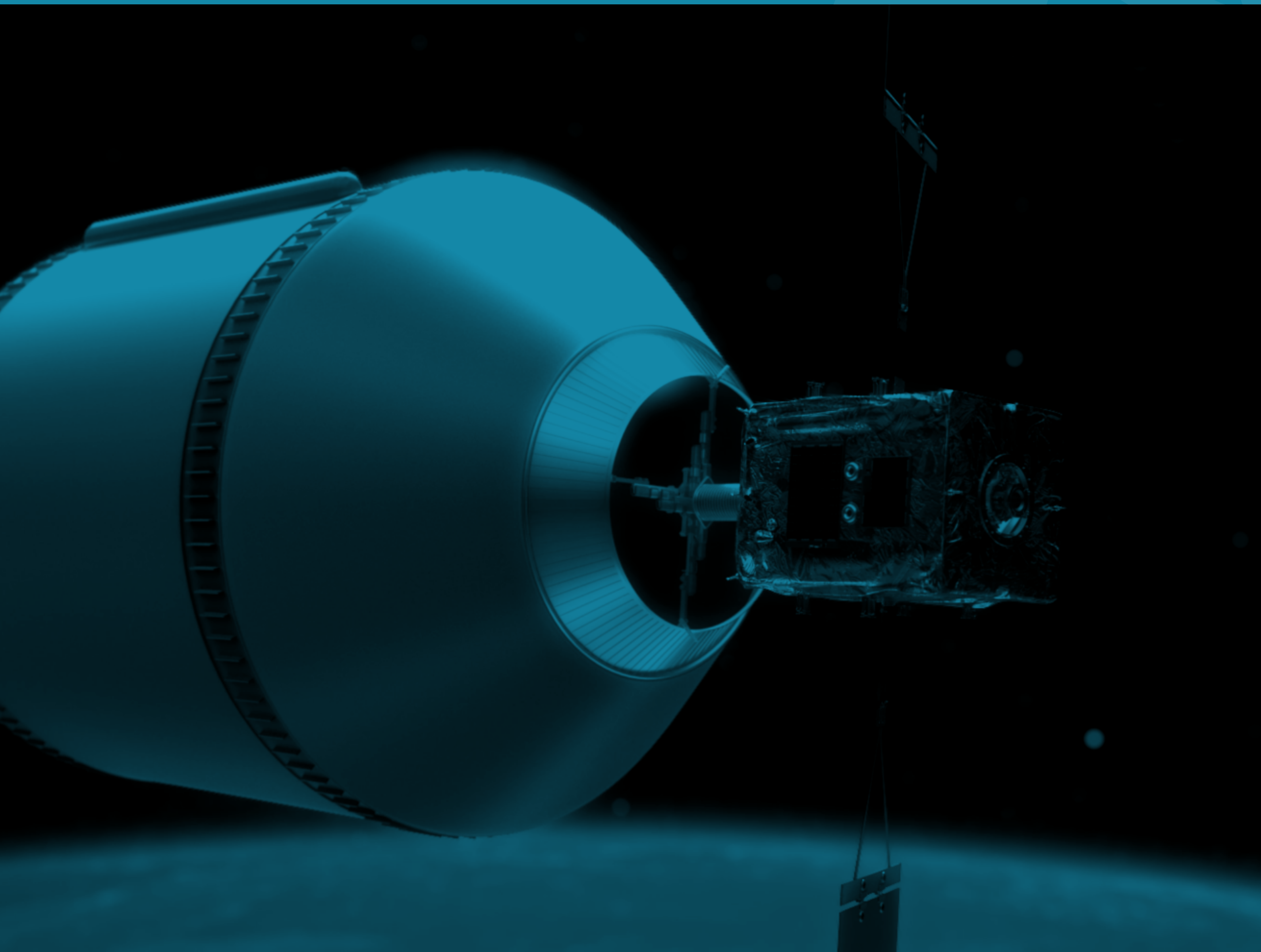
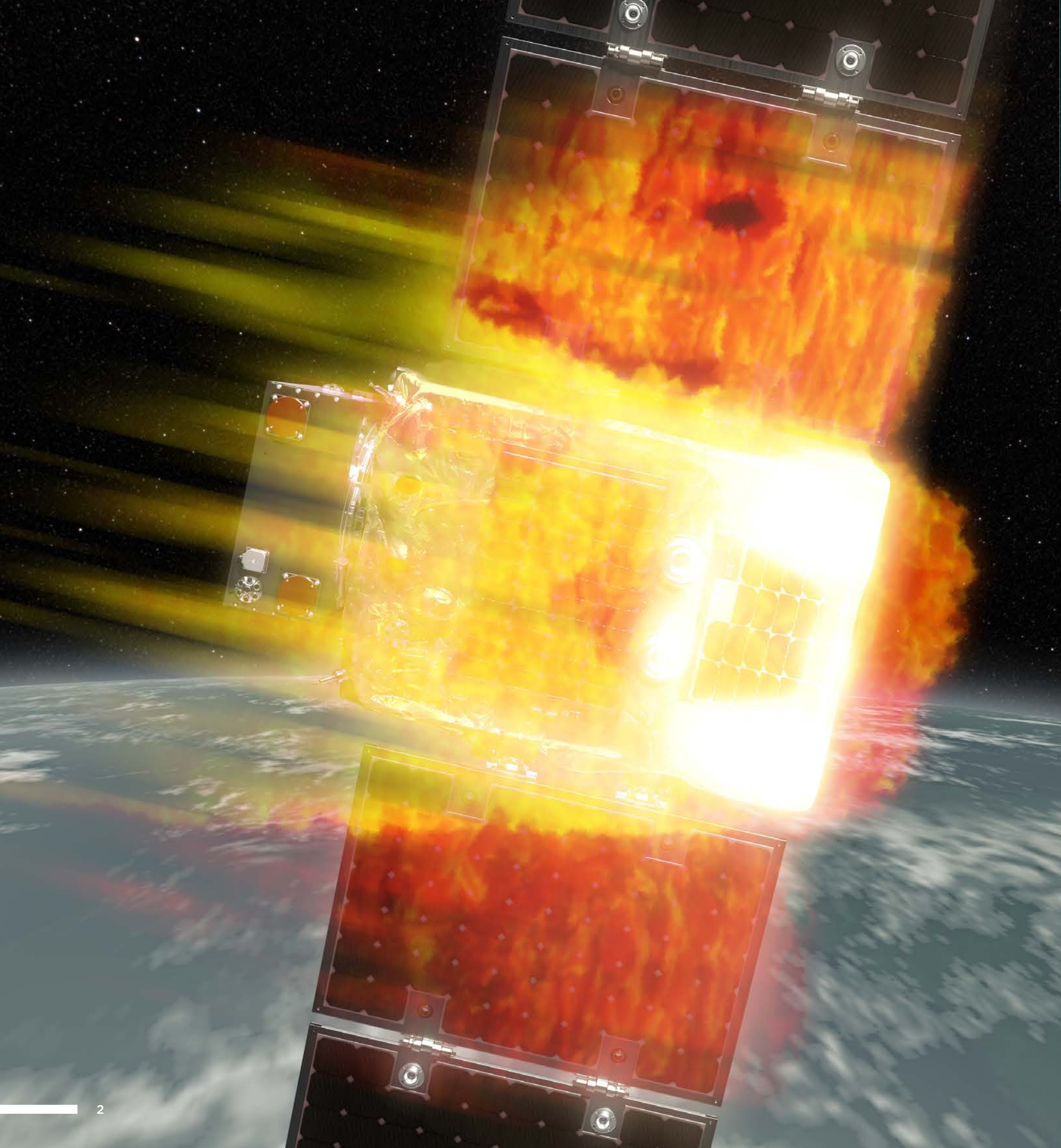
Astroscale

Decommissioning in Extreme Environments

Insights for the Satellite Industry





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Executive Summary

Space debris poses a direct threat to the future of space activity, leading to higher risks, increased costs and potentially unusable orbits. As space becomes busier and critical orbits become crowded, there is a pressing need to remove debris and return the space environment to its natural state.

Addressing this challenge in space is not without precedent on Earth. Whilst the physical aspects of the space domain make this a unique technical challenge, the issues faced by the space community are not unique. Industries surrounding the world's energy resources all, to varying degrees, consider how to deal with assets that pose a danger to the environment once they have reached the end of their operational life. The process, known collectively as decommissioning, is undertaken across the oil and gas, nuclear and even nascent wind power generation industries.

We consider decommissioning of satellites to involve removing assets from operational service and returning the environment of Earth's protected orbits to its natural state. This includes re-entry into the Earth's atmosphere for satellites in LEO and movement to a graveyard orbit for satellites in GEO. Decommissioning can be undertaken either using a satellite's own propulsion capabilities, outsourcing to third party debris removal services, or passively for satellites operating at low-LEO altitudes.

The complexity, and therefore cost, of satellite decommissioning may vary dramatically depending on the asset's health and capabilities at the time of decommissioning. In practice, satellites are not always decommissioned and can remain in critical orbits indefinitely. The case for decommissioning is clear; it can:

- Protect the orbital environment and safety for increasing human activity in orbit,
- Mitigate costs that satellite operators are burdened with as a result of operating in a polluted environment.
- Reduce collision risk, debris creation, and ultimately reduce the number of objects that could incur liabilities for space-active nations.

> *"Satellite decommissioning involves removing assets from operational service and returning the environment of Earth's protected orbits to its natural state.*

With the growing awareness for considering end-of-life practices to ensure a sustainable future in space, there is an opportunity to learn from other industries much more developed in their thinking. In space, as in other industries:

- **Assets historically have not been designed with decommissioning in mind**, rendering decommissioning more complex and costly.
- Assets are often left in **operation beyond their design life** which increases their risk of failure on orbit.
- Combined with the **challenges in understanding asset conditions in extreme environments** (whether in a high-radiation nuclear environment or isolated in space), operators are therefore faced with conflicting incentives on the appropriate time to decommission assets.
- **Decommissioning funding schedules are complex** since assets are often no longer revenue-generating at the time decommissioning is required.
- **Segmented decommissioning responsibility** for legacy and future waste observed in other sectors aligns with considerations in the satellite industry of the active removal of existing debris and future prevention.
- Across all sectors studied, **decommissioning requires significant innovation** and novel engineering approaches.
- **Decommissioning is often outsourced** to specialised third-party providers.

Decommissioning across extreme environments presents similar challenges and a compelling opportunity for cross-industry learning.Whilst decommissioning in space is an emerging market; the challenges faced by the satellite industry are not new or unique. Decommissioning is an industry in and of itself that presents opportunities for innovation and growth. The satellite industry can learn from other sectors and integrate decommissioning practices into the space life cycle to ensure a sustainable future.

Introduction

The global economy is dependent on satellites that provide a range of services critical for life on Earth. The satellite industry itself is a multibillion-dollar industry, with 2019 revenues of $271Bn that represent 74% of the entire global space economy.[1] This growing in-orbit activity is enabled by a significant expansion in the number of satellites in Earth orbit. Whilst around 10,000 satellites have been launched to date, tens of thousands more are planned to launch in the near future, largely driven by the growth of satellite constellations.

Such a dramatic increase in the orbital population will have a profound effect on the way in which future space activity is conducted. Crucial is the consideration of how to manage those satellites that are no longer operational and, for whatever reason, are still in orbit. Of the 10,000 satellites that have been launched, around 5,500 are still in orbit, but only around 2,300 of them are operational.[2]

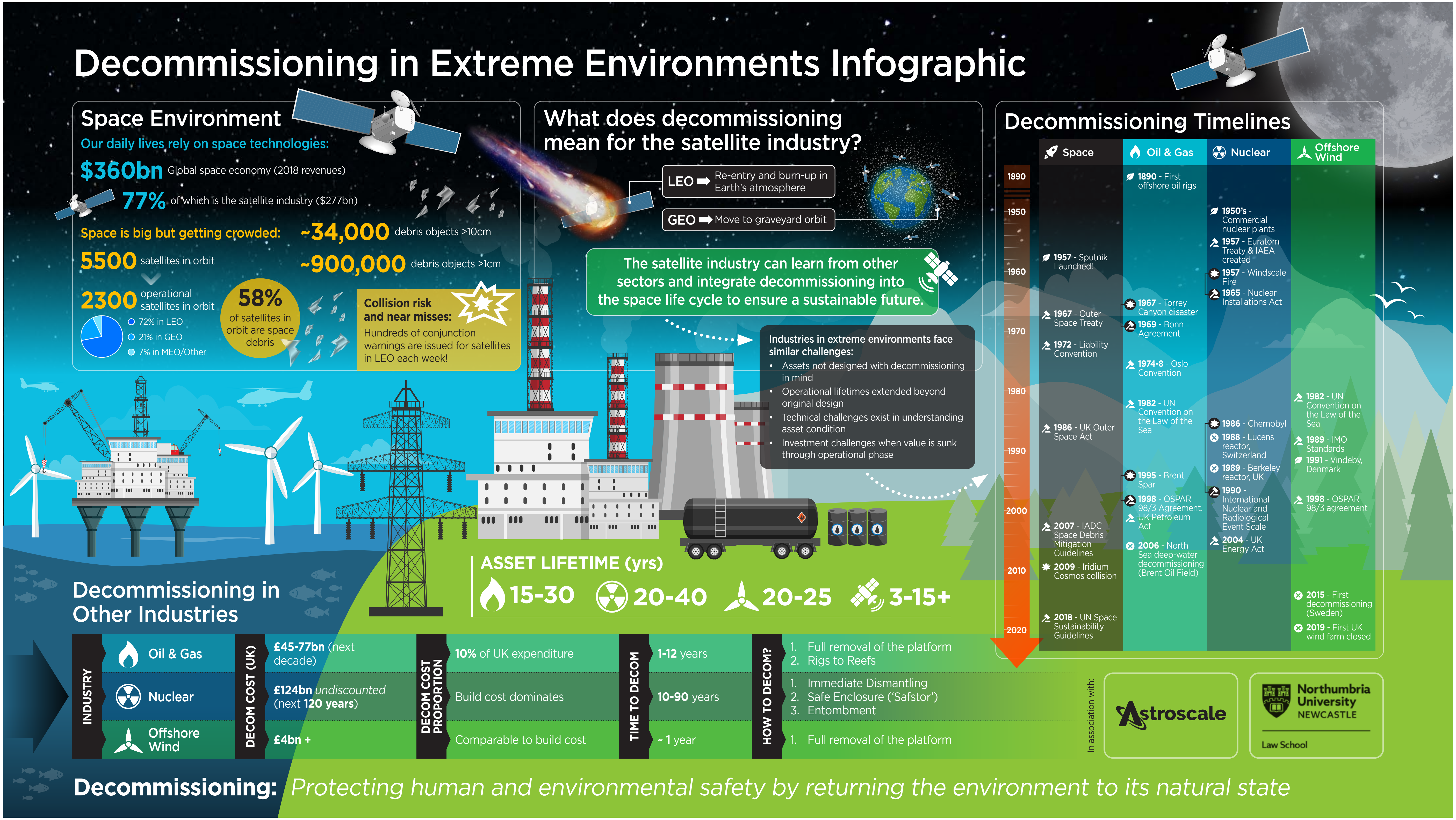
As space becomes busier and particular orbits are becoming crowded, there is now a pressing need to remove those satellites that have ended their useful life. End of life operations and procedures for getting inactive and inoperable satellites out of busy orbits will become ever more important.

Addressing the problem of returning environments back to their natural state is, however, not without precedent on Earth. The process, known collectively as decommissioning, is undertaken across the oil and gas, nuclear, and even nascent wind power generation industries.

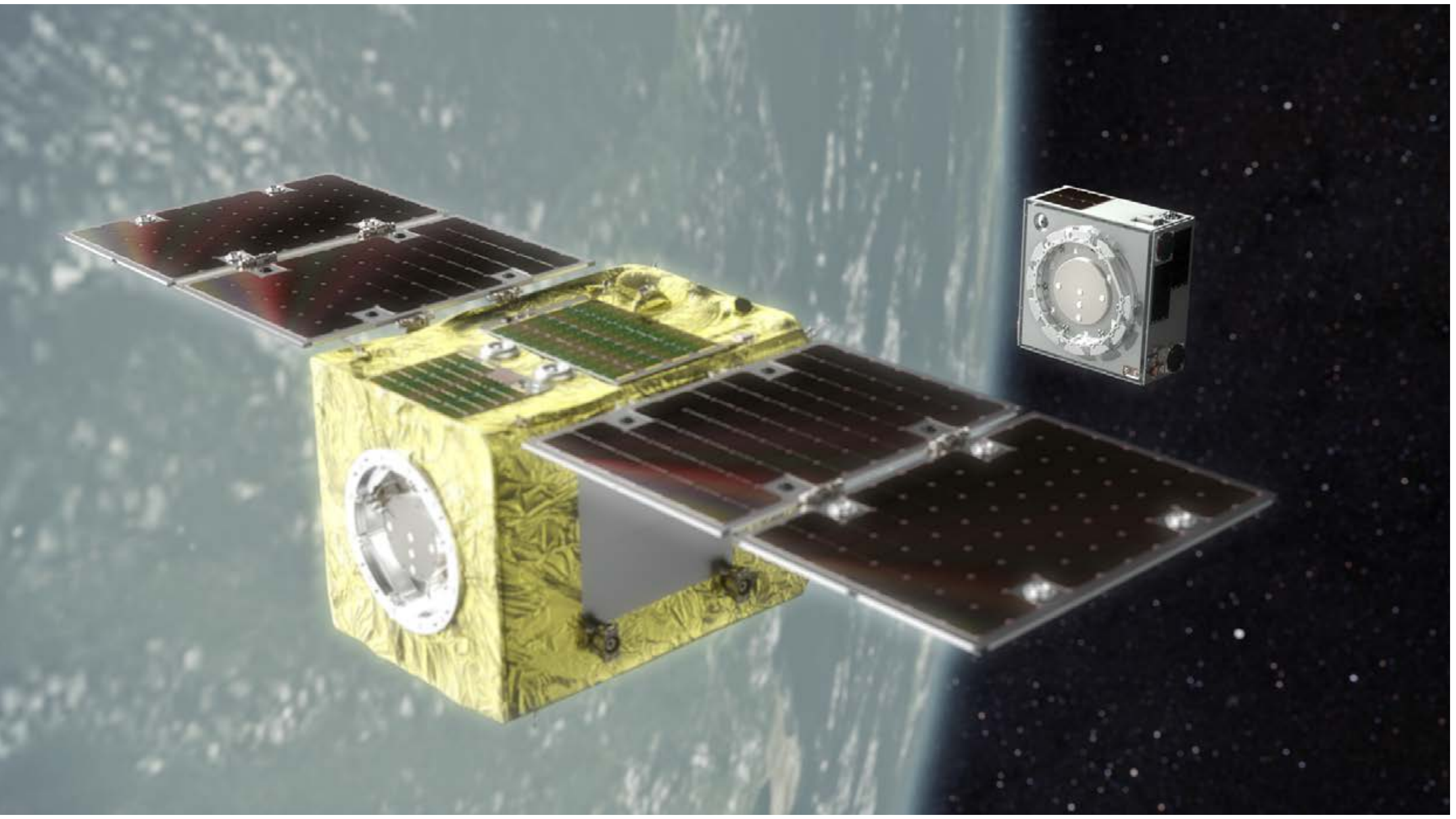
10,000 satellites launched to date

5,500 still in orbit

2,300 operational


Decommissioning in Extreme Environments Infographic
Space Environment
Our daily lives rely on space technologies:
$360bn Global space economy (2018 revenues)
77% of which is the satellite industry ($277bn)
Space is big but getting crowded:
~34,000 debris objects >10cm
~900,000 debris objects >1cm
5500 satellites in orbit
2300 operational satellites in orbit
72% in LEO
21% in GEO
7% in MEO/Other
58% of satellites in orbit are space debris
Collision risk and near misses:
Hundreds of conjunction warnings are issued for satellites in LEO each week!
What does decommissioning mean for the satellite industry?
LEO ➡ Re-entry and burn-up in Earth's atmosphere
GEO ➡ Move to graveyard orbit
The satellite industry can learn from other sectors and integrate decommissioning into the space life cycle to ensure a sustainable future.
Industries in extreme environments face similar challenges:
• Assets not designed with decommissioning in mind
• Operational lifetimes extended beyond original design
• Technical challenges exist in understanding asset condition
• Investment challenges when value is sunk through operational phase
ASSET LIFETIME (yrs)
15-30
20-40
20-25
3-15+
Decommissioning Timelines
Space
Oil & Gas
Nuclear
Offshore Wind
1890
1950
1960
1970
1980
1990
2000
2010
2020
1957 - Sputnik Launched!
1967 - Outer Space Treaty
1972 - Liability Convention
1986 - UK Outer Space Act
2007 - IADC Space Debris Mitigation Guidelines
2009 - Iridium Cosmos collision
2018 - UN Space Sustainability Guidelines
1890 - First offshore oil rigs
1967 - Torrey Canyon disaster
1969 - Bonn Agreement
1974-8 - Oslo Convention
1982 - UN Convention on the Law of the Sea
1995 - Brent Spar
1998 - OSPAR 98/3 Agreement. UK Petroleum Act
2006 - North Sea deep-water decommissioning (Brent Oil Field)
1950's - Commercial nuclear plants
1957 - Euratom Treaty & IAEA created
1957 - Windscale Fire
1965 - Nuclear Installations Act
1986 - Chernobyl
1988 - Lucens reactor, Switzerland
1989 - Berkeley reactor, UK
1990 - International Nuclear and Radiological Event Scale
2004 - UK Energy Act
1982 - UN Convention on the Law of the Sea
1989 - IMO Standards
1991 - Vindeby, Denmark
1998 - OSPAR 98/3 agreement
2015 - First decommissioning (Sweden)
2019 - First UK wind farm closed
Decommissioning in Other Industries
INDUSTRY
Oil & Gas
Nuclear
Offshore Wind
DECOM COST (UK)
£45-77bn (next decade)
£124bn undiscounted (next 120 years)
£4bn +
DECOM COST PROPORTION
10% of UK expenditure
Build cost dominates
Comparable to build cost
TIME TO DECOM
1-12 years
10-90 years
~ 1 year
HOW TO DECOM?
1. Full removal of the platform 2. Rigs to Reefs
1. Immediate Dismantling 2. Safe Enclosure ('Safstor') 3. Entombment
1. Full removal of the platform
In association with:
Astroscale
Northumbria University NEWCASTLE
Law School
Decommissioning: Protecting human and environmental safety by returning the environment to its natural state

Defining Satellite Decommissioning



Astroscale's ELSA-d mission will demonstrate the key technologies required for the decommissioning of prepared satellite clients.

With the growing awareness for considering end-of-life practices to ensure a sustainable future in space, it is necessary to examine the concept of decommissioning in the context of the satellite industry. Decommissioning for space operations is a novel approach and therefore it is necessary to propose a working definition of satellite decommissioning upon which this discussion is built.

The decommissioning of satellites involves removing assets from operational service and returning the environment of Earth's protected orbits to its natural state. For the purposes of this definition, the Earth's protected orbits are defined by the IADC[3] to include low Earth orbit up to 2000km (LEO), and the Geosynchronous Region of the geostationary altitude plus or minus 200 km (GEO).

Low Earth Orbit

Decommissioning in LEO involves reducing the orbital altitude of objects such that they can burn-up in the Earth's atmosphere. There are three methods of decommissioning in LEO:

1. **Passive:** Satellites at low altitudes will naturally decay quickly due to atmospheric drag. However, satellites that massively decay, without any manoeuvring capability, will still be at risk of collision as they descend through lower altitudes before burning up.
2. **Onboard manoeuvrability:** Satellites use on-board propulsion or other internal capabilities to de-orbit. This option requires satellites to be operational and have fuel available at the end of their operational life.
3. **Debris Removal Services:** Third party services can ensure that decommissioning is completed, regardless of asset position or condition.

Geostationary Earth Orbit

Decommissioning in GEO requires the movement of objects into a so-called 'graveyard orbit', beyond the GEO protected region, to ensure that the GEO belt is kept clear of failed satellites and debris. There are two methods of decommissioning in GEO:

1. **Onboard manoeuvrability:** Satellites use on-board propulsion or other internal capabilities to move to a graveyard orbit. This option requires satellites to be operational and have fuel available at the end of their operational life.
2. **Debris Removal Services:** Third party services can ensure that decommissioning is completed, regardless of asset position or condition.

"It is necessary to examine the concept of decommissioning in the context of the satellite industry.

Making the Case for Satellite Decommissioning

In practice, satellites are not always decommissioned and can remain in critical orbits for many years to indefinitely. As we learn from other industries, the objective of decommissioning is to protect human and environmental safety by returning the environment to its natural state. In the absence of decommissioning in the satellite industry, whereby debris is left in orbit, environmental and human safety is already being compromised. The following arguments present the rationale for satellite decommissioning.

Protect the Orbital Environment

- Space is recognised as **critical national infrastructure**
- As space becomes more congested, space safety becomes increasingly important

Protect Human Safety

- Orbital debris presents one of the **highest risks to the International Space Station**: the ISS performs up to **4 Debris Avoidance Manoeuvres** (DAMs) a year

Mitigate Cost

- Operators face **design, manufacturing and operational costs** to protect against lethal non-trackable debris and maintain high quality of service

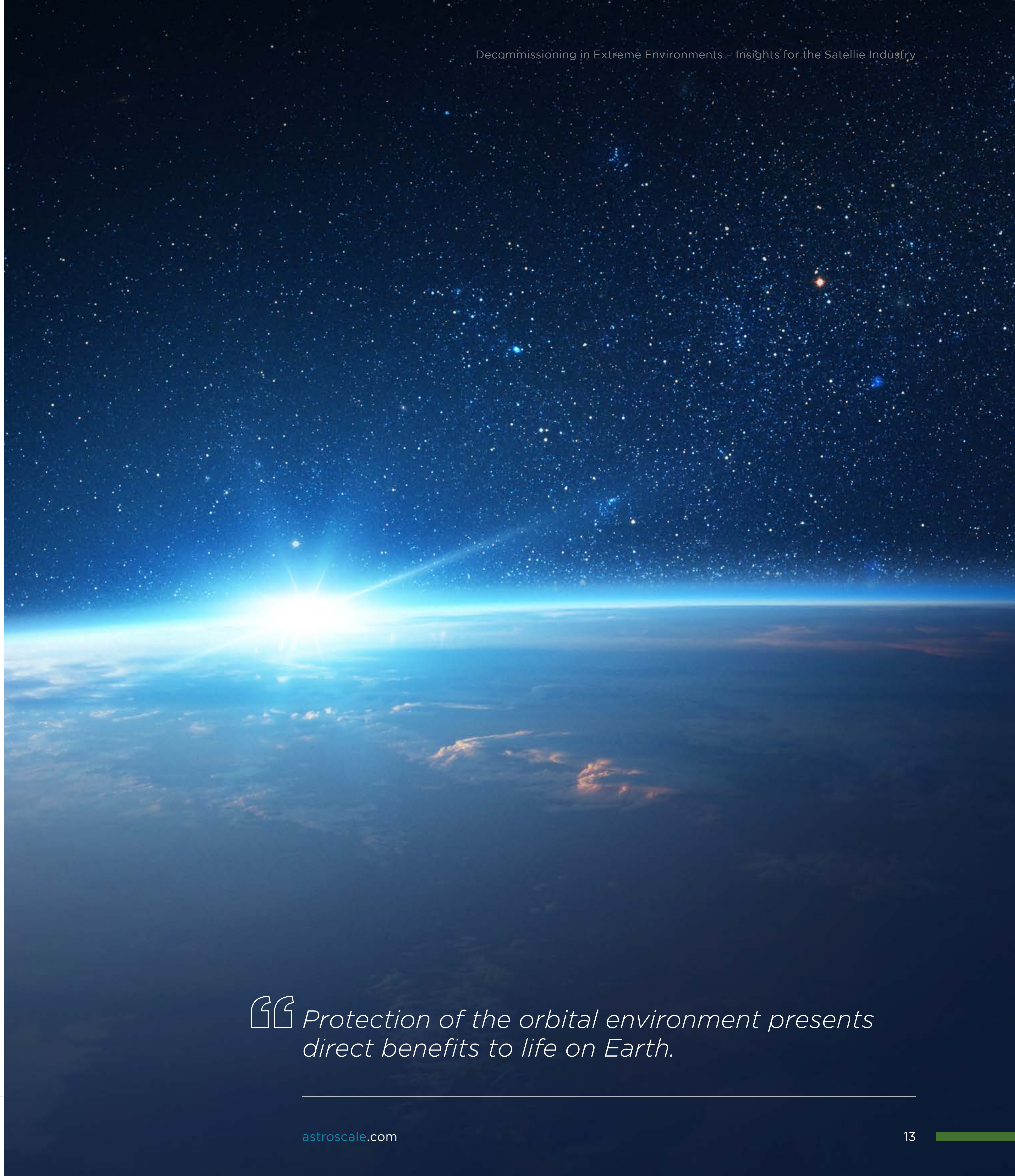
Reduce Liability

- 'Launching states' are **liable for damage** caused by their space objects – Outer Space Treaty (1967) and The Liability Convention (1972)

Protect the Orbital Environment

Decommissioning enables, by its own definition, the ability for satellite operators to protect the orbital environment and return it back to its natural state. As orbital congestion increases, space safety becomes of paramount importance. By leaving failed satellites in orbit, we increase the risk of damaging collisions with the operational satellites that are vital to our societal infrastructure. As such, protection of the orbital environment presents direct benefit to life on Earth. The global economy is dependent on satellites and in the UK, space was first acknowledged as critical national infrastructure in 2015.

By protecting the orbital environment, we are protecting our way of life and preventing damages to multiple industries which our society depends on. A potential loss of satellite services could be immensely damaging to the global economy; the loss of global positioning



"Protection of the orbital environment presents direct benefits to life on Earth.

Making the Case for Satellite Decommissioning - continued

services (GPS) alone is projected to cost $1 billion per-day.[4] Through robust decommissioning practices, in tandem with improvements to space object tracking and coordination, we can therefore ensure that the orbital environment is protected.

Protect Human Safety

As well as operational risk, failed satellites and debris pose an environmental and existential risk to human space activity. Orbital debris currently presents one of the highest risks to the International Space Station, and the astronauts aboard, with the station performing as many as four Debris Avoidance Manoeuvres (DAMs) per year and a total of 25 between the years of 1999 and 2018.[5] Were these debris to collide with the ISS, the result could be catastrophic.

With the expansion of the nascent space tourism market, such future passengers could be at risk from orbital debris and any potential collision could prove immeasurably catastrophic and damaging to the space tourism sector. The decommissioning of space assets can therefore reduce the debris risk for humans in space, protecting human safety and allowing human activity in space to flourish.

Mitigate Cost

Another benefit of satellite decommissioning is to mitigate costs that satellite operators are burdened with as a result of operating in a polluted environment. Inaction in dealing with space debris will inevitably lead to greater costs for operators in the future, and ultimately the general public.

Prevention with effective satellite decommissioning will be better than delayed remediation. As an example, operators will face design and manufacturing cost increases

in order to protect their assets against lethal non-trackable debris objects, while seeking to maintain a high quality of service. Maintenance costs are projected to increase by 18%[6] by 2030 due to the worsening debris environment. Furthermore, as space insurers begin to incorporate space debris into their risk modelling and pricing, premiums will likely increase, again causing further costs for operators. Insurers have already started to leave the satellite market and one insurer, Assure Space, is now excluding collision risk[7] from their LEO insurance coverage. There may be further regulatory and reputational costs to come as a result of the increasingly congested orbital environment. By establishing strong and safe decommissioning practices in the satellite industry today, we can mitigate the potential cost for operators in the future.

Reduce Liability

There is a legal conundrum at the heart of the discussion on decommissioning. Any attempt to engage in remedial activities, be it from a commercial company or a collaboration with a national space agency, will need to secure authorisation from a state regulator before engaging in debris remediation. Regulators may have been reluctant to grant this for fear of incurring liability for any damage caused should any such operation be unsuccessful. Paradoxically, States are less inclined to accept liability for space debris, including liability for in-orbit damages and removal costs, and feel that the responsibility for removal belongs to all states, including the associated costs. The introduction of a decommissioning regime to the protected orbits would reduce the risk of collisions between dead satellites, the creation of debris and would ultimately reduce the number of objects that could incur liabilities for space-active nations.

Legal and Policy Imperatives for Decommissioning

The law regulating outer space activity has international and national dimensions which will shape any decommissioning regime. The Treaty on Principles Governing the Activities of States in the Exploration Use of Outer Space, including the Moon and Other Celestial Bodies (The Outer Space Treaty) 1967 requires states to behave in a certain way and take responsibility for space activity on a national and international level.

The Treaty has, to date, been ratified by over 100 members of the United Nations and provides the underlying principles by which current activities in space are regulated. The Treaty permits States to explore, use and conduct scientific investigation in space. Individual states have a broad range of discretion as to what conditions they can impose on companies.

Article VI of the Treaty provides that States are internationally responsible for all national space activity, whether carried out by government or non-governmental entities such as people or companies. This has led to the development of legislation by States to manage any national space activity through domestic regulation. This regulation will usually take the form of a mandatory licensing regime. The UN Debris Mitigation Guidelines promulgated in 2007 have been accepted by both UK and US regulators as being the 'industry standard'. This input into the regulatory process is not limited to international institutions; the International Organization for Standards (ISO) is becoming an increasingly important voice in the harmonization of space operations and has set standards, such as ISO 24113 which covers disposal, re-entry, passivation.

There is no mention of any notion of a decommissioning regime in the original international space law treaties. As is seen in other decommissioning regimes, the consequences of a nuclear installation failing or the pollution from a malfunctioning oil rig have provided triggers which inform and shape the legal environment. Despite the widespread concerns regarding space debris there has been no binding treaty negotiated to combat the threat of space debris.

Given the current geopolitical environment, the chances of such a treaty being brought to fruition are small. Fortunately, the principles laid down with the Outer Space Treaty provide a much more expeditious and desirable route to embedding decommissioning as an essential element of satellite missions. As discussed, Article VI of the Treaty requires the State Parties to authorise national activity. Accordingly, in respect of enabling a decommissioning regime, the legal solutions are available to nations within the existing framework. States themselves can introduce a decommissioning requirement as part of their authorisation and licensing mechanisms.

It is suggested that there is nothing within the Outer Space Treaty or any other international agreement that would prevent states from doing this. Coupled with this, the incentive of limiting liability under Art VII of the Treaty should embolden States to examine the lessons learned from those in other sectors.

Shared Challenges of Decommissioning in Extreme Environments

Addressing the problem of returning environments back to their natural state is not without precedent on Earth. Whilst the physical aspects of the space domain make this a unique technical challenge, the issues faced by the space community are not unique. Industries surrounding the world's energy resources all, to varying degrees, consider how to deal with assets that pose a danger to the environment once they have reached the end of their operational life.

Each industry has its own decommissioning protocols and processes, but each one has at its heart, some form of requirement to remove the environmental threat posed by the particular asset, and in some cases return the area that was used back to the state it was in before it became operational. The challenges faced by each of the terrestrial energy industries in some way mimic the difficulties faced by the space community at this time; operating in either an extreme environment (such as oil and gas rigs), with extreme materials (nuclear materials), using experimental technology, but also facing severe environmental consequences if decommissioning of their assets is not addressed (as can be seen in all of these industries).

With the growing awareness for considering end-of-life practices to ensure a sustainable future in space, there is an opportunity to learn from other industries much more developed in their thinking. Decommissioning across extreme environments presents similar challenges and a compelling opportunity for cross-industry learning.

Assets are not designed with decommissioning in mind

Satellites are not typically designed with decommissioning in mind. This is less of a concern for satellites operating at lower altitudes, for which passive orbital decay may suffice as a decommissioning method. Satellites in GEO typically will have onboard propulsion as standard to ensure orbit maintenance, and therefore decommissioning capabilities if their assets retain fuel and remain operational at the end-of-life.

For satellites in higher LEO, onboard propulsion or third-party debris removal services are required to ensure successful decommissioning. Many satellites in LEO do not have propulsion or docking plates for prepared removal by a third-party service, and have no means to de-orbit themselves at the end of operational lifetime.

"The challenges faced by energy industries mimic the difficulties faced by the space community.

Historically in other industries, assets are similarly not designed with decommissioning in mind, which results in increased decommissioning costs once assets reach their end of life. This is particularly true for the satellite industry, where unprepared clients render decommissioning much more difficult and therefore more costly.

Shared Challenges of Decommissioning in Extreme Environments - continued

Operational lifetimes are extended beyond the original design

It is common practice for satellite operators to extend the operations of healthy spacecraft past their design lifetime, in order to increase their return on investment of the asset. Nearly a third of commercial GEO communications satellites in orbit are operating beyond their design lives.[8]

Whilst there are economic incentives to extend satellite lifetimes, this poses a risk to the orbital environment. The longer satellites continue to operate, the greater their likelihood is of failure, thus contributing to the growing debris problem. The reliability of the satellite could also potentially decrease more rapidly as a result of lifetime extension, due to the satellite components and systems being stretched beyond their intended capabilities. An example of this is ESA's Envisat, an Earth observation satellite with a design life of five years that remained operational for ten years before unexpectedly failing. At over 8000kg and orbiting in a 790km sun-synchronous orbit polar orbit, it now represents one of the most critical space debris objects in LEO, and is expected to remain on orbit for more than 150 years.[9]

In the oil and gas industry we see a similar trend, where rigs are extended beyond their operational lifetime to maximise revenue and efficiency. Oil and Gas UK previously reported that *'the majority of installations on the UK Continental Shelf have exceeded their design life'*.[10] A specific example is the South Arne Field, operated by the Hess Corporation. At the end of its planned design life, The Hess Corporation were required to prove to the Norwegian Ministry of Petroleum and Energy[11] that their platform remained safe, in order to continue operations. This illustrates how regulatory permission can be required to extend asset lifetimes, in recognition of the risk it poses to the environment.

Challenges exist in understanding asset conditions

It is difficult to analyse the condition of satellites in orbit due to the fact that they are in space and inherently hard to reach. The nuclear industry shares this challenge, given limited understanding of assets conditions due to the extreme radiation environment. The offshore wind and oil industries also share this challenge with infrastructure located in remote areas with limited access.

Such difficulties in understanding assets can pose a problem for future decommissioning. It is challenging for an operator to determine the optimum time for decommissioning without fully understanding an asset's condition. This poses the risk of both potentially dangerous unexpected failures, as well as pre-emptive disposal which does not provide optimum efficiency, thus causing investment uncertainty. In order to carry out effective decommissioning it is therefore important to properly understand asset conditions, and to find innovative solutions to the challenges that operators face in doing so.

Decommissioning funding schedules are complex

As in many other sectors, once satellites reach their end-of-life they are no longer providing revenue to the operator. This presents a challenge for the financing of decommissioning services if funds are not accounted for during the operational and revenue generating phase of an asset's life. In other sectors, innovative solutions have been identified to address this challenge.

Shared Challenges of Decommissioning in Extreme Environments - continued

In the nuclear industry, end-of-life practices must be considered and financially accounted for from the beginning of operations. There are typically three ways that decommissioning is financed in the nuclear sector:[12]

Prepayment: funds are deposited in a separate and dedicated account before operational service begins. Such funds cannot be withdrawn for any purpose other than for decommissioning.

External sinking fund: Funds are set aside during the operational lifetime of the asset through an additional levy fee that is passed onto consumers. Such funds are placed in a trust fund outside the operator's control.

Surety fund, letter of credit, or insurance that guarantees decommissioning costs will be covered even if the operator defaults.

In the UK oil & gas sector, the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) can require operators to set aside funds if it believes they may not afford the future costs of decommissioning. To date, OPRED has agreed nine security agreements,[13] with a combined value of £844million, with operators to ensure they have sufficient funds available to cover the decommissioning costs.

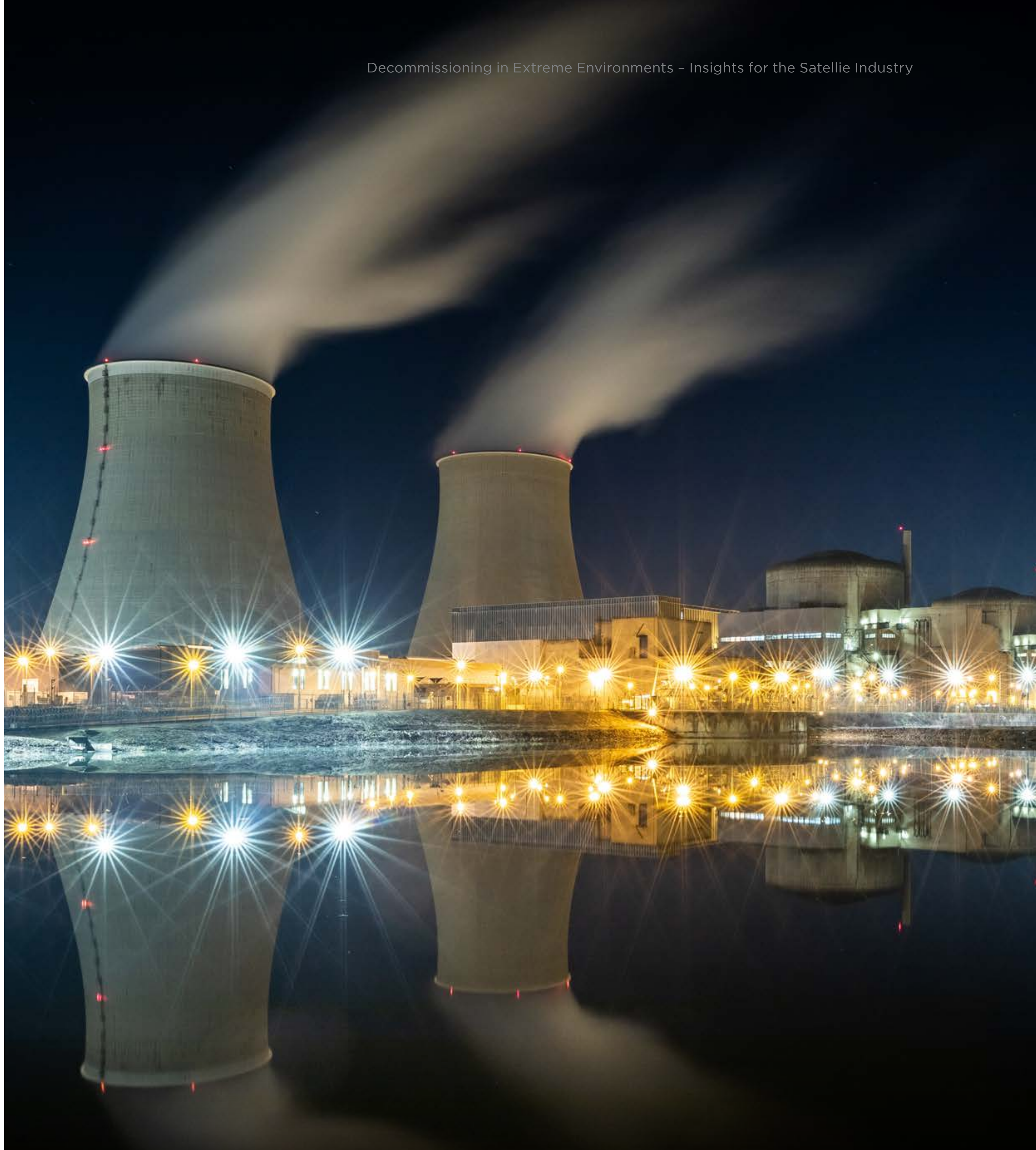
Decommissioning requires significant innovation and novel engineering approaches

The decommissioning of satellites, particularly those that require third-party debris removal services, is complex. The technology solutions required for satellite decommissioning are still being developed, requiring significant innovation. Decommissioning in the nuclear and oil & gas industries will similarly require 'never-done-before' solutions and significant innovation. Funding programmes, such as the UKRI 'Robots for a Safer World Industrial Strategy Challenge' are designed to support the required technology development and innovation required in extreme environments such as nuclear and offshore energy, deep mining, and space.

Segmented decommissioning responsibility for legacy and future waste

In many sectors, the responsibility of existing legacy waste is seen as an environmental concern that falls to the government. Future waste or debris is considered the responsibility of the operator that will generate that waste. In the nuclear industry we see a clear distinction between legacy waste and future waste, where legacy waste is the responsibility of the Nuclear Decommissioning Authority, and the responsibility of future waste remains with the operator itself.

This aligns with the two decommissioning services considered to address space debris: active debris removal (ADR) and end-of-life (EOL) services. ADR services are primarily targeting debris that is already in orbit, and both the European Space Agency (ESA) and the Japanese Space Agency (JAXA) have announced plans for institutional ADR missions. EOL services typically focus on removing future debris, with large satellite constellations as potential customers to mitigate the growth of further debris in orbit.



Specialised Decommissioning Services

The provision of decommissioning services is often outsourced to specialised third-party providers. This is seen in the nuclear and oil industries, where operators do not tend to carry out decommissioning themselves, but rather employ external companies that specialise in decommissioning. Such companies allow operators to outsource complex removal processes.

Decommissioning Case Studies

Oil and Gas

Oil and gas decommissioning occurs when the field production comes to an end and all the usable oil or gas has been processed, facilities must be dismantled, and the operator must return the ocean and seafloor to the original pre-lease condition.

This commonly involved the removal of pipes, well sealing, platform removal and site clearance of the surrounding area.

An alternative method of decommissioning, known as 'Rigs to Reefs', transforms abandoned oil rigs into artificial reefs that can support local wildlife and marine life. The origins of offshore oil and gas rigs date back to the 1890s. Decommissioning of oil rigs is, in contrast however, a relatively new phenomenon, with the first decommissioning process not occurring until over 100 years later.

Key Events

Torrey Canyon Oil Disaster 1967
Ship grounded and subsequently broke apart, causing 117,000 tonnes of oil to be spilt. This disaster led directly to the Bonn Agreement for cooperation in dealing with pollution of the North Sea by oil, and also the creation of further international conventions on oil safety.

Bonn Agreement 1969
The first "Agreement for Cooperation in Dealing with Pollution of the North Sea by Oil" provides, amongst other things, common operational approaches for prevention and clean up of oil and other pollutants by the states bordering the North Sea.

International Maritime Organization (IMO) 1989
Established generally accepted decommissioning standards.[14]

OSPAR Agreement 1998
OSPAR commission setting conventions for decommissioning globally.[15]

Brent Spar Saga 1991-95
In 1991 Shell announced their withdrawal from the Brent Spar oil field and their plans to dispose of the rig in the deep Atlantic waters, raising serious environmental concerns. In 1995, Greenpeace began a public campaign[16] against Shell's decommissioning approach and Shell subsequently conceded their position, agreeing to decommission the oil rig in a more sustainable manner onshore. The incident had a lasting effect on decommissioning expectations within the offshore oil industry and signatory members of the OSPAR convention updated their framework to align with these expectations.

UK Petroleum Act 1998
Significantly contributed to establishing best practices for decommissioning within the industry. The current decommissioning of offshore oil and gas installations is nationally regulated through the Petroleum Act and is enforced by the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED).

Oil and Gas Authority Established 2015
The Oil and Gas Authority's role is to regulate, influence and promote the UK oil and gas industry. The OGA is committed to ensuring that decommissioning is executed in a safe, environmentally sound and cost-effective manner.

Nuclear

Nuclear decommissioning is the process of safely closing a nuclear power plant in order to retire it from service after its useful life has ended.

The first nuclear reactor was originally built in the 1950s and nuclear decommissioning began in the 1980's. The International Atomic Energy Agency defines three key decommissioning options for nuclear operators:[17]

- **SAFSTOR:** a nuclear facility is placed and maintained in a condition that allows the facility to be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use.[18]
- **Immediate dismantling** of nuclear facilities and decontaminating land.
- **Entombment** of the facility to allow the remaining on-site radioactive material to remain on-site without ever removing it totally.

Key Events

Windscale Fire 1957
Uranium in one of the reactors at the Windscale plant caught fire and burned for three days. The reactor was eventually put out, with a significant amount of radioactive fallout spreading across the UK and Europe.[19] Overall, the Windscale fire disaster directly led to the Nuclear Installations Act (1965) introducing a licencing framework for nuclear power plants.

Euratom Treaty 1957
The Euratom Treaty significantly contributed to the safer and better use of nuclear energy within the industry, including decommissioning practices.[20] Euratom Directives establish the national and ultimate responsibility of Member States for the nuclear safety of nuclear installations, including decommissioning operations.

UK Energy Act 2004
Led to the creation of the Nuclear Decommissioning Authority (NDA) and the Nuclear Decommissioning Funding Account. The NDA develops national strategies for decommissioning and developed key understandings of the funding needed to carry out the process.

Offshore Wind

Offshore wind decommissioning is defined as the process of completely removing the wind turbine, foundations and transition pieces thus restoring the ocean and seafloor to its original state.

It includes all the necessary measures performed to restore a site to its original state as reasonably practicable.

Offshore wind energy is a relatively new industry with the first offshore-wind installation built in 1991 in Denmark. Offshore wind decommissioning is also a very recent phenomenon, with the first wind farm decommissioning taking place in Sweden in 2015.

In Conclusion

The space industry is increasingly aware of space debris and the growing threat it poses to the orbital environment. By reframing the discussion using the concept of decommissioning, we can leverage expertise and lessons learned from other industries that face similar challenges. Decommissioning can be viewed both as a process for environmental renewal and as a revenue-generating industry. It is the optimal time for all of the stakeholders to be proactive.

Whilst there are compelling similarities between the decommissioning challenges and practices observed across industries, each industry will have its own particular decommissioning processes that recognise the different circumstances and history of the sector's development. In other industries we tend to see regulatory processes be driven by catastrophic events. Such incidents have not yet occurred in the satellite industry, leading to a lack of maturity in satellite decommissioning expectations. However, when law and regulation is born out of crisis, the pressure for decisive political action may mean that wider stakeholders in the space industry may lose control of shaping that response. It is now the optimal time for all of the stakeholders to be proactive; heeding the warning signs from the orbital environment and learning the lessons of these other industries before a catastrophic and expensive disaster in space occurs.

The risk to human life is perhaps more direct and tangible in other industries, however a sustainable space environment is vital to protecting our way of life on Earth. Nonetheless, the warning signs to the space sector have not translated into any meaningful legal initiatives to protect the orbital environment. Although not on the scale of Chernobyl or the Brent Spar affair, the space community has seen what a collision in space looks like with the Iridium-Cosmos Collision in 2009.

Accepting that there will be a financial implication for regulators mandating decommissioning practices is an undoubted barrier to broader acceptance. The complexity, and therefore cost, of satellite decommissioning may vary dramatically depending on the asset's health and capabilities at the time of decommissioning. In the nuclear industry, using an 'immediate' dismantling approach can result in cost savings over a 'deferred' approach. Early adoption of decommissioning could have a significant cost benefit in the satellite sector also. The integration of docking mechanisms into satellite design can further reduce the cost of future decommissioning. The consideration of future decommissioning costs means that the satellite industry should be designing satellites with decommissioning in mind and encourage more active consideration of decommissioning practices more generally.

Whilst decommissioning in space is an emerging market; the challenges faced by the satellite industry are not new or unique. Decommissioning is an industry in and of itself that presents opportunities for innovation and growth. We observe that decommissioning is an integrated part of the life cycle for other industries and that end-of-life practices must be considered and financially accounted for from the beginning of operations. As such, the satellite industry can learn from other sectors and integrate decommissioning practices into the space life cycle to ensure a sustainable future.

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