A Green Paper for the Sustainability of the UK's Space Economy

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The Green Toolkit for a New Space Economy Team

1. Introduction

The Green Toolkit is an online information resource designed to assist companies working in the space industry to identify and respond to the social and environmental impacts of their activities. The toolkit seeks to enhance sustainability in the sector, in line with UK and international policy and objectives.[1] The space industry in the UK is developing rapidly but is doing so in the context of significant social and environmental challenges. Some of these challenges have been addressed through voluntary and state initiatives that pre-date or straddle the current growth in space activities, as is the case with water contamination, so that the relevance of these measures for the space industry may not be immediately obvious. Other measures seek specifically to encourage or mandate best practices within the space industry itself.

For small and medium sized companies (smes) in particular, understanding this complex regulatory landscape can seem daunting. In response, the Green Toolkit is designed to offer, firstly, a unified platform that identifies legal requirements and voluntary standards across the whole lifecycle of a space project, from design to completion. Secondly, to highlight specific areas where sustainable choices can be made and where there is scope for innovation and improvement. Thirdly, to provide guidance regarding the various metrics and methods of evaluation, for instance in relation to carbon capture, that can assist socially and environmentally sustainable development for the future.

By supporting companies to meet, and articulate, their compliance with legal and ethical requirements the toolkit can enhance domestic and international competitivity and help to attract commercial investment and public subsidies. It can also be relevant for other stakeholders. For citizens, it offers reassurance that the space industry is committed to being part of the solution to our environmental problems, not a cause. For regulators, such as the Civil Aviation Authority (CAA), the toolkit can assist those applying for licences to clearly identify, articulate, and provide evidence of their sustainability credentials. From a government perspective, the toolkit can highlight areas for further regulatory consideration or where additional financial support or guidance could be desirable, thereby encouraging innovation and helping to build a strong environmental reputation for the UK space industry.

The Green Toolkit is designed to sit alongside and complement, not replace, the existing sustainability assessment and ranking tools (environment management and audit schemes EMAS) that are currently available. EMAS are used by industry to develop an environmentally aware management culture. Potential benefits include enhanced production efficiency, legislative compliance, transparency and credibility for investors and public, and employee buy-in.[2] EMAS can include sector specific enquiries, though the space sector does not as yet appear to be attracting distinct attention in the more generic services. With an increasing number of

[1] UK Government, UK National Space Strategy, updated 1 February 2022, at: National Space Strategy - GOV.UK (www.gov.uk), Goal 2; and, from a Scottish perspective, Space Scotland, SSAF, the Scottish Government, A Strategy for Space in Scotland, October 2021, at: https://scottishspace.org/wp-content/uploads/2021/10/a_strategy_for_space_in_scotland.pdf, chapter 6.

[2] See, for an example, the services offered by the non-profit making company CDP at: https://www.cdp.net/en.

organisations offering EMAS, the need for greater comparability, consistency and transparency has been recognised.[3] In addition, these tools are primarily targeted at larger corporations, though some schemes can be relevant for smes: BS 8555 (2016) was developed, for example, to offer a number of phased stages to building an environmental management system that could provide a path to meeting the global standards in International Organization for Standardization's ISO 14001.[4]

One example of a ranking system that does have a direct space focus is the Space Sustainability Rating, developed collaboratively by MIT, Univ. Texas, ESA, WEF, and Bryce, with a focus to date on the design, operation, and end of life of a satellite, and minimising space debris.[5] As discussed further below, there are also a range of ISO standards that address specific aspects of satellite activity, notably ISO 24113, which establishes top-level space debris mitigation standards.[6]

The Green Toolkit is not a rating system: it encourages, but does not formalise, self-assessment. Rather, it provides information relating to the environmental and socio-cultural challenges of space activities and, where available, measures that can be taken to mitigate them. These include adherence to recognised voluntary standards and ranking systems, such as those discussed above. In line with the approach in the European Space Agency's (ESA) Green Agenda,[7] it focuses on the whole lifecycle, including the initial manufacturing and procurement stages, as well as a wide range of environmental concerns, such as resource depletion, so that the toolkit catches aspects not covered, or addressed only in a fragmented fashion, by other rating or standardisation systems.

The Green Toolkit presented here is ambitious and within the short space of the SPRINT project we have been able only to map in outline illustrative elements of the platform. Key challenges for any such project will be to ensure sustainability over time and that the information provided is reliable, comprehensive, and up to date. A clear indication of provenance will be important, with a preference for data obtained from state and public bodies, international and established civil society organisations, and peer reviewed academic publications. A platform feature enabling those using the Toolkit to comment on the material provided and exchange information could enhance accuracy and the sharing of good practices.

The following part of this Green Paper explains the satellite life cycle, key sustainability concerns, and the regulatory frameworks at both the international and domestic levels. The Green Paper as submitted is very much a scoping exercise, identifying key dimensions that will be used to populate the online platform and is to be understood as work in progress.

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[3] IFRS, Consultation Paper on Sustainability Reporting, September 2020, at: Consultation Paper on Sustainability Reporting (ifrs.org).
[4] See, for details: Comment on standard for phased implementation of environmental management systems | BSI (bsigroup.com) and ISO - ISO 14001:2015 - Environmental management systems — Requirements with guidance for use.
[5] Website details at: https://spacesustainabilityrating.org/.
[6] See details at: https://www.iso.org/standard/72383.html.
[7] ESA, Green Agenda at: ESA - ESA Green Agenda.

2. The satellite life cycle

i) Overview of the various stages of production, launch, exploitation, end of life

The life stages of satellites generally include satellite design, satellite manufacturing, journey to launch (storage, transportation, quality check), launch, and repurposing. For smes, the life cycle of a small satellite is commonly about 3 to 6 years, which consists of the following stages:

1. <u>Designing and Assembly (1 ~ 2 years)</u>
   Designing a satellite
   Manufacturing and assembly
   Environment and Qualification tests
2. <u>Deployment (~ 1 year)</u>
   Arranging a launch provider.
   Setting up tracking and commanding ground stations
   Schedule the launch and deliver the satellite to a launch provider
3. <u>Operation (2 ~ 3 years)</u>
   Operating satellites for undertaking the planned mission
4. <u>End of Mission</u>
   At the end of the mission, the satellite should perform the post-mission disposal (PMD). The Inter-Agency Space Debris Coordination Committee (IADC) regulations require that LEO satellites should not be removed from the LEO protected zone within 25-year after the compilation of the mission.[8]

Available data suggests the majority of observable pollution is attributable to stages 2 & 3 activities.[9] However, design and end-of-mission activities also generate environmental and socio-economic risks, warranting the shift from a linear to a circular economy approach to space activities.[10] Currently, a number of UK, European and international norms establish the various environmental and social requirements and assessments that apply during the life cycle of a small satellite. These norms will be explored in Sections 4-7 below.

ii) Specific discussion of Interstellar Space Technologies Ltd' project as a novel example

Interstellar Space Technologies is an SME focused on building next-generation scalable in-space manufacturing and construction facilities. Building capabilities for the creation of materials in space that are impossible to manufacture on Earth providing multiple benefits including reducing energy consumption and the development of sustainable space infrastructures.

[8] IADC regulations are compiled at: https://www.iadc-home.org/documents_public.
[9] Thibult Maury, et al. "Application of environmental life cycle assessment (LCA) within the space sector: a state of the art." 2020 *Acta Astronaut* 170, 122.
[10] Stefania Paladini, Krish Saha, and Xavier Pierron. "Sustainable space for a sustainable Earth? Circular economy insights from the space sector." 2021 *Journal of Environmental Management* 289, 112511.

The space environment features microgravity, high purity vacuum, and near absolute zero temperatures, which provides a unique environment to manufacture advanced and novel materials in space. Moreover, manufacturing in space can transform the way we build satellites, components, recycle in space, and construct large structures including space stations and Space Based Solar Power Stations. Manufacturing in space may also play a crucial role for space exploration on the Moon, Mars and beyond. Interstellar Space Technologies works on innovative solutions for sustainable space manufacturing, following these five principles: 'lower cost', 'high quality', 'scalability', 'adaptability' and 'sustainability'.

Interstellar Space Technologies' space platform is a dedicated in-space manufacturing scalable satellite platform, which aims to become the world's first mini manufacturing space station, combined with a continuous re-usable resource supply vehicle. This platform will enable access to space, can use multiple launch providers to send this platform to Lower Earth Orbit (LEO), and manufacture and operate in space. Manufactured materials will be returned to Earth with the resource supply/delivery vehicle, while the satellite enabled with manufacturing capabilities will continue to orbit and wait for the next resource vehicle to arrive and hence follow the cycle. The resource supply/delivery vehicle is expected to be refurbished and re-used multiple times, while the manufacturing enabled satellite is planned to have a lifespan in orbit of around ten years, i.e. double the average lifetime of a usual satellite.

Due to the new space economy perspective, Interstellar Space Technologies provides an interesting and novel case for consideration in assessing sustainability models in the space industry.

3. Sustainability and space

i) Development of sustainability concerns in the space field and parallels with international environmental law and law of the sea

As the conclusions to the 4th Summit for Space Sustainability attest, there is a strong consensus among governments, academic experts and industry for international regulation and coordination in order to achieve space sustainability. The views expressed echo regulatory initiatives already underway across a variety of jurisdictions, where space sustainability plans at the national level follow recommendations, guidelines and targets set by both the Outer Space Treaty regime and the Climate Change regime:

At the international level, the UN Office for Outer Space Affairs (UNOOSA) established a Working Group on the Long-term Sustainability of Outer Space Activities, tasked with producing voluntary guidelines to reduce risks to long-term sustainability, such as space debris mitigation. In 2019, the "Guidelines for the Long-term Sustainability of Outer Space Activities" of the Committee on the Peaceful Uses of Outer Space (COPUOS) were adopted. These were designed to increase safety, cooperation, capacity-building and R&D.[11] Among Committee members, there is growing discussion on the need for the costs of space debris mitigation to follow *Common but*

[11] See COPUOS Sustainability Guidelines at: V1906077.pdf (unoosa.org).

Differentiated Responsibilities and Respective Capabilities (CBDR–RC), which is a principle within the United Nations Framework Convention on Climate Change (UNFCCC).[12]

At the UK level, the Government is following the UNOOSA 2019 Guidelines, by investing in space projects, such as the Active Debris Removal (ADR) programme, which aims to minimise the footprint of space activities through recyclable manufacturing, retrieving satellites and mitigating any debris. The UK National Space Surveillance and Tracking Programme includes within its satellite monitoring activity a collision assessment service, which has now opened for registration for all UK licensed satellite operators.[13]

At the national level, a Scottish Space Sustainability Roadmap is delivering recommendations to both private and public sectors to ensure Scotland's space activities are in line with Scotland's pledge under the Paris Agreement to transition to a net zero carbon emission by 2045. Interim targets for the short- and medium-term are set to contribute 50% global reduction in CO2 equivalent by 2030 targeted by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5C°.[14]

The legal regime of sustainability in space shares key features with international environmental law and the law of the sea. These include a number of principles, such as the Principle of Preventive Action and the Polluter Pays Principle (Article 4 OST; Article 2, 3 Liability Convention 1972; RIO – 16; UNEP – Principle 8; Stockholm Declaration – Principle 26). Satellite regulations also follow customary standards developed elsewhere by the shipping or aviation industries, such as rules regarding the construction, design, equipment, and manning (CDEM). Global Navigation Satellite Systems (GNSS) and the International Maritime Organization's Vessel Traffic Services share common safety standards on navigational aids, traffic schemes, monitoring, and communication technologies.[15]

Moreover, sustainability in space overlaps with other regimes of environmental protection, such as the 1972 London Dumping Convention and its 1996 Protocol.[16] The purpose is to ensure that controlled or uncontrolled re-entries do not pose an undue risk to people or property, including through environmental pollution caused by hazardous substances dumped at sea.[17] Another applicable environmental treaty is the Convention on Long-Range Transboundary Air Pollution, which introduces commitments for Parties such as the UK to reduce emissions of volatile organic compounds, including black carbon, a common pollutant of rocket launches, which is considered

[12] *Ibid*, para. 123.
[13] See UK Government's Plan for Space Sustainability at: Government announces package of new measures to drive space sustainability - GOV.UK (www.gov.uk).
[14] Astroagency Optimat, "Scottish Space Sustainability Roadmap", Final Report, Scottish Enterprise, 19 May 2022.
[15] International Convention for the Safety of Life at Sea (SOLAS), 1974 UNTS Volume Number, 1184, 1185 (p.2).
[16] 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1046 UNTS 120, [ATS] 1985 16, 11 ILM 1294 (1972), UKTS 43 (1976).
[17] *Supra* note 11, Guideline D.2, para 5.

a fine particulate matter to be abated.[18] Major contributors to such pollution, such as India and China, shall be encouraged to join the Convention's additional Protocol.[19]

We can expect further regime convergence between outer space law and international environmental law in the years to come. Earlier this year, a UNEP draft resolution established an intergovernmental committee to negotiate a legally binding treaty on plastic pollution to reduce plastic pollution in the marine environment. A similar approach could be suggested for space, with UNOOSA given a mandate to negotiate a treaty on outer space debris mitigation and adaptation. The view at UNOOSA is that it is of utmost importance to have legally binding instruments that provide clarity on the responsibility of countries in terms of collisions with space debris.[20]

ii) Identification of categories of concerns:

1. Carbon footprint

Global active space- and ground-based astronomical facilities emitted an equivalent of at least 1.2 million tonnes of CO_2 each year.[21] This is roughly equivalent to 30 million barrels of oil consumed annually. More specific to our concern, case studies for life-cycle carbon footprints of satellite missions are very scarce. The ESA has estimated that for one of its Copernicus Earth observation satellites, 44% of the carbon footprint is attributable to launcher-related activities, 25% to the operations phase and 19% to the definition, qualification and production of the spacecraft.[22] Overall, it is estimated that between 50% to 70% of the carbon footprint of a space mission is related to the launcher production, launch campaign and launch event.

Studies on the emission embodiment of a satellite are still scarce. Instruments such as PAS 2080[23], which offer a full specification for managing whole life carbon in infrastructure, will soon be in use at Prestwick Spaceport in Ayrshire to assess the whole life carbon cycle of the built environment, in line with the Scottish government's net-zero climate change plan.[24]

2. Land, air and sea pollution

i) Land pollution from initial launch discharge

[18] Convention on Long-Range Transboundary Air Pollution, 13 November 1979 1302 UNTS 217, 18 ILM 1442

[19] Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, 30 November 1999 2319 UNTS 81.

[20] *Supra* note 11, Guideline, para. 127.

[21] Jürgen Knödlseder, et al. "Estimate of the carbon footprint of astronomical research infrastructures." 2022 *Nature Astronomy* 6.4, 503.

[22] Augustin Chanoine, "Environmental impacts of launchers and space missions." 2017 Clean Space Industrial Days, ESTEC.

[23] The Construction Leadership Council Infrastructure Carbon Review, "Guidance Document for PAS 2080", 2022, online: Guidance-Document-for-PAS2080_vFinal.pdf (constructionleadershipcouncil.co.uk)

[24] Joanne Wheeler & Matthew Archer, "The Environmental Narrative for the UK Launch Industry", Via Satellite, 22 February, 2022.

Clouds generated during lift-off contain reactive chemicals such as hydrochloric acid and aluminium oxide. These substances mix up with water from the deluge system that cool down the launch pad and the rocket. This cloud then spreads throughout the surrounding environment, affecting soil and water quality and damaging vegetation.

ii) Air pollution from launch

Due to their ultra-hazardous effect on ambient air quality, volatile satellite propellants and rocket fuels may cause harm to the atmosphere. Atmospheric impact occurs when particles of soot and aluminium absorb and reflect incoming solar radiation in the stratosphere, thereby altering the temperature and radiation levels at these altitudes, which may affect the ozone layer.

Two sources of air pollution must be distinguished: the satellite launch and the satellite propulsion once in space. First, chemicals such as hydrazine, hydrogen peroxide, or black carbon can be found in rocket fuel, which has the potential to be both toxic and corrosive. Rocket engines emit substantial amounts of sulfur and black carbon. Second, similar risks are identified for satellite thrusters and satellite electric propulsion, which may damage the ozone layer.

iii) Marine pollution by space debris

One critically exposed maritime pollution is Point Nemo, a South Pacific Oceanic Uninhabited Area. This spacecraft cemetery 3,000 miles off New Zealand's eastern coast is where obsolete spacecraft are routinely crashed.[25] The spacecraft cemetery is entirely in a marine area beyond national jurisdiction. Among the space debris sunk in the area, 190 are Russian, which includes military space stations, fifty-two pieces belong to the United States, eight are European and six are Japanese. Some space cemetery debris comes from private space operations (Space X).

3. Resource depletion

Two laws of economics highlight the current rate of unsustainable resource extraction and usage in space: the Jevons Paradox and Moore's Law:

i) Moore's Law

Moore's law is, classically, the empirical observation that the number of electronic components integrated into a chip doubles every 18 months to 2 years.[26] Spacecraft technology is rapidly evolving: every one or two years the size and cost of satellites decreases following Moore's law.[27] The speed of technological upgrade accelerates planned obsolescence of satellite-as-waste: it pays more to ship satellites every 2 years because of the advantages awarded by technological upgrade, than to design long-life satellites (15-year+ lifespan).

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[25] Vito De Lucia & Viviana Iavicoli. "From outer space to ocean depths: the spacecraft cemetery and the protection of the marine environment in areas beyond national jurisdiction" Cal. W. Int'l LJ 49 (2018): 345.
[26] Gordon Moore, "Cramming more components onto integrated circuits." 1965 Electronics magazine 114.
[27] Daniel Berleant, et al., "Moore's law, Wright's law and the Countdown to Exponential Space." 2021 *arXiv* preprint 2107.09637.

ii) The Jevons Paradox

As Moore's Law reduces the size of satellites, a greater number of satellite constellations, particularly mega constellations, is launched by a wider range of market players. The gains in efficiency generate higher energy consumption: this is called the Jevons Paradox.[28]

During the Industrial Revolution, energy-efficient steam engines had accelerated Britain's consumption of coal. As Jevons observed, since the cost of steam-powered coal extraction became cheaper, coal consumption overall increased. The same can be observed with global electricity, copper, rubber, petroleum consumption, and now lithium: every passing stage of technological progress is correlated with a total expansion of global energy demand.

Technological progress in satellite manufacturing increases the efficiency with which resources are used (reducing the amount necessary for any one use), but the falling cost of use increases demand for satellite launches, negating the efficiency gains.

Efficiency gains are lost by increased demand for satellite technology, which requires extraction of raw materials on Earth, such as bauxite for solar panels and lithium for satellite battery packs.

4. Social, cultural and heritage impact: thinking more widely about sustainability

<u>Setting: space activity directly impacts people across the planet</u>

The space domain is unique in its global scope and reach. Spacecraft and launch trajectories cover wide swathes of the Earth, and they have real impact on people, their livelihood and our shared cultural heritage.

This global reach allows the space sector to deliver social goods, including rural broadband, international communications, and earth monitoring capabilities that track climate change, deforestation and nuclear proliferation. However, this global nature also means there are many kinds of societal harms that can result from space activity. This section outlines some of the most pressing complications.

<u>Launch and re-entry debris on land</u>

The number of launch and re-entry debris incidents have increased as space activity ramps up. Rocket and spacecraft parts have crashed back onto earth with increasing regularity, including from Chinese Long March 5B launches in 2020, 2021 and 2022, and American SpaceX in 2016 and 2022. These have affected areas as far afield as the Ivory Coast, Indonesia and Australia.[29]

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[28] William Stanley Jevons, *The coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coalmines*, Macmillan and Co, 1865, London.
[29] Michael Byers, et al., "Unnecessary risks created by uncontrolled rocket reentries", 2022 Nature Astronomy at: https://doi.org/10.1038/s41550-022-01718-8; *BBC News*, "Space debris Australia: Piece of SpaceX capsule crashes to Earth in field", August 3, 2022 at: https://www.bbc.co.uk/news/world-australia-62414438; *The Guardian*, "SpaceX capsule confirmed as source of space debris that crashed on farm in

A 2022 study concluded that there is 'a 10% chance of one or more casualties over a decade', with the risk 'being disproportionately borne by populations in the Global South'.[30]

As a mitigation strategy, one solution is to opt for controlled rocket reentries that steer large debris away from land.

Launch and re-entry debris on water

Water bodies have historically been considered safe areas for debris to land on the premise that these are remote and 'empty' spaces or *terra nullius*. These notions are mistaken; there are some unique marine areas that are lived-in, which sustain the health, livelihood, and cultural heritage of adjacent societies. One such area is the North Water Polynya, located in Baffin Bay between Canada and Greenland. Known as Pikialasorsuaq or Sarvarjuaq to the local Inuit, the polynya is the most biologically productive area in the Arctic Ocean. It supports an extensive ecosystem including crucial populations of plankton, fish and marine mammals. Since 2002, Russia-operated launches from Plesetsk Cosmodrome have dropped rocket stages containing the toxic rocket fuel hydrazine into the Polynya and the neighboring Barents Sea. Several of these launches carried international payloads, including satellites owned by the ESA and Japan, both of which have banned the use of hydrazine in their own jurisdictions on account of its toxicity.[31]

As Okalik Eegeesiak, Chair of the Inuit Circumpolar Council, commented on a previous hydrazine-fuelled launch, 'this rocket will not be falling into no-man's land… Inuit live here, Inuit use the animals in these waters to feed our families. This is our home.' The Inuits' diet and nutrition depends on the animals and flora supported by the Polynya, making the Inuit populations more exposed to the effects of environmental contaminants. Hunting and gathering is an important part of Inuit identity and culture, and pollution from hydrazine could lead to adverse health outcomes on a population that is already suffering from heavy metal and organic pollutants.[32] We do not yet know the exact level of harm caused by these hydrazine pollution events, however studies of hydrazine pollution from Baikonur Cosmodrome launches in Kazakhstan indicate that the toxin affects the land and population via aerosol dispersion and soil contamination. These studies also indicate adverse health effects on local populations, including weakened immune systems and thyroid disease across all age groups. There is also a 1993 report in the *New Scientist* that attributes the mass dying of fish in the Karin peninsula to hydrazine pollution from Plesetsk.[33] The 'precautionary principle' (Principle 15 of the Rio Declaration, 1992) calls for states to take actions to avoid potential environmental damage, even if there is a lack of scientific certainty. The UN Declaration on the Rights of Indigenous Peoples obliges states to 'take effective measures to

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Australia", August 3, 2022 at: https://www.theguardian.com/australia-news/2022/aug/03/spacex-capsule-confirmed-as-source-of-debris-that-landed-on-australian-farm.

[30] Byers, *ibid*.

[31] Michael Byers & Cameron Byers, "Toxic Splash: Russian Rocket Stages Dropped in Arctic Waters Raise Health, Environmental and Legal Concerns." 2017 *Polar Record* 53:6, 580 at: https://doi.org/10.1017/S0032247417000547.

[32] Tiff-Annie Kenny & Tad Lemieux, "Latest rocket launch renews concerns over Inuit food security." *The Conversation*, October 19, 2017 at: https://theconversation.com/latest-rocket-launch-renews-concerns-over-inuit-food-security-85708.

[33] Toxic Splash, *supra* note 31.

ensure that no storage or disposal of hazardous materials shall take place in the lands or territories of indigenous peoples without their free, prior and informed consent' (Article 29.2).

Mitigation strategies:

- Choose launches that use non-toxic fuel
- Avoid using launch trajectories that go over or near to marine protected areas, as outlined by the UN Environment Programme's Protected Planet resource: https://www.protectedplanet.net/en

Spacecraft reflectivity and light pollution

Spacecraft that reflect light cause light pollution and affect the look of the night sky. Decreasing light pollution is important for ground-based astronomy, but also for the skywatching traditions of many societies around the world. While satellite constellations like Starlink have bore the brunt of public criticism and media attention, individual spacecraft operators can play an important role in adopting the best standards to decrease their contribution to the problem of light pollution.

Light pollution from satellites alters peoples' relationships to the cosmos, severing centuries-old traditions and erasing the abilities to connect with the stars. For many societies, the sky contains moral truths and serves as a storehouse of important historical, navigational, economic and social knowledge.[34] One particularly vulnerable tradition belongs to Aboriginal and Torres Straits Islanders, who have 'dark constellations' which are formed of dark spaces in the sky, including a celestial emu that is composed of dark dust lanes of the Milky Way. As the year progresses, the celestial emu moves across the sky, marking the actual emus' breeding and egg-laying seasons. This celestial motion informs Aboriginal societies' notions of time and their economic and social practices. Increased light pollution from cities and spacecraft are now making the celestial emu and other celestial patterns difficult to see, even in remote communities.[35] Oceanic wayfinding traditions, particularly those of Pacific communities from Hawai'i to Aotearoa (New Zealand), depend on the visibility of stars on the horizon.[36] Because of these cultural ramifications, light pollution has been called 'astrocolonialism' or even 'cultural genocide'.[37]

One mitigation strategy would be to lower overall reflectivity of spacecraft where possible when designing and constructing the spacecraft.

[34] Duane Hamacher, et al., "Whitening the Sky: light pollution as a form of cultural genocide." 2020 *Journal of Dark Sky Studies* 1, at: https://doi.org/10.48550/arXiv.2001.11527.
[35] *Ibid*.
[36] See 2021 SATCON2 Community Engagement Working Group Report at: https://assets.pubpub.org/jwly60e8/21637248975523.pdf.
[37] "Whitening the Sky" *supra* note 34; "SpaceX's Satellite Megaconstellations Are Astrocolonialism, Indigenous Advocates Say", *Vice*, 5 October 2021, at: https://www.vice.com/en/article/k78mnz/spacexs-satellite-megaconstellations-are-astrocolonialism-indigenous-advocates-say.

Colonial legacies of ground-based infrastructure

Parts of our ground-based infrastructure (launch sites and ground stations) have benefited from past colonial actions, the ramifications of which continue to impact local communities today. The situation is particularly acute in equatorial launch sites and ground stations in the Global South, where colonial authorities disregarded local and Indigenous communities, taking their lands without consultation or sufficient recompense often in the name of 'scientific progress' or 'national security'.

The ESA's Kourou spaceport in French Guiana embodies the problematic legacies of our colonial past. The territory itself was colonised by the French in the seventeenth-century, formed of land taken from Indigenous owners.[38] French Guiana's equatorial position, low population density, and proximity to the coast made it an ideal location for France's spaceport in 1964, after the French lost their first launch site in Algeria. The creation of the spaceport exacerbated patterns of economic inequality in the local community, creating a new dependence on European space funding while atrophying other economic sectors. Living standards in French Guiana are still significantly lower than in mainland France. The spaceport's success has also raised the political stakes in the territory, with French troops deployed to guard 'Europe's Spaceport' and the highly successful Ariane launcher programme. During the Cold War, Kourou enabled France and Western Europe to pursue an independent space policy. Local social and independence movements were repressed partly in light of Kourou's strategic importance.[39]

Other equatorial ground sites with problematic legacies and local situations include the Alcântara Space Center in Brazil, which threatens to displace without recompense or consultation Quilombola communities, descendents of slaves that have lived in the area for hundreds of years.[40] Colonised islands across the world are the sites of important ground stations, including Diego Garcia, Puerto Rico, Guam, Samoa, Tinian, Wake, St Helena, Ascension, the French Seychelles, Christmas Island/Kiritimati, and Hawaii, each with their own unique histories of colonialism and Indigenous dispossession.[41]

A mitigation strategy is to investigate the local conditions of the ground facilities being used, and opt to use facilities that repair relationships with and gives back to the local community.

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[38] Alexandre Sommer-Schaechtele, "The Indigenous World 2021: French Guiana", International Work Group for Indigenous Affairs, 18 March, 2021, at: https://www.iwgia.org/en/french-guiana/4218-iw-2021-french-guiana.html.

[39] Said Bouamama, "French Guiana: the negative legacy of French colonialism." *International Viewpoint*, August 21, 2018 at: https://internationalviewpoint.org/spip.php?article5664.

[40] Terence McCoy & Heloisa Traiano, "A story of slavery – and space", *The Washington Post*, March 26, 2021 at: https://www.washingtonpost.com/world/interactive/2021/brazil-alcantara-launch-center-quilombo/.

[41] Ruth Oldenziel, "Islands: The United States as a Networked Empire", in Gabrielle Hecht (ed.), *Entangled Geographies: Empire and Technopolitics in the Global Cold War*, MIT Press, 2011, pp. 13-41 at: https://doi.org/10.7551/mitpress/9780262515788.003.0002.

4. Regulatory framework

In this section, we provide an overview of international and domestic law relevant for the development of space activities in the UK. This resource is primarily designed to inform and assist in populating the Green Toolkit platform but could also be developed to offer a further orientation briefing for those using the site. The section covers binding rules, as well as voluntary standards and non-binding guidance, which are either space specific or applicable to industry in general.

At the international level, there are five foundational space treaties, the first of which, the Outer Space Treaty, was adopted in 1967 (detailed at 5i below). The UK is a signatory to all but the Moon Agreement (1979). Although treaties contractually bind the states that ratify them, their domestic impact depends on whether the state adopts a 'monist' or 'dualist' approach to international law. For monist states, the terms of a treaty can take direct effect domestically without the need for further implementing measures while for a dualist state, such as the UK, a treaty will only create individual rights and obligations once it has been implemented, usually through a domestic act of Parliament.

The international space treaties were agreed at a time when space activity was the domain of states not private enterprise and limited in scale. They were not designed, therefore, with the challenges we face today in mind. The Outer Space Treaty (1967) establishes the founding principle in Article 1 that 'the exploration and use of outer space' is to be 'carried out for the benefit and in the interests of all peoples'; the Liability Convention imposes liability on the launching state for damage caused by its space objects to the surface of the earth or to other space objects in flight, when at fault; while the Moon Treaty addresses sustainability concerns in Articles 4 and 7, but is applicable to only a handful of states. A number of terms or phrases in these provisions, such as 'fault' or 'benefit of …all peoples', require further clarification if they are to shape state policy or guide industry behaviour. The UN Committee on the Peaceful Uses of Outer Space (COPUOS), of which the UK is a founding member, and its two legal and scientific sub-committees, has thus sought to co-ordinate state activities, support the exchange of good practice, and develop guidelines to give concrete effect to these overarching principles. Although guidelines, such as the COPUOS Guidelines for the Long-Term Sustainability of Outer Space Activities,[42] are non-binding, they identify specific actions that states are expected to take to address safety and environmental concerns. They can thus influence domestic policy and lay the foundation for the eventual adoption of binding standards.

In addition to the five core space treaties, a range of international agreements address environmental and sustainability concerns more generally, such as the Partial Test Ban Treaty (1963)[43], and are discussed in more detail in section 5 below.

Alongside international organisations such as the UN, regional organisations such as ESA, of which the UK is a member, play an important role in developing policy, coordinating space

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[42] See COPUOS Guidelines, *supra* note 11.
[43] Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, 480 U.N.T.S. 43, entered into force October 10, 1963.

activities, and supporting innovation and sustainability among their participating states. The ESA has developed its own Sustainability Principles and, as previously noted, its Green Agenda is designed to ensure that future ESA programmes contribute to sustainability goals and reduce any negative impact on the environment.[44] ESA is a central player in the European Cooperation for Space Standardisation (ECSS),[45] which also includes industry and agency members, including the UK Space Agency. The ECSS develops non-binding standards for the space industry in order to facilitate interoperability and enhance quality. ECSS standards with a focus on sustainability focus on space debris and planetary protection.

The EU is an increasingly important player in the European space field, with competence under Article 189 of the Treaty on the Functioning of the European Union to develop its own space policy. Article 189 authorises the EU to engage in joint space activities with its Member States; to adopt supporting measures, excluding harmonisation of national laws; and to establish 'appropriate relations' with ESA. The European Space Programme has well-established earth observation and geostationary satellite navigation and positioning services, and is developing initiatives in relation to space traffic management and the provision of secure satellite connectivity to protect critical infrastructures.[46]

States also enter into strategic agreements among themselves, on a bilateral or multilateral basis, in order to enhance co-operation and/or commit to basic standards when undertaking space development. The UK-Australia Space Bridge, for example, supports activities that assist in tackling climate change, while agreements such as the Artemis Accords commit to mitigating and limiting additional space debris and protecting the space heritage.[47]

Ultimately, international commitments and standards, however important and desirable, require implementing measures if binding obligations are to be created in the UK. The key space-related UK statutes are the Outer Space Act 1986 and the Space Industry Act 2018. Space launch and flight operations, which require a licence, are overseen by the space regulatory authority, the Civil Aviation Authority (CAA). The CAA has established licensing terms and accompanying guidance, including a number of sustainability and safety related provisions (domestic statutory and regulatory provisions are detailed further at 7 below). Non-space specific environmental and heritage-related concerns are similarly protected through national legislation, with certain matters devolved to the nations or even local level, for instance, as part of the planning process for industrial (eg launch site) development.

Finally, industry itself is contributing to the development of voluntary standards relevant for the space industry at UK and international levels, notably through the BS and ISO standards. Adherence to these standards can help to establish compliance with specific licensing conditions.

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[44] For details on these policy initiatives, see ESA at: ESA - Responsibility & Sustainability.
[45] See ECSS at: https://ecss.nl/.
[46] For details, see EU Space Programme: EU Space Programme (europa.eu).
[47] For details of the UK-Australia Space Bridge, see UK Space Agency, "Successful First Year for UK-Australia Space Bridge", 23 February 2022, at: Successful first year for UK-Australia Space Bridge - GOV.UK (www.gov.uk). The Artemis Accords, sections 9 & 12, signed 13 October 2020, can be accessed at: Artemis-Accords-signed-13Oct2020.pdf (nasa.gov).

In order to understand the legal and regulatory framework applicable across the whole life-cycle of space activities we consequently need to take into account the subtle interplay between international and industry initiatives, on the one hand, and national law and regulation on the other.

5. International Treaty Law

a) Space specific

Article IX of the Outer Space Treaty outlines the fundamental and general obligations for the preservation of the space environment.[48] Article IX obligations require states to carry out activities within their jurisdiction and control without causing environmental damage to other states or in areas beyond national jurisdiction, such as outer space. Equally, Art. VII of the Moon Agreement requires State Parties to preserve the environment throughout their exploration and use of the moon, and carry out their activities with the least possible disturbance or harmful consequences to the current balance of the environment.[49] Member States must therefore avoid potentially harmful interference and contamination, such as toxic fallout from rocket emissions and satellite propellants.

b) Environmental law

A range of environmental regulations apply to space activities. For example, the Convention on Long-Range Transboundary Air Pollution[50] regulates "air pollution whose physical origin is situated wholly or in part within the area under the national jurisdiction of one State and which has adverse effects in the area under the jurisdiction of another State at such a distance that it is not generally possible to distinguish the contribution of individual emission sources or groups of sources." The 2012 amendments to the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol) to the Convention on Long-range Transboundary Air Pollution introduces commitments for Parties (including the UK) to reduce emissions of volatile organic compounds, including black carbon, a common pollutant of rocket launches, which is considered a fine particulate matter to be abated.

Similar risks are identified for satellite thrusters. Hazardous mercury is one of the cheapest and easiest to store propellants for satellite electric propulsion. Considering the risk that mercury could return to Earth if used as a satellite propellant, the precautionary approach has been adopted to phase out the use of mercury as a satellite propellant under international environmental law. In 2022, at the Fourth Meeting of the Conference of the Parties to the Minamata Convention on

[48] Sergio Marchisio, "Article IX" in S Hobe, B Schmidt-Tedd & K-U Schrogl (eds), *Cologne Commentary on Space Law*, vol 1, Carl Heymanns Verlag, 2009, p. 175.
[49] Agreement Governing the Activities of States on The Moon and Other Celestial Bodies Dec. 5, 1979, 1363 U.N.T.S. 3, at: https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/moon-agreement.html.
[50] Convention on Long-Range Transboundary Air Pollution, 13 November 1979 1302 UNTS 217, 18 ILM 1442.

Mercury, a provision was adopted to phase out the use of mercury by 2025.[51] As exemplified by the Mercury ban, there is growing regime convergence between outer space law and international environmental law.

6. International soft law and guidance

Various soft law mechanisms address the environmental impact of space activities. One non space-specific guideline, which is designed to assess the life cycle impact of manufactured products, is I.S.O. standard 14062 (2002), which requires environmental impact assessment of all products at any stage, whether raw material acquisition, manufacture, distribution, use, or disposal.[52]

Turning to space-specific guidelines, the European Space Agency (ESA) has set a prime example by combining a life cycle assessment method with an eco-design approach in its satellites. The main areas of concern for sustainable design relate to the satellite thruster and the power system (batteries and solar panels). The soft law approaches to sustainable satellite design and manufacturing is further explored below.

a) Satellite propulsion

ECSS-E-ST-35 Liquid and electric propulsion defines the regulatory aspects applicable to elements and processes for liquid, including cold gas, and electrical propulsion for spacecraft. It defines the environmental design and engineering aspects for fuels to not create hazardous particles. Pursuant ECSS-E-ST-35 4.5.9(b), filters shall be installed immediately downstream of potential particle generating components and directly upstream of components sensitive to pollution or contamination. Equally important is the re-launch leak test, performed to authorize fuelling, which illustrates a preventive approach to harm caused by pollution.[53] The UK Space Agency National Propulsion Test Facility, open in 2021, follows the ECSS standards of the ESA. The ESA commissioned, reviewed the design and implementation phases of the facility, which is in charge of simulating high altitude testing of thrusters, and prevent future pollution of the atmosphere by satellite propellants.

b) Responsible Manufacturing of Lithium-Ion Batteries (LIB)

ECSS-Q-ST-60C (July 2008) EEE and ECSS-E-ST-20C Rev.2 (April 2022) set standards for the responsible manufacturing of LIBs for space activities. Manufacturers must first assess the risk entailed by the hazardous nature of battery technologies used aboard spacecraft. High current short-circuits may provoke wider damage to the spacecraft and ultimately provoke space debris. Internal pressure may vent the cells' contents, in extreme cases explosively. The electrolyte, cell

[51] Minamata Convention on Mercury, 10 October 2013, entered into force 16 August 2017, UNTS 3202, Annex B on the phase-out of mercury-added propellant for satellites.
[52] See International Organization for Standardization, "ISO/TR 14062:2002, Environmental management – Integrating environmental aspects into product design and development", at: https://www.iso.org/standard/33020.html.
[53] See ECSS-E-ST-10-03C Rev.1 (31 May 2022) - Space Engineering Testing, 7(b).

reactants, and/or reaction products expelled can be corrosive (e.g. alkaline cells, lithium-SO2, Lithium SOCl2), flammable (e.g. lithium cell organic electrolytes) or toxic endangering any nearby personnel as well as neighbouring equipment.

Design of the battery shall preclude over-temperature, excessive currents including short circuit, overcharging, over discharge and cell leakage. Battery product assurance requirements are applicable to prime contractor, subcontractors and suppliers: A DCL or "Declared Components List" must be established to check component conformity. Prohibited hazardous toxic substances include "beryllium oxide (except if identified in the procurement specification), cadmium, magnesium, mercury, zinc, radioactive material and all material which may cause safety hazard." In other words, the battery manufacturing requirements *may authorize use of hazardous components* as long as these components are disclosed in procurement specification.[54]

c) Responsible Sourcing of Solar Panel Raw Materials

Bauxite is a raw source of solar panel manufacturing. Solar panel semi-conductors are multi-junction cells made of indium gallium phosphide. Bauxite is extracted as a source of indium gallium in Ghana and elsewhere. The UK imposes transparent reporting obligations under Section 54(4) of the UK Modern Slavery Act of 2015.[55] Additionally, the UK aims to create a more circular economy for critical minerals to both reduce waste and reduce pressures on suppliers. Rules for the responsible sourcing of space manufacturing materials may also be found in the OECD Guidelines for responsible supply chain of minerals, which recommend due diligence reporting, identification of risks, verification of extraction and refining outside of war zones.[56] Finally, the United Nations Framework Classification establishes a global system for responsible management and development of mineral and energy resources. This classification is designed to ensure sustainable management of all mineral and energy resources.[57]

7. UK domestic law

This section provides a brief overview of the UK regulatory framework relevant to sustainability and environmental matters in the manufacture and launching of satellites within the UK. The first part focuses on those laws and regulations specifically created for the space industry, while the second part is a compilation of regulations which, while not directly targeting the space industry, may be of consequence. The third part includes recent legislation and policies, highlighting what might be of upcoming relevance.

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54 See Henri Boullier & Emmanuel Henry, "Toxic Ignorance. How Regulatory Procedures and Industrial Knowledge Jeopardise the Risk Assessment of Chemicals", 2022 *Science as Culture* 1.

55 UK Modern Slavery Act 2015, Part 6, Section 54, at: https://www.legislation.gov.uk/ukpga/2015/30/section/54/enacted.

56 OECD, "OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas", OECD Publishing, Paris, 2016 at: http://dx.doi.org/10.1787/9789264252479-en.

57 United Nations Economic Commission for Europe, "United Nations Framework Classification for Resources", at: United Nations Framework Classification for Resources (UNFC) | UNECE.

The UK actively promotes the implementation of the COPUOS Guidelines on the Long Term Sustainability of Outer Space Activities and in June 2022 the government announced a package of measures designed to 'make the UK a world leader in space sustainability'.[58] This includes the development of a new space sustainability standard and review of potential regulatory initiatives designed to incentivise industry to adopt sustainable practices. Envisaged benefits that could drive the adoption of such practices are reduced costs of launch licences and insurance.

a) Space Industry Specific Regulation

Environment Impact Assessment and Space Debris Mitigation

There are two main statutes that regulate the UK space industry, the Outer Space Act 1986 ('OSA 1986') and the Space Industry Act 2018 ('SIA 2018'), with several accompanying secondary pieces of legislation.[59] Following enactment of the Space Industry Act 2018, the scope of the OSA 1986 was limited to space activities undertaken by UK entities outside the UK, while the SIA 2018 is applicable to space activities occurring within UK territory, thus being the most relevant statute for this research.

The SIA 2018 essentially establishes a licensing regime for (i) operators (i.e. to carry out spaceflight activities e.g. launch operators, return operator, and orbital operator),[60] (ii) operating a spaceport,[61] and (iii) range control.[62]

The only direct reference to environmental considerations in the SIA 2018 is found in section 11, which requires that a licence applicant for a spaceport or operator licence submits an assessment of the environmental effects ('AEE') of the activities for which they seek to obtain a licence.[63] The AEE is a factor considered by the regulator, the CAA, when deciding whether or not to grant a licence,[64] and may lead to the CAA attaching certain conditions when granting a licence.[65] Particular conditions that may be included in a licence can be found in Schedule 1 of the SIA 2018, notably compliance with space debris mitigation guidelines.[66] The CAA considers a sustainable activity (or mission) to be 'one that meets the requirements of the present without

58 UK Government, "Government announces package of new measures to drive space sustainability", press release, 23 June 2022, at: Government announces package of new measures to drive space sustainability - GOV.UK (www.gov.uk)
59 Not all appear relevant to sustainability or the environment but for the purpose of completeness, these are: Space Industry Regulations 2021, Space Industry (Appeals) Regulations 2021, Spaceflight Activities (Investigation of Spaceflight Accidents) Regulations 2021, and the Contracting Out (Functions in Relation to Space) Order 2021.
60 SIA 2018, s.3.
61 SIA 2018, s.3(2).
62 CAA, "Applying for a licence under the Space Industry Act 2018" (2021), CAP 2210, at: https://publicapps.caa.co.uk/docs/33/Applying%20for%20a%20licence%20under%20the%20Space%20Industry%20Act%202018%20(CAP2209)%20(1).pdf.
63 SIA 2018, s.11(2) & s.11(3).
64 *Ibid*, s.11(5).
65 *Ibid*, s.11(5)(b) & s.13.
66 *Ibid*, Schedule 1 s.1(g) & s.5.

compromising the ability of subsequent generations to embark on activities (or missions) to meet their own requirements in the future'.[67]

The UK government has published guidance on how an AEE should be completed and what it may include, depending on the type of licence sought.[68] The guidance states that the AEE must consider the direct or indirect effects of the proposed spaceflight activity in relation to the following environmental features:

- population and human health
- biodiversity (for example, ecology, flora and fauna)
- air quality
- noise and vibration
- water (for example, quantity and quality)
- marine environment
- climate (for example, greenhouse gas emissions, impacts relevant to adaption)
- land, soils and peat
- landscape and visual impact material assets and cultural heritage (including architectural and archaeological aspects)[69]

The effects considered include those arising from accidents or disasters that could occur during, or as a result of, the proposed activities.[70]

In completing the AEE, applicants may find the Mitigation Hierarchy Guide, a tool designed to help limit the negative environmental impacts of development projects, useful.[71] The guide establishes a structured framework for considering actions that can avoid, minimise, restore, and offset damage.

In addition, the CAA guidance published for orbital operator licence applicants and licensees presents a non-exhaustive list of best practice standards, which includes a reference to the IADC Space Debris Mitigation Guidelines, the European Code of Conduct for Space Debris Mitigation, and the Space Debris Mitigation Guidelines of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space.[72] Further sustainability standards can be incorporated into the assessment process for granting licences by the CAA over time.

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[67] CAA, 'Applying for a licence under the Space Industry Act 2018'(2021), CAP 2210, para.5.10, at: https://publicapps.caa.co.uk/docs/33/Applying%20for%20a%20licence%20under%20the%20Space%20Industry%20Act%202018%20(CAP2209)%20(1).pdf.

[68] UK Government, "Guidance for the assessment of environmental effects", at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904454/guidance-for-the-assessment-of-environmental-effects..pdf.

[69] *Ibid*, p.15.

[70] *Ibid.*

[71] The Biodiversity Consultancy, 'A cross-sector guide for implementing the Mitigation Hierarchy' (2015) at: <http://www.csbi.org.uk/wp-content/uploads/2017/10/CSBI-Mitigation-Hierarchy-Guide.pdf> accessed 10 August 2022.

[72] CAA, 'Guidance for Orbital Operator licence applicants and orbital Operator Licenses' (2021) <https://publicapps.caa.co.uk/docs/33/Guidance%20for%20Orbital%20Operator%20licence%20applicants%20and%20Orbital%20Operator%20Licensees%20(CAP2210).pdf> accessed 9 August 2022, Annex A.

Human Resources Requirements

In order to reduce the risk of accidents, which apart from injury could have environmental consequences, the CAA requires the operators of launch, return and range control licences, to have in place training programmes that comply with standards established by the Space Industry Regulations 2021.[73]

Waste management – Solar Panels and Batteries

In the UK, electrical and electronic equipment ('EEE') is regulated to reduce the amount of waste that is destroyed or sent to landfills. The Waste Electrical and Electronic Equipment Regulations 2013 (as amended) ('WEEE') place obligations on producers, importers, distributors, and resellers of EEE to register as producers or join a producer compliance scheme depending on the amount of EEE they place on the UK market. The WEEE regulations include measures for the reuse, treatment, and recovery of EEE,[74] but regulation 8 explicitly excludes from regulation equipment designed to be sent into space.[75]

b) General Environmental Regulation

A number of environmental laws and regulations that are not targeted specifically at space activities may be applicable to certain space related manufacturing processes or launch activities. These include:

- Clean Air Act 1933. The act aims to improve air quality standards in respect of sulphur dioxide and fine particles. It prohibits the emission of dark smoke.[76]
- Environmental Protection Act 1990. A statutory nuisance can be caused by emitting any dust or effluvia from any trade or business premises, or smoke, fumes or gases from premises, that are prejudicial to health or a nuisance. For a nuisance action to succeed the offence must cause material harm, be persistent, or likely to recur. Nuisances may include smoke from bonfires, unpleasant odours, grit, and dust.[77]
- The Greenhouse Gas Emissions Trading Scheme Order 2020. This establishes a trading scheme that aims to limit, or encourage the limitation of, the emission of greenhouse gases of regulated activities by operators of installations and aviation activities by aircraft operators.[78]

[73] CAA, 'Training Requirements' <https://www.caa.co.uk/space/guidance-and-resources/training-requirements/> accessed 9 August 2022. See also: Space Industry Regulations 2021, Reg 69(4) to 69(7), 188 and 190.
[74] Waste Electrical and Electronic Equipment Regulations 2013 (as amended), Regs.30-32.
[75] *Ibid*, Reg 8(a).
[76] Clean Air Act 1933, s.2.
[77] Environmental Protection Act 1990, Part III.
[78] The Greenhouse Gas Emissions Trading Scheme Order 2020, 16.

- UK National Emissions Ceilings Regulations 2018. The regulations impose reporting duties on the government relating to the emission or concentration of particulate matter, nitrogen oxides, ammonia, non-methane volatile organic compounds, and sulphur dioxide, as well as emission reduction commitments.[79]

- Environmental Permitting (England and Wales) Regulations 2016 and The Environmental Authorisations (Scotland) Regulations 2018. These measures regulate waste pollution from industrial installations. Rule-making authorities can set standard rules to regulate a facility,[80] and have powers to prevent or remedy pollution.[81] Satellite manufacturing sites that fall under the regulated facility interpretation because they carry out certain specified activities,[82] will require an environmental permit to operate.[83]

- Environmental Noise (England) Regulations 2006 and Environmental Noise (Scotland) Regulations 2006: These regulations apply to environmental noise, mainly for transport and especially road, rail, and aviation and noise in large urban areas. Noise can also be a statutory nuisance under the Environmental Protections Act 1990, listed above.

- The Control of Major Accident Hazards Regulations 1999, together with specific guidance on safety and environmental standards for fuel storage sites (see also below).[84] The regulations aim to reduce the risk to the public from sites that store and use a range of hazardous chemicals. The list of dangerous substances to which the regulations apply and qualifying quantities are set out in Schedule 1.

- Storing Oil/Fuel. There are different statutes for different parts of the UK on how oil should be stored. These are: The Control of Pollution (Oil Storage) (England) Regulations 2001, The Water Environment (Oil Storage) (Scotland) Regulations 2006, The Control of Pollution (Oil Storage) Regulations (Northern Ireland) 2010, Guidance on the Water Resources (Control of Pollution) (Oil Storage) (Wales) Regulations 2016. Requirements relate to matters such as the structural integrity of the container, its capacity etc. If the satellite manufacturer is using hydrazine-based fuel, which is the

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[79] The National Emissions Ceilings Regulations 2018; Department for Environment, Food & Rural Affairs, "Emissions of air pollutants in the UK –Background" (2022) at: https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-background.
[80] Environmental Permitting (England and Wales) Regulations 2016, Reg 26.
[81] *Ibid*, Reg 57.
[82] *Ibid*, Reg 8 and Schedule 1. Most of these activities are unlikely to be relevant but there is reference to, for example, the use of certain listed substances (eg gallium and platinum) so that the schedule should be reviewed for applicability.
[83] *Ibid*, Reg 12.
[84] Health and Safety Executive, "Safety and environmental standards for fuel storage sites" (2009), at: https://www.hse.gov.uk/comah/buncefield/fuel-storage-sites.pdf.

current standard propellant for satellites,[85] there is some guidance on how this is to be handled, particularly in relation to work safety.[86]

c) New and future regulatory initiatives

This part discusses a number of recent measures and policies/initiatives pursued by the UK, which could be relevant for future satellite activities.

- Environment Act 2021. The Act extends producer responsibility to require producers to pay the full net cost of managing their products at end of life, incentivising them to design their products with sustainability in mind or pay the cost for disposal.[87] If applied to satellite manufacturing this could, for example, impose certain obligations regarding how those parts of the satellite that do not burn up on re-entry are disposed of. More generally, the Act requires the introduction of further long-term measures, with legally binding targets, in at least one of the following areas: water, air quality, biodiversity, and waste.[88] There is also a specific short-term target to reduce fine particulate matter in ambient air,[89] which could have ramifications for future satellite launches given the activity's contribution to this matter.

- Energy Bill 2022 – 2023. The proposed Energy Bill's most relevant aim concerns the promotion of further investment in low-carbon industries, as a step towards decarbonisation and greater sustainability. The Bill also introduces business models for the transport and storage elements of carbon capture usage and storage (CCUS) projects and industrial carbon capture. The Bill is at an early stage, having been introduced in July 2022, so its final form and impact is yet to be determined.

- Resource and Waste Strategy for England: This is an attempt to explore how companies can be asked to report on reuse, repair, and recycling of their resource usage.[90] The relevant metrics have yet to be developed but eventually this strategy may result in new reporting duties.

- Rare Earth Metals Strategy: No regulation could be found in relation to rare earth metals but there is a UK strategy. The UK has projects in lithium, tin and tungsten extraction, and growing capabilities for refining several other critical minerals. The UK aims to create a more circular economy for critical minerals to both reduce waste and

85 Kelly Oakes, "Making satellites safer: the search for new propellants" (*Horizon*, 2020), at: https://ec.europa.eu/research-and-innovation/en/horizon-magazine/making-satellites-safer-search-new-propellants.
86 Public Health England, "Hydrazine Incident Management", at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/566781/hydrazine_incident_management.pdf.
87 Environment Act 2021, ss.50-51.
88 *Ibid*, s.1.
89 *Ibid*.
90 UK Government, "Our Waste, Our Resources: A strategy for England" (2018) at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/765914/resources-waste-strategy-dec-2018.pdf.

reduce pressures on suppliers, which could lead to implementing measures in the future.[91]

- Dark Sky Policy Plan: The All-Party Parliamentary Group for Dark skies produced a policy paper following an extensive consultation on how to address light pollution through new initiatives.[92] So far, however, the focus is on light pollution from earthly infrastructure and installations rather than that caused by satellites.

Apart from the Dark Sky policy, these initiatives fall under the more general aims of developing a Circular Economy. The Waste (Circular Economy) (Amendment) Regulations 2020 (SI 2020/904) transposed the legislative aspects of the EU's 2020 Circular Economy Package in England and Wales. The Scottish Government is currently consulting over a proposed Circular Economy Bill.[93] The British Standards Institute ('BSI') states that BS 8001 is the first practical framework and guidance on the circular economy and has been written in such a way that it can be used anywhere in the world. It is intended to apply to any organisation, regardless of location, size, sector, and type.[94] This could be a point of reference when considering how best to build a circular economy commitment into satellite manufacturing and launch.

It is apparent from the above research that the UK government and devolved nations are committed to addressing sustainability concerns and are beginning to build policies to support the challenging reorientation to a circular economy. In relation to space activities, this has to date been primarily recognised by the inclusion of an AEE in satellite licensing applications, but there is scope to broaden the focus here beyond launch and operation, with the present, understandable, focus on space debris. A wider perspective at the licensing stage would create a powerful incentive for companies to begin to consider sustainability early in the satellite life cycle, from design, manufacture and sourcing to ultimate end of life. A broader range of sustainability standards could also be included in CAA guidance for licence applicants, possibly incorporating future standards envisaged in the June 2022 Government announcement of a package of new space sustainability initiatives. Non-space-industry specific environmental regulation has in the past largely derived from the EU, with planning requirements and control of small particle emission pollution caused by the launch of satellites being potentially the most relevant. In the future, further regulation to align these activities with the circular economy can be

[91] Department for Business, Energy & Industrial Strategy, "Policy Paper: Resilience for the Future: The UK's critical minerals strategy" (2022) at: https://www.gov.uk/government/publications/uk-critical-mineral-strategy/resilience-for-the-future-the-uks-critical-minerals-strategy.
[92] All-Party Parliamentary Group, "Ten Dark Sky Policies for the Government" (2020), at: https://static1.squarespace.com/static/5e567fb65a380a76eb3c8133/t/60c72d0311d31c3137515f31/1623665931233/APPG+for+Dark+Skies+-+10+dark+sky+policies.pdf.
[93] Scottish Government, "Delivering Scotland's Circular Economy - Proposed Circular Economy Bill" Consultation, 30 May 2022, at: https://www.gov.scot/publications/delivering-scotlands-circular-economy-consultation-proposals-circular-economy-bill/.
[94] BSI, "The rise of the Circular Economy: BS 8001 - A new standard is available", at: https://www.bsigroup.com/en-GB/standards/benefits-of-using-standards/becoming-more-sustainable-with-standards/BS8001-Circular-Economy/.

envisaged, but to date the regulatory framework in the environmental field is complex and its application to/relevance for the space sector is not always clear.

8. Toolkit interface and design

Taking the challenges and opportunities of Interstellar Space Technologies as the example case

With the tasks and activities identified at the pre-launch stage, we customised the design with 4 types of projects – Design, Satellite Preparation, Manufacturing and Journey to Launch. As shown in Figure 1, Mohit Joshi (CEO of Interstellar Space Technologies) can manage the project currently running in his company with the support of toolkit. As the business grows with these projects proceed, he can freely manage them by adding and removing sections. Moreover, the sharing function is to allow businesses to exchange project information for collaboration.

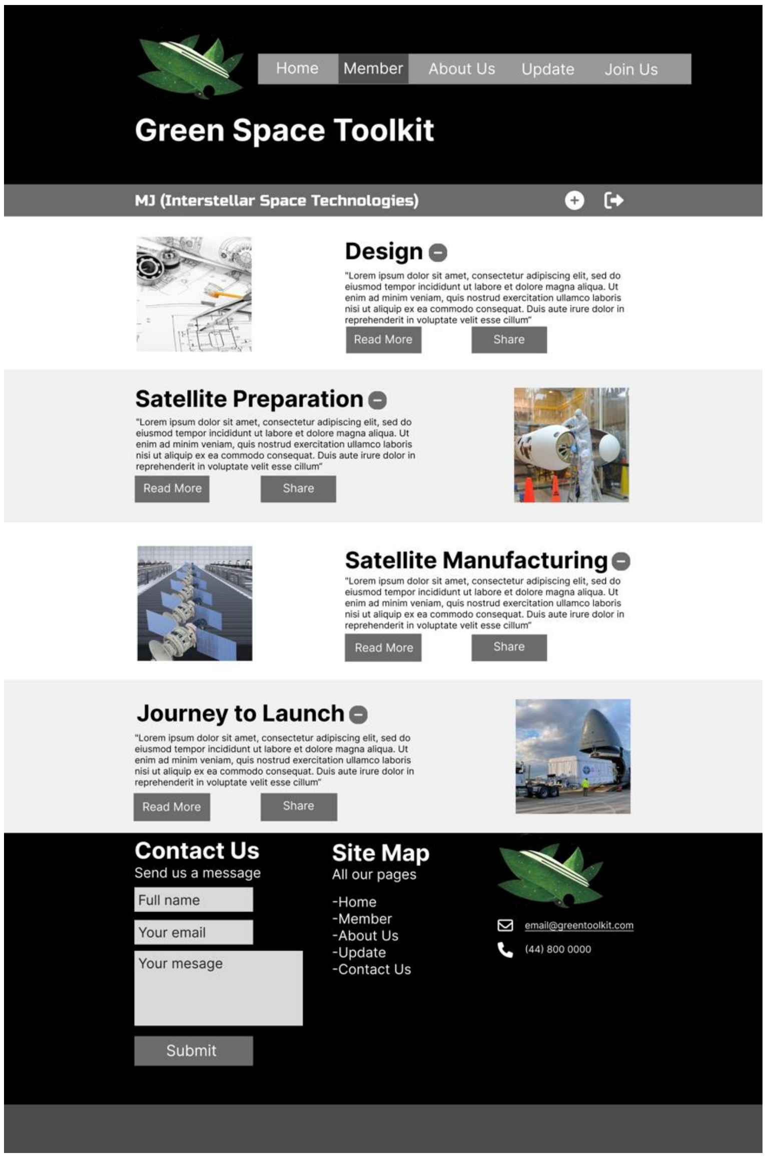

Figure 1: The profile page allowing SMEs to edit atomic projects in the lifecycle

To further edit and read the legal requirements, risks and opportunities of being more sustainable, Mohit can simply click "Read More" button. For instance, Figure 2 shows the "Preparation" page which depicts elements contained. As per the requirements, Mohit can select the specific types of components. In the example, we show the batteries selected has risks (red) and legal requirements (green) matched out in the system.

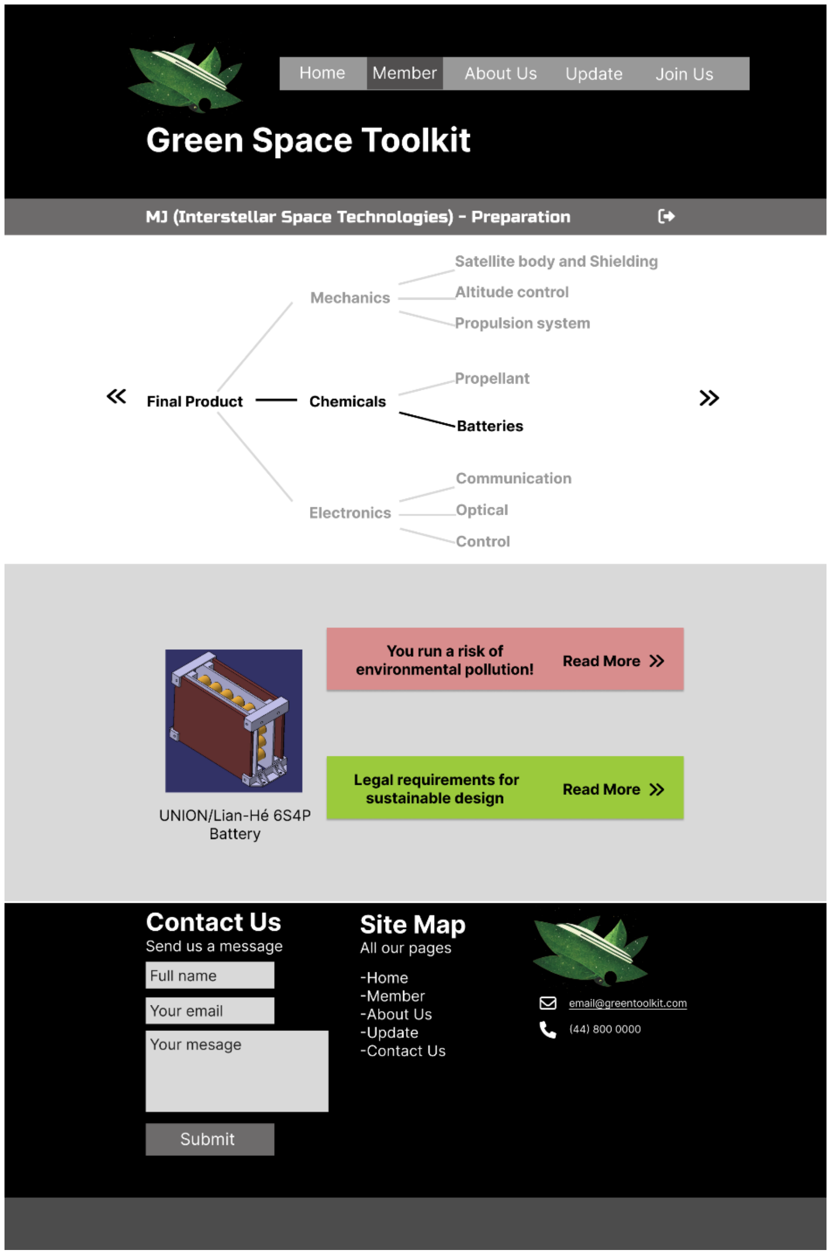

Figure 2: The project page (#Preparation of batteries)

The user can expand the sections to read more detail. Figures 3.1 and 3.2 shows the expanded texts of these two

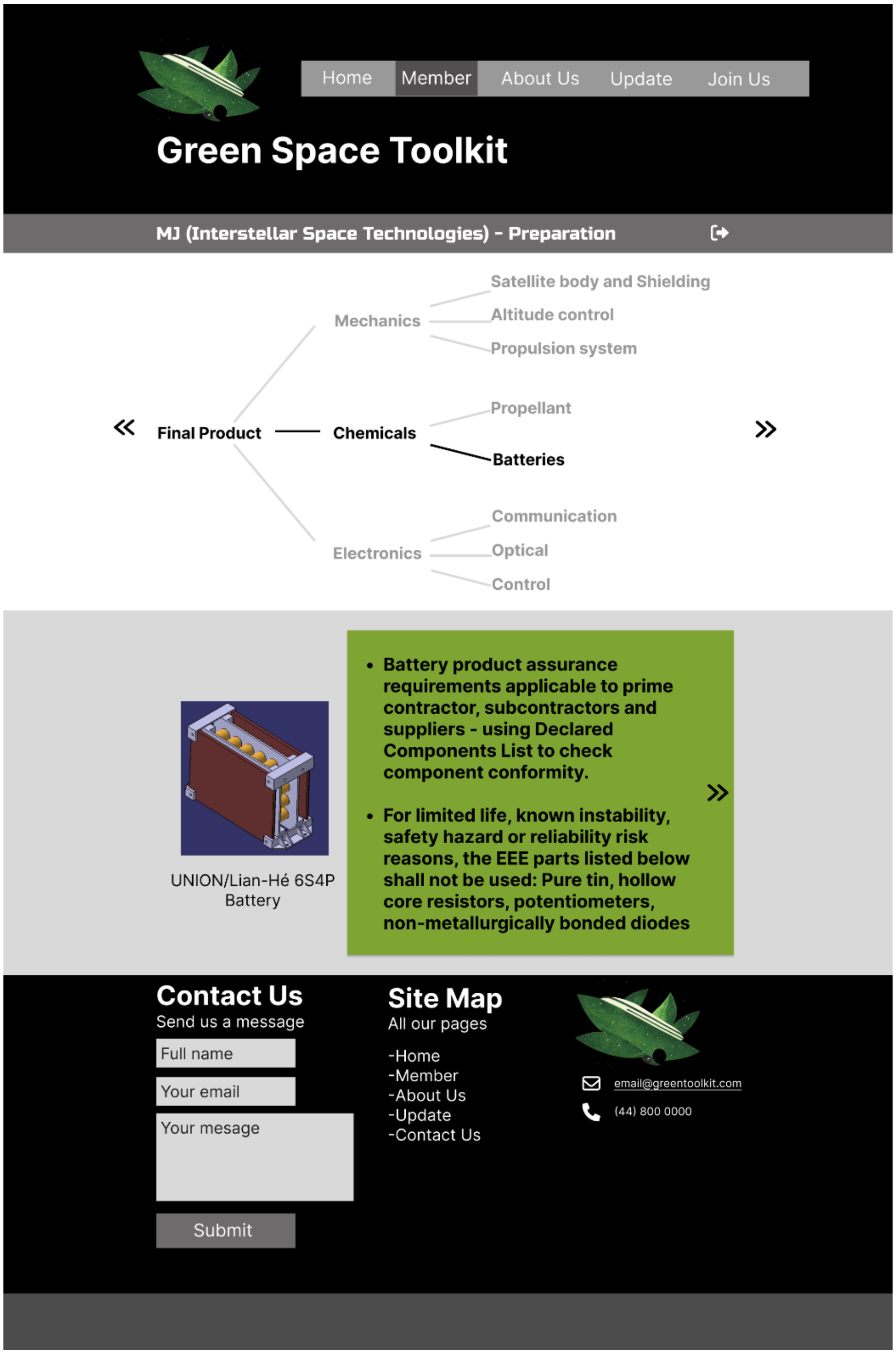

Figure 3.1: Expanding sections (#Preparation of batteries), Legal requirements (expanded)

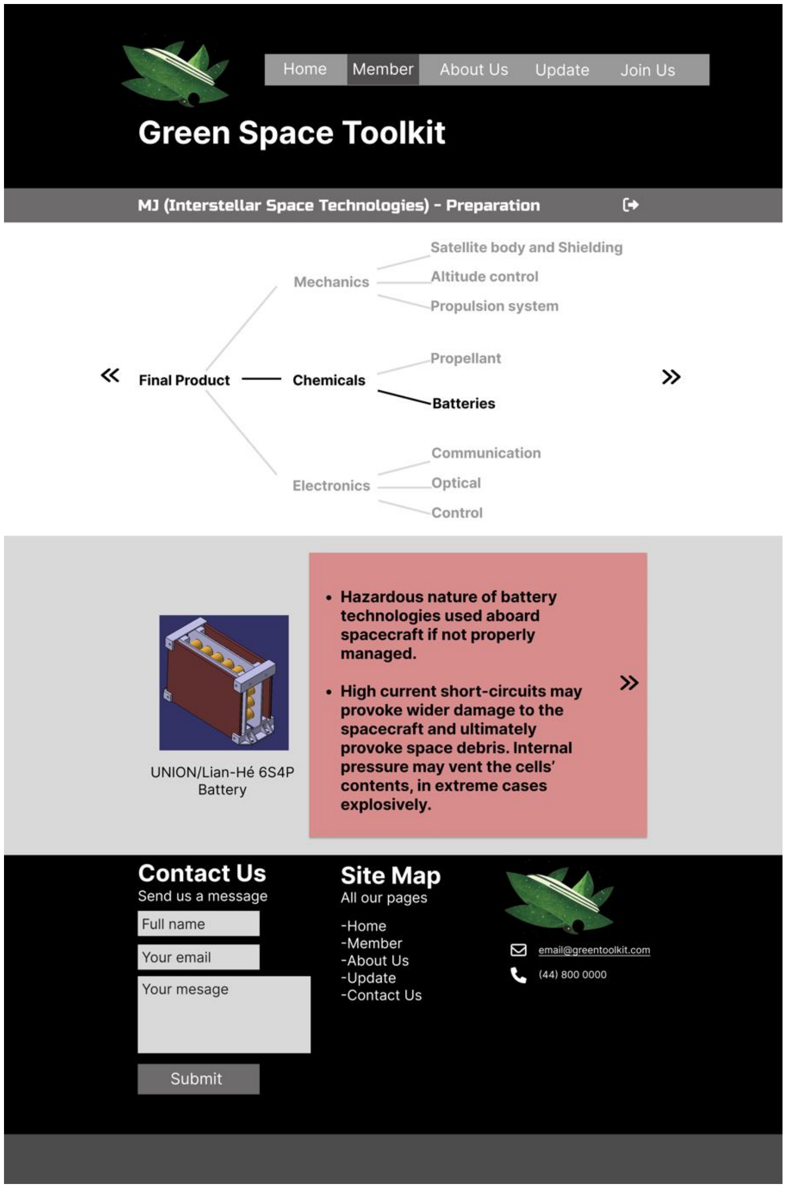

Figure 3.2: Expanding sections (#Preparation of batteries), Risks of generating pollutions (expanded)

In addition to the requirements and risks, our toolkit features a third category of contents – innovative design of sustainable space. Taking the propellant filter as the example, we marked these options in amber as shown in Figure 4. By taking these options, we expect more and more SMEs and practitioners are acknowledged with knowledge and good practices, building a sustainable future together.

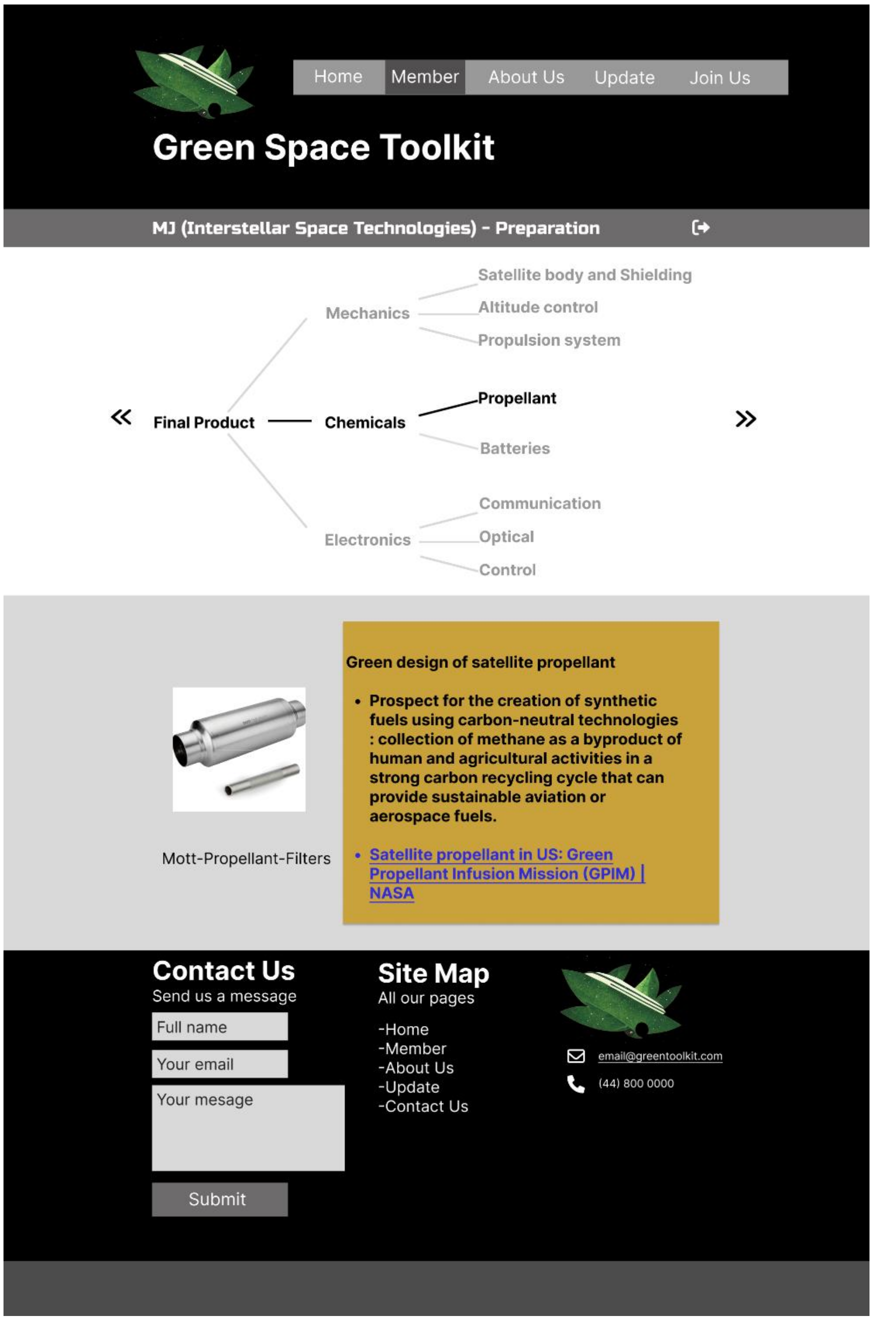

Figure 4 Opportunities of sustainable design (Preparation of Propellant)

9. Final Comments

During the course of the Green Toolkit project the participants met on a regular basis online and, despite travel disruption, in person at the Space Sustainability Summit in London on the 22-23 June 2022. As part of the project, a small workshop was organised at the University of Edinburgh Bayes Centre to present early findings and obtain initial feedback from those working in, or advising, industry. We are once again grateful to Kristina Tamane (Space Sector Business Development Lead University of Edinburgh, Co-Chair of Environmental Task Force at Space Scotland); Derek Harris (Skyrora); Luke Vanstone (STFC UKRI) and Daniel Ridley (HyImpulse UK Ltd.)

Kristina Tamane opened the workshop with a presentation on the development of sustainability policies in Scotland. Matthias Wong then explored different aspects of sustainability, in particular the cultural and social aspects, often overlooked but pertinent even in the context of space activities. Rachael Craufurd Smith considered the relationship between the Green Toolkit and other sustainability and ranking services. Michael Picard and Rajeshwari Suryakanth Nagamarpalli outlined key regulatory and legal measures designed to support sustainability at international and domestic levels and their relevance for specific satellite components, such as batteries. Finally, Yang Lu considered the challenges and opportunities involved in designing an 'intuitive sustainability platform for industry', providing an initial example of what the proposed platform currently looks like and how users can focus on specific issues arising across the whole satellite life cycle.

We received thoughtful and supportive input from those attending. There was general agreement that legal and regulatory information was quite fragmented. Particularly for smes working at different points in the satellite life cycle a centralised guide, with granular information on matters such as materials used in solar panels or batteries, their environmental impact, and procurement options, with links to relevant guidance, could be extremely helpful. A key suggestion was to build into the platform a facility for comments and exchange of information from industry and other users. As noted previously, this would enable concerns, new information, and good practice to be shared. Commercial confidentiality and accuracy of the information were also considered important matters requiring further attention. The former can partly be addressed through platform architecture, while the latter will require the development of a clear and transparent policy regarding the resources that can be used.

After the workshop, further refinements were made to the Green Toolkit platform and this scoping Green Paper. Ultimately, it is intended that the information in the Green Paper, setting out relevant laws, regulations, voluntary standards, guidance and policy, will be used to refine and populate information on a unified Green Toolkit platform. That is the next step.

For more information and latest updates, please visit our project website at https://bit.ly/toolkitforspace