Satellite battery life cycle
Risks and recommendations to satellite operators in the UK

Li-ion batteries (LIB) used in satellites are considered dangerous goods of Class 9 by the United Nations.[1] As dangerous goods, they require a full risk assessment, which includes all stages of design, sourcing, testing, operational life, demise and recovery.[2]

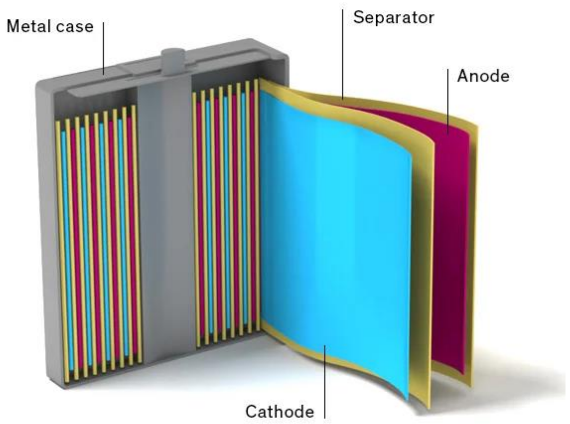
Our Green Toolkit offers an overview of the risks and recommendations for each stage of the battery's life. It provides guidance and identifies key standards that can be employed to determine:

- Whether your battery is safe, sustainable and fit for purpose
- Whether the operational use of your battery is safe and sustainable

Is the product safe, sustainable and fit for purpose?

Verify with your supplier that battery design and mineral sourcing conform to relevant safety and sustainability standards.

1. Design



Design risk

- Cathode material breakdown
- Thermal runaway producing explosion and fire
- Obsolescence

Recommendation: ***source sustainably designed batteries****, which*

- Follow ISO/ESA/NASA Declared Components List prohibiting hazardous toxic substances, i.e., pure tin, hollow core resistors, potentiometers, non-metallurgically bonded diodes, wire link fuses < 5A, beryllium oxide, cadmium, magnesium, mercury, zinc, radioactive material
- Preclude over-temperature, excessive currents, overcharging, over discharge, electrolyte leakage & thermal runaway
- Integrate three-dimensional cells with silicon wafers instead of foil
- Coat electrodes with metal oxides or nitrides (atomic layer deposition technique) for durability

[1] UN Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria Part III subsection 38.3: 'Miscellaneous dangerous goods' including UN 3090, Lithium metal batteries; UN 3480, Lithium-ion batteries; UN 3551, Sodium ion batteries with organic electrolyte.

[2] ISO Standard 14044:2006 Environmental management — Life cycle assessment; Wilson, Andrew R., et al. "Implementing life cycle sustainability assessment for improved space mission design." Integrated Environmental Assessment and Management 19.4 (2023): 1002-1022.

2. *Sourcing materials and minerals*

Batteries are typically made of lithium cobalt oxide, lithium nickel manganese cobalt oxide, or lithium nickel cobalt aluminum oxide[3]

Risks

1. Environmental degradation
2. Violation of international labour protection standards in mining areas

Recommendations

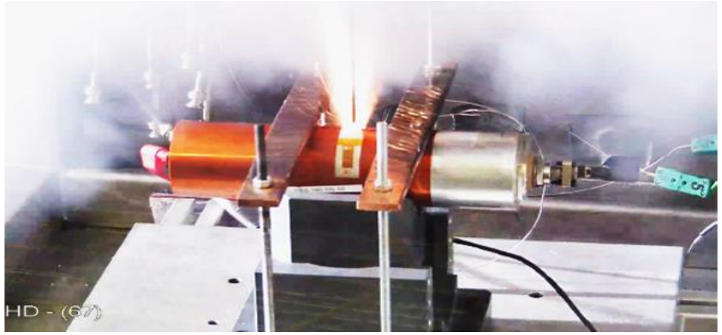
1. Partner with suppliers who sourced primary materials with a company certified by a third party for sustainable mining management
   Examples to follow:
   CRAFT Code
   https://www.craftmines.org/en/
   Aluminium certification
   https://aluminium-stewardship.org/asi-standards/performance-standard
   - Reuse or recycle, when possible, to reduce environmental footprint.
   - *Example: secondary-production aluminium only requires around 5% of the energy needed for primary production*
2. Make sure your supplier conforms to UK Modern Slavery Act 2015, United Nations Guiding Principles on Business and Human Rights, Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policies, OECD Guidelines for Multinational Enterprises & OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (OECD Guidance)
   a. Implement procedures, such as import controls, to avoid sourcing minerals from regions known to be high-risk or conflict-affected.
   b. Require battery suppliers to complete a self-assessment on geographic origins of their minerals, the sourcing practices they follow, and the measures they have in place to prevent forced labour.
   c. Subject high-risk suppliers in conflict-affected regions to independent third-party audits
   d. Request chain-of-custody documentation or certifications, which verify ethical sourcing.
   e. Give high-risk suppliers who fail to meet these standards a defined period to comply or face contract termination.

[3] Tembo, P. M., C. Dyer, and V. Subramanian. "Lithium-ion battery recycling—a review of the material supply and policy infrastructure." *NPG Asia Materials* 16.1 (2024): 43.

Is the operational use of the product safe and sustainable?

Verify with your supplier if pre-launch testing was conducted. When operational, your battery must also be durable and avoid combustion. Finally, as an operator, have you thought of putting in place a demisability and recovery plan?

3. *Pre-launch testing*



Risk

- Battery failure endangers the entire space mission
- Damage to spacecraft in orbit creating space debris

Recommendations: ***check your battery provider***

- Carries out battery pack & cell safety engineering tests (radiation, wear-out, over-discharge, short-circuit, vent, burst, protective devices)[4]
- Performs battery failure and hypervelocity impact tests[5]
- Performs lifetime tests to determine the technology limitations and required battery sizing
- Evaluates battery current, voltage, and lifetime, end-of-discharge voltage, based on mission requirements[6]

[4] ECSS-E-HB-20-02A Li-ion battery testing handbook (October 2015).
[5] JSC 26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Material (April 2014).
[6] ISO 17546:2024– Space systems — Lithium-ion battery for space vehicles — Design and verification requirements, 6.2.7 Over-voltage portection.

4. *Operational life cycle*

Risk

- High current short-circuits may damage the spacecraft and provoke space debris.[7]
- Internal pressure may explode the cells' contents.
- The electrolyte expelled can be corrosive, flammable or toxic, endangering nearby equipment.

Recommendations

- *In-orbit venting prevents gas concentration[8]*
- *In-orbit cooling reduces thermal runaway*
- *Steel box protects robustness of electronics from orbital debris environment*

[7] ISO 17546:2024– Space systems — Lithium-ion battery for space vehicles — Design and verification requirements, E.5.4. Short-circuit.
[8] ISO 17546:2024– Space systems — Lithium-ion battery for space vehicles — Design and verification requirements, 6.2.11 Venting.

5. Demise & recovery

Risks

Risks of atmospheric pollution during ablation of spacecraft, including battery pack

Creation of space debris

Recommendations[9]

- Before decommissioning, passivate the battery by
  - 1) discharging as much as possible
  - 2) isolating the battery from the solar arrays to prevent any charging
  - 3) maintaining the battery temperature below the relevant safety thresholds
- Implement systems-level techniques to minimize heat, optimize heat transfer, lower melting point of battery pack, passivate battery
- 'Design for demise' recommendations consider re-entry shielding of cells
  - 48Ah Li-ion cells are anticipated to survive re-entry with >15J of KE at impact
  - Follow re-entry with LIB collection strategy for waste LIBs & increase their re-use and recyclability rate
- Design for dismantling, recycling and recovery: ensure access to repair and maintenance by allowing for reuse/recycling/repair of components when space object is recovered[10]

Conclusion: Three key indicators of good practice

Procuring batteries for satellite operations requires adherence to standards to ensure performance and safety, as well as compliance with transportation rules. Finally, ensure you source your batteries from a certified supplier.

1. Compliance with standards

ISO 17546:2024– *Space systems — Lithium-ion battery for space vehicles — Design and verification requirements*

Reproduced in BS ISO 17546:2024– *Space systems. Lithium-ion battery for space vehicles. Design and verification requirements*

This standard specifies the design and minimum verification requirements for lithium-ion rechargeable batteries, including lithium-ion polymer types, used in space vehicles. The standard addresses the entire lifecycle of the battery, from cell activation through fabrication, testing, storage, transportation, mission operation, and disposal. However, it does not cover recycling processes.

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[9] ECSS-Q-ST-60-15C Space Product Assurance Radiation Hardness Assurance–EEE Components 2012; ECSS-Q-ST-70-02C Space Product Assurance Thermal Vacuum Outgassing Test for the Screening of Space Materials 2008; ECSS-E-HB-20-02A Li-ion battery testing handbook (1 October 2015); JSC 66548, Requirements for Flight Certification and Acceptance of Commercial off the Shelf (Cots) Lithium-Ion (Li-Ion) Batteries (NASA); JSC 20793 Crewed Space Vehicle Battery Safety Requirements (NASA); ISO 17546:2024– Space systems — Lithium-ion battery for space vehicles — Design and verification requirements, 9.C Mission in Orbit and end life.

[10] UK Ecodesign for Energy-Related Products and Energy Information Regulations 2021, Schedule 19 Ecodesign requirements for electronic displays at: <https://www.legislation.gov.uk/uksi/2021/745/schedule/19/made>.

2. **Compliance with Transportation and Safety Regulations**

Lithium batteries are classified as dangerous goods, subject to strict transportation regulations. Ensure suppliers are knowledgeable about and comply with regulations such as those outlined by the International Air Transport Association (IATA) and the United Nations (UN), including proper shipping documentation and safety protocols.

- UN/DOT 38.3 standard ensures the safe transportation of lithium-ion and lithium-metal batteries
- US military MIL-STD-810 also provides guidance on Environmental Stress Testing, testing the durability of electronics by simulating harsh environmental conditions like temperature, shock, vibration, and more.

3. **Find a certified supplier**

By adhering to these standards above, battery manufacturers can ensure that batteries used in satellites are safe and reliable for the space environment.

- Examples in the UK: https://www.enersys.com/en-gb/products/batteries/absl/absl-li-ion-space-battery/