# Life Cycle Analysis

## Purpose

This Life Cycle Analysis (LCA) is designed to consider the lifetime impacts of a full-scale autonomous landmine sweeper, by evaluating embodied energy, construction wastes, consumables and transport wastes. A 1:5 ratio of small-scale to full-scale material mass is assumed.

## Construction Components

***APPENDIX*** *shows a full breakdown of the embodied energy in each component of the robot.*

The total embodied energy within the materials of the robot is 467MJ.

## Construction Waste

|  |  |  |
| --- | --- | --- |
| **Component** | **Mass** | **Main material constituents** |
| Packaging Material | 1kg | Polystyrene Foam, Cardboard |

## Lifetime Consumables

|  |  |  |
| --- | --- | --- |
| **Component** | **Usage rate** | **Main material constituents** |
| Paint | 3g per landmine | Paint |
| Electricity | 3.7wH per landmine | N/A |

Assuming a lifetime of 3 years, marking 200 landmines per year, total energy consumed is 8MJ, and total paint consumed is 1.8kg.

## Transport

It is assumed that all materials will be transported 5000km by road. This may be indicative of energy for greater transport distances, as a more energy efficient method, such as rail transport, may be used. Transport distance will vary greatly depending on the location that the robot is deployed. Secondary data suggests a range of 500 to 5000 kilojoules of energy is used to transport one tonne of cargo one kilometre by road freight (Fraser, Swaminathan, & Thompson, 1995)

|  |  |  |  |
| --- | --- | --- | --- |
| **Total Mass** | **Embodied Energy (J/kg-km)** | **Distance** | **Total Energy** |
| 3.77kg | 1000 | 5000km | 18.85MJ |

## Recyclable Components

|  |  |  |
| --- | --- | --- |
| **Recyclable Material** | **Mass** | **Reference** |
| Printed Circuit Board | 375g | (Ning, Lin, Hui, & McKay, 2017) |
| Aluminium | 580g | (Australian Aluminium Council LTD, 2020) |
| Plastics | 1045g | (SUEZ Australian and New Zealand, n.d.) |
| Rubber | 410g | (Conserve Energy Future, 2020) |
| Copper | 35g | (Liu, et al., 2020) |
| Total: | 2445g |  |

## Non-Recyclable Components

|  |  |
| --- | --- |
| Lithium Polymer | 295g |

From this, approximately 90% of the components in the robot, by mass, can be recycled.

A diagram showing material and energy flow over the lifetime of the robot is provided in ***APPENDIX***.

## Discussion

The full-scale LCA is based on a 1:5 scale up of the prototype. Real-world scale-up values may differ. For example, the driveline components may be changed so that a higher voltage motor and battery can be used, to increase performance. The LCA will need to be re-calculated based on the considerations of a thorough full-scale design, however this should be indicative of the basic lifecycle impacts.

The robot is made up of 90% recyclable components by mass, which can help to decrease its long-term impact, however the battery is not recyclable, and may be difficult to dispose of.

By mass, plastic is the main material used in robot construction. This is more difficult to recycle than some other materials, like metals or biodegradable materials, however it is favoured for a lower purchase price. If there are less budgetary constraints in the full-scale model, these materials may be used instead to improve recyclability.

Over the operational life of the robot, its inputs include paint and electricity. Electricity input could be minimized by increasing motor and drive efficiency or adding solar panels, and paint-efficiency could be improved by investigating reusable markers or alternate paintbrush designs.

# Bibliography

Australian Aluminium Council LTD. (2020). *Recycling*. Retrieved from Australian Aluminium Council: http://aluminium.org.au/aluminium/recycling/

Ciceri, N. D., Gutowski, T. G., & Garetti, M. (2011, May 16). *A Tool to Estimate Materials and Manufacturing Energy for a Product.* Retrieved from Environmentally Benign Manufacturing: http://web.mit.edu/ebm/www/Publications/9\_Paper.pdf

Conserve Energy Future. (2020). *Rubber Recycling*. Retrieved from Conserve Energy Future: https://www.conserve-energy-future.com/recyclingrubber.php

Crawford, R., Stephan, A., & Prideaux, F. (2019, November 20). *EPiC database*. Retrieved from EPiC database - Copper wire: https://melbourne.figshare.com/articles/EPiC\_database\_-\_Copper\_wire/9979649

CSIRO. (2000). *Embodied and Lifetime Energies in the Built Environment.* Retrieved from TecEco.

Fraser, J., Swaminathan, S., & Thompson, L. S. (1995, March 29). *Energy Use in the Transport Sector.* Retrieved from TGA Transport Concepts: http://www.tgaassoc.com/documents/energy-text&figures-dec2007.pdf

Hanania, J., & Donev, J. (2017, January 8). *Iron*. Retrieved from Energy Education: https://energyeducation.ca/encyclopedia/Iron

Milne, G., & Reardon, C. (2013). *Embodied Energy*. Retrieved from YourHome: https://www.yourhome.gov.au/materials/embodied-energy

Ning, C., Lin, C. S., Hui, D. C., & McKay, G. (2017, March 28). *Waste Printed Circuit Board (PCB) Recycling Techinques*. Retrieved from SpringerLink: https://link.springer.com/article/10.1007/s41061-017-0118-7

SUEZ Australian and New Zealand. (n.d.). *Plastic Recycling*. Retrieved from SUEZZ in Australia and New Zealand.

Thomitzek, M., Cerdas, F., & Herrmann, S. T. (2019). *Cradle-to-Gate Analysis of the Embodied Energy in Lithium Ion Batteries.* Braunschweig: ScienceDirect.

# APPENDIX

## 1: Component Embodied Energy Breakdown

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Component** | **Scaled Up Mass (g)** | **Main material constituents** | **Embodied Energy (MJ/kg)** | **Reference** | **Energy(MJ)** |
| Magnet Sensor | 5 | Printed Circuit Board | 151 | (Ciceri, Gutowski, & Garetti, 2011) | 0.755 |
| Motor Gearbox | 500 | Plastic | 90 | (Milne & Reardon, 2013) | 45 |
| Distance Sensors | 85 | Printed Circuit Board | 151 | (Ciceri, Gutowski, & Garetti, 2011) | 12.835 |
| Servo Motor | 75 | Plastic | 90 | (Milne & Reardon, 2013) | 6.75 |
| Paintbrush | 10 | Plastic | 90 | (Milne & Reardon, 2013) | 0.9 |
| Pull-up Resistor | 5 | Iron | 25 | (Hanania & Donev, 2017) | 0.125 |
| Battery | 295 | Lithium Polymer | - | (Thomitzek, Cerdas, & Herrmann, 2019) | 123 |
| Battery connector | 10 | Copper | 671 | (Crawford, Stephan, & Prideaux, 2019) | 6.71 |
| Battery Wire | 25 | Copper | 671 | (Milne & Reardon, 2013) | 16.775 |
| Microcontroller | 125 | Printed Circuit Board | 151 | (Ciceri, Gutowski, & Garetti, 2011) | 18.875 |
| Motor Controller | 160 | Printed Circuit Board | 151 | (Ciceri, Gutowski, & Garetti, 2011) | 24.16 |
| Wheels | 410 | Rubber | 110 | (Milne & Reardon, 2013) | 45.1 |
| Chassis | 290 | Aluminium plate | 180 | (CSIRO, 2000) | 52.2 |
| 3d printer filament | 190 | Plastic | 90 | (Milne & Reardon, 2013) | 17.1 |
| Manufactured Component | 290 | Aluminium plate | 180 | (CSIRO, 2000) | 52.2 |
| Nuts, screws and standoffs | 270 | Plastic | 90 | (Milne & Reardon, 2013) | 24.3 |

**Total: 466.785MJ**

## 2: Energy and Material FlowA close up of a logo Description automatically generated