# Life cycle assessment of a smart socket used for eliminating wasted energy in Buildings

SME

**Measurable Energy**

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**Life Cycle Assessment of Carbon Footprint of the Smart Power Socket Supplied by Measurable Energy**

# 1 Introduction

The main objective of this study is estimating the carbon footprint of the smart power socket supplied by Measurable Energy. In this assessment the emissions were considered for:

1. Energy and material used to make the power socket components.
2. Energy used to transport the power socket.
3. End of life and recyclability of the power socket components.

# 2 Input data

Most of the input data (materials and masses) was provided by Measurable Energy but assumptions were made to assign materials to some components based on the market most common practice (**Table 1**). Moreover, the production processes of the components were selected based on the normal production routes of the materials, for example, copper can be made using casting or vaporisation, but the former is the normal and most used method for copper, same principal applies for other materials in the list.

**Table 1**. The list of materials used in the production of the power socket

| Component | **Material** | Process | **Part mass (kg)** | **Qty.** |
|---|---|---|---|---|
| **Rear Casework** | Polypropylene | Polymer moulding | 0.025 | 1 |
| **VA Lens** | Polyoxymethylene | Polymer moulding | 0.0015 | 1 |
| **Fascia Plate** | Urea-formaldehyde | Polymer moulding | 0.065 | 1 |
| **Earth Shutter** | Polycarbonate | Polymer moulding | 0.0015 | 2 |
| **Fascia Button** | Urea-formaldehyde | Polymer moulding | 0.0011 | 2 |
| **Earth Strap** | Copper | Extrusion, foil rolling | 0.0092 | 1 |
| **Screw Terminal link** | Copper-Co-Be alloy | Casting | 0.00081 | 2 |
| **Live Neutral Contact** | Copper-Co-Be alloy | Casting | 0.0061 | 4 |
| **Earth Contact** | Copper-Co-Be alloy | Casting | 0.0034 | 2 |

| | | | | |
|---|---|---|---|---|
| **Spring** | Low alloy steel | Casting | 0.00057 | 2 |
| **CCA_83 (Screw)** | Low alloy steel | Casting | 0.0061 | 7 |
| **Wire Clamp** | Low alloy steel | Casting | 0.0081 | 5 |
| **NFC Tag** | Single crystalline silicon, electronics | Casting | 0.00048 | 1 |
| **Rivet** | Low alloy steel | Casting | 9.3e-05 | 2 |

**Datasheets**

Detailed datasheets of the materials of the components of the power socket are given in the appendix session. Each datasheet includes the composition of the material, which is important when considering recyclability, for example, some materials are coated with non-recyclable coatings which may affect the end of life potential of the entire material or may require an additional step before recycling is possible. The list also includes energy consumption, carbon footprint and water footprint at the primary production stage and at the processing stage in details. Normally, the focus is on material sustainability but processing route cannot be neglected, see **Tables 17 - 24** to observe how the processing route affect the energy consumption and subsequently the carbon and water footprint. Finally, the end of life options of the material are presented, including Recycle, Downcycle, Combust, Landfill and Biodegrade. In addition, the energy consumption and carbon footprint for Recycle and Combust options are provided.

# 3 Life Cycle Assessment Report

## 3.1 Introduction

The life cycle consists of the following stages: material, manufacture, transport, use and end of life. **Figure 1** below shows the fraction of energy consumption and carbon footprint at each stage while **Table 2** shows the actual values of both in addition to their fraction at each stage of the life cycle.

As can be seen, there is a consistent relationship between the energy consumption and carbon footprint at all the stages. The material stage gave the highest carbon footprint, 86%, followed by manufacturing, 13%, while transport and use together account for less than 1%.

End-of-life (EoL) phase splits into two components: Disposal and EoL potential, they both represent the influence of expected end-of-life recovery rate on the benefit that can be obtained in subsequent life cycles. For the power socket, the total carbon footprint is 1.62 kg while the end-of-life potential is 0.911 kg. This means that after the life span of the product, if the product components are dealt with according to the optimum practice, for example recycling the recyclable components, there is an opportunity to offset 0.911 kg of the 1.62 kg carbon emissions.

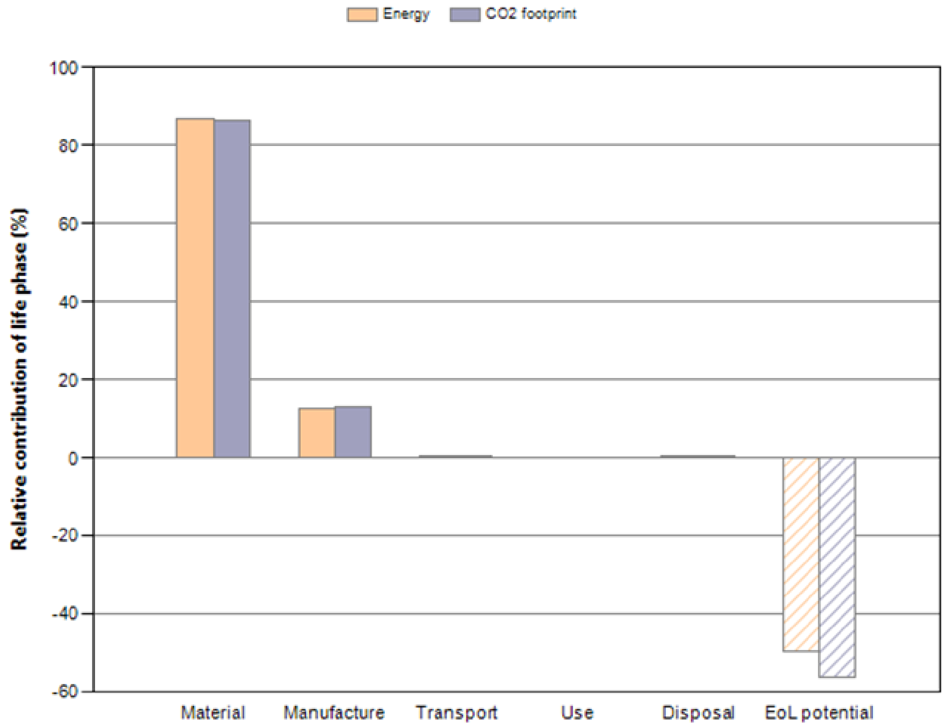


**Figure 1.** Fraction of energy consumption and carbon footprint at each stage of the life cycle of the power socket

**Table 2.** Values and fractions of energy consumption and carbon footprint at each stage of the life cycle of the power socket

| Phase | **Energy (MJ)** | **Energy (%)** | **$CO_2$ footprint (kg)** | **$CO_2$ footprint (%)** |
|---|---|---|---|---|
| Material | 20.8 | 86.7 | 1.4 | 86.3 |
| **Manufacture** | 2.98 | 12.4 | 0.209 | 12.9 |
| **Transport** | 0.0838 | 0.4 | 0.00604 | 0.4 |
| **Use** | 0 | 0.0 | 0 | 0.0 |
| **Disposal** | 0.119 | 0.5 | 0.00833 | 0.5 |
| Total (for first life) | **23.9** | **100** | **1.62** | **100** |
| **End of life potential** | -11.8 | | -0.911 | |

## 3.2 Energy Analysis

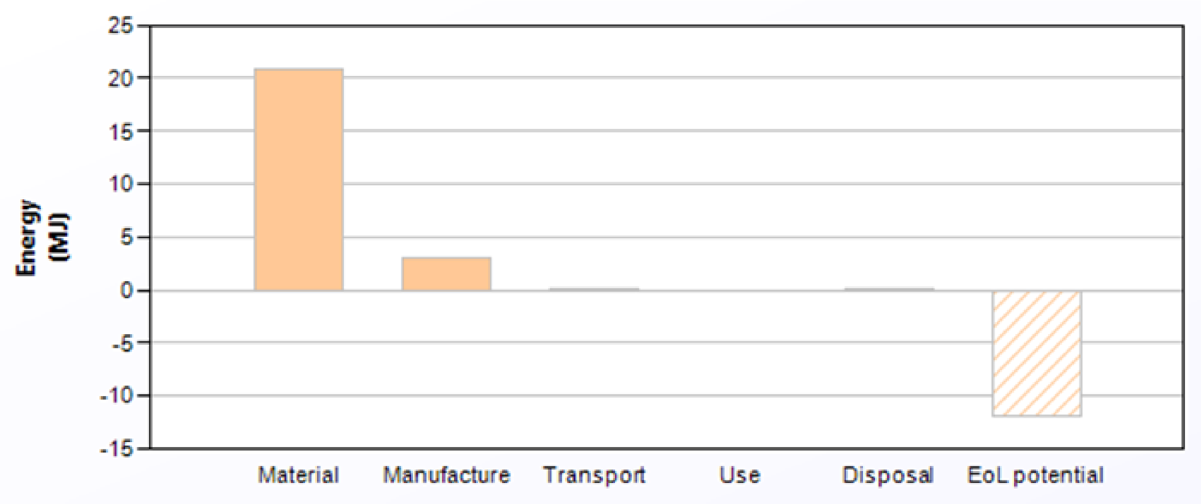


**Figure 2.** Values of energy consumption at each stage of the life cycle of the power socket

| | **Energy (MJ/year)** |
|---|---|
| **Equivalent annual environmental burden (averaged over 20 year product life):** | 1.2 |

**Detailed breakdown of individual life phases**

### 3.2.1 Material:

**Table 3**. The list of components, materials, recycled content, mass, quantity and equivalent energy consumption value and fraction

| Component | **Material** | **Recycled content (%)** | **Part mass (kg)** | **Qty.** | **Total mass (kg)** | **Energy (MJ)** | **%** |
|---|---|---|---|---|---|---|---|
| **Rear Casework** | PP (homopolymer, clarified/nucleated) | Virgin (0%) | 0.025 | 1 | 0.025 | 1.7 | 8.4 |
| **VA Lens** | POM (copolymer) | Virgin (0%) | 0.0015 | 1 | 0.0015 | 0.13 | 0.6 |
| **Fascia Plate** | UF (alpha cellulose filler) | Virgin (0%) | 0.065 | 1 | 0.065 | 2.6 | 12.5 |
| **Earth Shutter** | PC (10-15% PTFE, lubricated) | Virgin (0%) | 0.0015 | 2 | 0.003 | 0.34 | 1.6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Fascia Button** | UF (alpha cellulose filler) | Virgin (0%) | 0.0011 | 2 | 0.0022 | 0.088 | 0.4 |
| **Earth Strap** | Copper, C12200, hard (phosphorus de-oxidized arsenical h.c. copper) | Virgin (0%) | 0.0092 | 1 | 0.0092 | 0.54 | 2.6 |
| **Main Board (PCB)** | Printed circuit board assembly | Virgin (0%) | 0.055 | 1 | 0.055 | 7.1 | 34.3 |
| **Screw Terminal link** | Copper-Co-Be alloy, CuBe1Co2, C82000, cast | Virgin (0%) | 0.00081 | 2 | 0.0016 | 0.15 | 0.7 |
| **Live Neutral Contact** | Copper-Co-Be alloy, CuBe1Co2, C82000, cast | Virgin (0%) | 0.0061 | 4 | 0.024 | 2.3 | 11.0 |
| **Earth Contact** | Copper-Co-Be alloy, CuBe1Co2, C82000, cast | Virgin (0%) | 0.0034 | 2 | 0.0068 | 0.64 | 3.1 |
| **Spring** | Low alloy steel, SAE 4130, cast, normalized & tempered | Virgin (0%) | 0.00057 | 2 | 0.0011 | 0.037 | 0.2 |
| **CCA_83 (Screw)** | Low alloy steel, SAE 4130, cast, normalized & tempered | Virgin (0%) | 0.0061 | 7 | 0.043 | 1.4 | 6.6 |
| **Wire Clamp** | Low alloy steel, SAE 4130, cast, normalized & tempered | Virgin (0%) | 0.0081 | 5 | 0.041 | 1.3 | 6.3 |
| **NFC Tag** | Single crystalline silicon, electronics | Virgin (0%) | 0.00048 | 1 | 0.00048 | 2.4 | 11.5 |
| **Rivet** | Low alloy steel, SAE 4130, cast, normalized & tempered | Virgin (0%) | 9.3e-05 | 2 | 0.00019 | 0.006 | 0.0 |
| Total | | | | **34** | **0.28** | **21** | **100** |

### 3.2.2 Manufacture:

**Table 4**. The list of components, materials, processing route, amount and equivalent energy consumption value and fraction

| Component | Process | Amount processed | | Energy (MJ) | % |
|---|---|---|---|---|---|
| **Rear Casework** | Polymer moulding | 0.025 | kg | 0.59 | 19.7 |
| **VA Lens** | Polymer moulding | 0.0015 | kg | 0.024 | 0.8 |
| **Fascia Plate** | Polymer moulding | 0.065 | kg | 0.96 | 32.1 |
| **Earth Shutter** | Polymer moulding | 0.003 | kg | 0.073 | 2.5 |
| **Fascia Button** | Polymer moulding | 0.0022 | kg | 0.032 | 1.1 |
| **Earth Strap** | Extrusion, foil rolling | 0.0092 | kg | 0.037 | 1.2 |
| **Screw Terminal link** | Casting | 0.0016 | kg | 0.015 | 0.5 |
| **Live Neutral Contact** | Casting | 0.024 | kg | 0.23 | 7.6 |
| **Earth Contact** | Casting | 0.0068 | kg | 0.063 | 2.1 |
| **Spring** | Casting | 0.0011 | kg | 0.013 | 0.4 |
| **CCA_83 (Screw)** | Casting | 0.043 | kg | 0.49 | 16.3 |
| **Wire Clamp** | Casting | 0.041 | kg | 0.46 | 15.5 |
| **Rivet** | Casting | 0.00019 | kg | 0.0021 | 0.1 |
| Total | | | | **3** | **100** |

### 3.2.3 Transport:

Breakdown by transport stage

**Table 5**. Transport type, distance and equivalent energy consumption value and fraction

| Stage name | Transport type | Distance (km) | Energy (MJ) | % |
|---|---|---|---|---|
| **Shipping** | 32 tonne (4 axle) truck | 3.2e+02 | 0.084 | 100.0 |
| Total | | **3.2e+02** | **0.084** | **100** |

Breakdown by components

**Table 6**. The list of components, mass and equivalent energy consumption value and fraction

| Component | Mass (kg) | Energy (MJ) | % |
|---|---|---|---|
| **Rear Casework** | 0.025 | 0.0075 | 9.0 |
| **VA Lens** | 0.0015 | 0.00045 | 0.5 |
| **Fascia Plate** | 0.065 | 0.02 | 23.3 |
| **Earth Shutter** | 0.003 | 0.0009 | 1.1 |
| **Fascia Button** | 0.0022 | 0.00066 | 0.8 |
| **Earth Strap** | 0.0092 | 0.0028 | 3.3 |
| **Main Board (PCB)** | 0.055 | 0.017 | 19.7 |
| **Screw Terminal link** | 0.0016 | 0.00049 | 0.6 |
| **Live Neutral Contact** | 0.024 | 0.0073 | 8.8 |
| **Earth Contact** | 0.0068 | 0.002 | 2.4 |
| **Spring** | 0.0011 | 0.00034 | 0.4 |
| **CCA_83 (Screw)** | 0.043 | 0.013 | 15.3 |
| **Wire Clamp** | 0.041 | 0.012 | 14.5 |
| **NFC Tag** | 0.00048 | 0.00014 | 0.2 |
| **Rivet** | 0.00019 | 5.6e-05 | 0.1 |
| Total | **0.28** | **0.084** | **100** |

### 3.2.4 Use:

Relative contribution of static and mobile modes

**Table 7**. Use consumption during static and mobile modes and equivalent energy consumption value and fraction

| Mode | **Energy (MJ)** | **%** |
|---|---|---|
| **Static** | 0 | |
| **Mobile** | 0 | |
| Total | **0** | **100** |

### 3.2.5 Disposal:

**Table 8**. The list of components, disposal option and equivalent energy consumption value and fraction

| Component | **End of life option** | **Energy (MJ)** | **%** |
|---|---|---|---|
| **Rear Casework** | Landfill | 0.005 | 4.2 |
| **VA Lens** | Landfill | 0.0003 | 0.3 |
| **Fascia Plate** | Landfill | 0.013 | 10.9 |
| **Earth Shutter** | Landfill | 0.0006 | 0.5 |
| **Fascia Button** | Landfill | 0.00044 | 0.4 |
| **Earth Strap** | Recycle | 0.0064 | 5.4 |
| **Main Board (PCB)** | Re-manufacture | 0.011 | 9.2 |
| **Screw Terminal link** | Recycle | 0.0011 | 1.0 |
| **Live Neutral Contact** | Recycle | 0.017 | 14.4 |
| **Earth Contact** | Recycle | 0.0048 | 4.0 |
| **Spring** | Recycle | 0.0008 | 0.7 |
| **CCA_83 (Screw)** | Recycle | 0.03 | 25.1 |
| **Wire Clamp** | Recycle | 0.028 | 23.8 |
| **NFC Tag** | Landfill | 9.6e-05 | 0.1 |

| | | | |
|---|---|---|---|
| **Rivet** | Recycle | 0.00013 | 0.1 |
| Total | | **0.12** | **100** |

### 3.2.6 EoL potential:

**Table 9**. The list of components, end of life option and equivalent energy consumption value and fraction

| Component | **End of life option** | **Energy (MJ)** | **%** |
|---|---|---|---|
| **Rear Casework** | Landfill | 0 | 0.0 |
| **VA Lens** | Landfill | 0 | 0.0 |
| **Fascia Plate** | Landfill | 0 | 0.0 |
| **Earth Shutter** | Landfill | 0 | 0.0 |
| **Fascia Button** | Landfill | 0 | 0.0 |
| **Earth Strap** | Recycle | -0.42 | 3.5 |
| **Main Board (PCB)** | Re-manufacture | -7 | 58.8 |
| **Screw Terminal link** | Recycle | -0.12 | 1.0 |
| **Live Neutral Contact** | Recycle | -1.8 | 15.4 |
| **Earth Contact** | Recycle | -0.51 | 4.3 |
| **Spring** | Recycle | -0.027 | 0.2 |
| **CCA_83 (Screw)** | Recycle | -1 | 8.6 |
| **Wire Clamp** | Recycle | -0.96 | 8.1 |
| **NFC Tag** | Landfill | 0 | 0.0 |
| **Rivet** | Recycle | -0.0044 | 0.0 |
| Total | | **-12** | **100** |

## 3.3 $CO_2$ Footprint Analysis

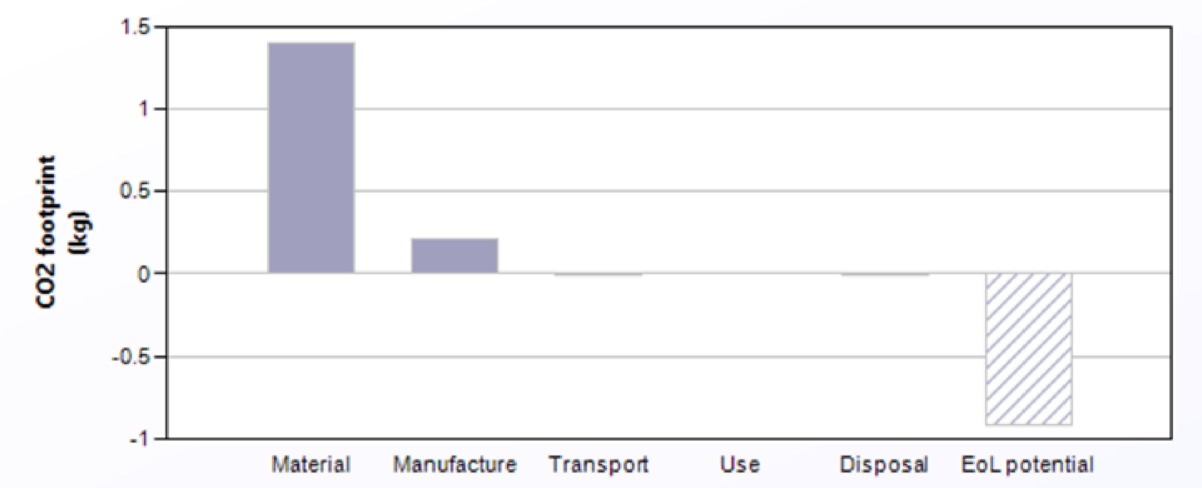


**Figure 3**. Values of carbon footprint at each stage of the life cycle of the power socket

| | **$CO_2$ (kg/year)** |
|---|---|
| **Equivalent annual environmental burden (averaged over 20 year product life):** | 0.0812 |

Detailed breakdown of individual life phases

### 3.3.1 Material:

**Table 10**. The list of components, materials, recycled content, mass, quantity and equivalent carbon footprint value and fraction

| Component | **Material** | **Recycled content (%)** | **Part mass (kg)** | **Qty.** | **Total mass (kg)** | **$CO_2$ footprint (kg)** | **%** |
|---|---|---|---|---|---|---|---|
| **Rear Casework** | PP (homopolymer, clarified/nucleated) | Virgin (0%) | 0.025 | 1 | 0.025 | 0.045 | 3.2 |
| **VA Lens** | POM (copolymer) | Virgin (0%) | 0.0015 | 1 | 0.0015 | 0.0048 | 0.3 |
| **Fascia Plate** | UF (alpha cellulose filler) | Virgin (0%) | 0.065 | 1 | 0.065 | 0.11 | 8.1 |
| **Earth Shutter** | PC (10-15% PTFE, lubricated) | Virgin (0%) | 0.0015 | 2 | 0.003 | 0.016 | 1.1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Fascia Button** | UF (alpha cellulose filler) | Virgin (0%) | 0.0011 | 2 | 0.0022 | 0.0039 | 0.3 |
| **Earth Strap** | Copper, C12200, hard (phosphorus de-oxidized arsenical h.c. copper) | Virgin (0%) | 0.0092 | 1 | 0.0092 | 0.033 | 2.4 |
| **Main Board (PCB)** | Printed circuit board assembly | Virgin (0%) | 0.055 | 1 | 0.055 | 0.53 | 38.2 |
| **Screw Terminal link** | Copper-Co-Be alloy, CuBe1Co2, C82000, cast | Virgin (0%) | 0.00081 | 2 | 0.0016 | 0.013 | 1.0 |
| **Live Neutral Contact** | Copper-Co-Be alloy, CuBe1Co2, C82000, cast | Virgin (0%) | 0.0061 | 4 | 0.024 | 0.2 | 14.3 |
| **Earth Contact** | Copper-Co-Be alloy, CuBe1Co2, C82000, cast | Virgin (0%) | 0.0034 | 2 | 0.0068 | 0.056 | 4.0 |
| **Spring** | Low alloy steel, SAE 4130, cast, normalized & tempered | Virgin (0%) | 0.00057 | 2 | 0.0011 | 0.0027 | 0.2 |
| **CCA_83 (Screw)** | Low alloy steel, SAE 4130, cast, normalized & tempered | Virgin (0%) | 0.0061 | 7 | 0.043 | 0.1 | 7.2 |
| **Wire Clamp** | Low alloy steel, SAE 4130, cast, normalized & tempered | Virgin (0%) | 0.0081 | 5 | 0.041 | 0.096 | 6.9 |
| **NFC Tag** | Single crystalline silicon, electronics | Virgin (0%) | 0.00048 | 1 | 0.00048 | 0.18 | 12.7 |
| **Rivet** | Low alloy steel, SAE 4130, cast, normalized & tempered | Virgin (0%) | 9.3e-05 | 2 | 0.00019 | 0.00044 | 0.0 |
| Total | | | | **34** | **0.28** | **1.4** | **100** |

### 3.3.2 Manufacture:

**Table 11**. The list of components, processing route, amount and equivalent carbon footprint value and fraction

| Component | **Process** | **Amount processed** | **$CO_2$ footprint (kg)** | **%** |
|---|---|---|---|---|
| **Rear Casework** | Polymer moulding | 0.025 kg | 0.044 | 21.1 |
| **VA Lens** | Polymer moulding | 0.0015 kg | 0.0018 | 0.9 |
| **Fascia Plate** | Polymer moulding | 0.065 kg | 0.072 | 34.4 |
| **Earth Shutter** | Polymer moulding | 0.003 kg | 0.0055 | 2.6 |
| **Fascia Button** | Polymer moulding | 0.0022 kg | 0.0024 | 1.2 |
| **Earth Strap** | Extrusion, foil rolling | 0.0092 kg | 0.0028 | 1.3 |
| **Screw Terminal link** | Casting | 0.0016 kg | 0.0011 | 0.5 |
| **Live Neutral Contact** | Casting | 0.024 kg | 0.017 | 8.1 |
| **Earth Contact** | Casting | 0.0068 kg | 0.0047 | 2.3 |
| **Spring** | Casting | 0.0011 kg | 0.00078 | 0.4 |
| **CCA_83 (Screw)** | Casting | 0.043 kg | 0.029 | 14.0 |
| **Wire Clamp** | Casting | 0.041 kg | 0.028 | 13.3 |
| **Rivet** | Casting | 0.00019 kg | 0.00013 | 0.1 |
| Total | | | **0.21** | **100** |

### 3.3.3 Transport:

Breakdown by transport stage

**Table 12**. Transport type, distance and equivalent carbon footprint value and fraction

| Stage name | Transport type | Distance (km) | $CO_2$ footprint (kg) | % |
|---|---|---|---|---|
| **Shipping** | 32 tonne (4 axle) truck | 3.2e+02 | 0.006 | 100.0 |
| Total | | **3.2e+02** | **0.006** | **100** |

Breakdown by components

**Table 13**. The list of components, mass and equivalent carbon footprint value and fraction

| Component | Mass (kg) | $CO_2$ footprint (kg) | % |
|---|---|---|---|
| **Rear Casework** | 0.025 | 0.00054 | 9.0 |
| **VA Lens** | 0.0015 | 3.2e-05 | 0.5 |
| **Fascia Plate** | 0.065 | 0.0014 | 23.3 |
| **Earth Shutter** | 0.003 | 6.5e-05 | 1.1 |
| **Fascia Button** | 0.0022 | 4.8e-05 | 0.8 |
| **Earth Strap** | 0.0092 | 0.0002 | 3.3 |
| **Main Board (PCB)** | 0.055 | 0.0012 | 19.7 |
| **Screw Terminal link** | 0.0016 | 3.5e-05 | 0.6 |
| **Live Neutral Contact** | 0.024 | 0.00053 | 8.8 |
| **Earth Contact** | 0.0068 | 0.00015 | 2.4 |
| **Spring** | 0.0011 | 2.5e-05 | 0.4 |
| **CCA_83 (Screw)** | 0.043 | 0.00092 | 15.3 |
| **Wire Clamp** | 0.041 | 0.00088 | 14.5 |
| **NFC Tag** | 0.00048 | 1e-05 | 0.2 |
| **Rivet** | 0.00019 | 4e-06 | 0.1 |
| Total | **0.28** | **0.006** | **100** |

### 3.3.4 Use:

Relative contribution of static and mobile modes

**Table 14**. Use consumption in the static and mobile modes and equivalent carbon footprint value and fraction

| Mode | **$CO_2$ footprint (kg)** | **%** |
|---|---|---|
| **Static** | 0 | |
| **Mobile** | 0 | |
| Total | **0** | **100** |

### 3.3.5 Disposal:

**Table 15**. The list of components, disposal options and equivalent carbon footprint value and fraction

| Component | **End of life option** | **$CO_2$ footprint (kg)** | **%** |
|---|---|---|---|
| **Rear Casework** | Landfill | 0.00035 | 4.2 |
| **VA Lens** | Landfill | 2.1e-05 | 0.3 |
| **Fascia Plate** | Landfill | 0.00091 | 10.9 |
| **Earth Shutter** | Landfill | 4.2e-05 | 0.5 |
| **Fascia Button** | Landfill | 3.1e-05 | 0.4 |
| **Earth Strap** | Recycle | 0.00045 | 5.4 |
| **Main Board (PCB)** | Re-manufacture | 0.00077 | 9.2 |
| **Screw Terminal link** | Recycle | 7.9e-05 | 1.0 |
| **Live Neutral Contact** | Recycle | 0.0012 | 14.4 |
| **Earth Contact** | Recycle | 0.00033 | 4.0 |
| **Spring** | Recycle | 5.6e-05 | 0.7 |
| **CCA_83 (Screw)** | Recycle | 0.0021 | 25.1 |
| **Wire Clamp** | Recycle | 0.002 | 23.8 |
| **NFC Tag** | Landfill | 6.7e-06 | 0.1 |

| | | | |
|---|---|---|---|
| **Rivet** | Recycle | 9.1e-06 | 0.1 |
| Total | | **0.0083** | **100** |

### 3.3.6 EoL potential:

**Table 16**. The list of components, end of life option and equivalent carbon footprint value and fraction

| Component | **End of life option** | **$CO_2$ footprint (kg)** | **%** |
|---|---|---|---|
| **Rear Casework** | Landfill | 0 | 0.0 |
| **VA Lens** | Landfill | 0 | 0.0 |
| **Fascia Plate** | Landfill | 0 | 0.0 |
| **Earth Shutter** | Landfill | 0 | 0.0 |
| **Fascia Button** | Landfill | 0 | 0.0 |
| **Earth Strap** | Recycle | -0.024 | 2.6 |
| **Main Board (PCB)** | Re-manufacture | -0.52 | 57.4 |
| **Screw Terminal link** | Recycle | -0.011 | 1.2 |
| **Live Neutral Contact** | Recycle | -0.16 | 18.0 |
| **Earth Contact** | Recycle | -0.046 | 5.0 |
| **Spring** | Recycle | -0.0019 | 0.2 |
| **CCA_83 (Screw)** | Recycle | -0.073 | 8.0 |
| **Wire Clamp** | Recycle | -0.069 | 7.6 |
| **NFC Tag** | Landfill | 0 | 0.0 |
| **Rivet** | Recycle | -0.00032 | 0.0 |
| Total | | **-0.91** | **100** |

# 4 Life cycle assessment of carbon footprint

**End of life scenarios**

The life cycle assessment included three case scenarios. Firstly, “optimum scenario” which assumes all the components can be recycled so increasing the end of life potential. This assumption was made based on the recyclability of the material rather than the recycle fraction in the current supply, for example, polypropylene is recyclable but only 5.26 - 5.81% is currently being recycled (**Table 17**), in this case polypropylene end of life is assumed to be recycled. Secondly, “current scenario” which is based on the recycle fraction in the current supply rather than the recyclability of the material, in this case polypropylene end of life is assumed to be landfill. Thirdly, “worst scenario” which assumes all the components none of the components can be recycled, even if the material is recyclable and has a high recycle fraction in the current supply, for example, copper is recyclable and around 43% is currently being recycled (**Table 21**), despite that, copper end of life is assumed to be landfill. The main purpose for this comparison is to understand the current improvement that Measurable Energy has achieved and the opportunity available for further improvement.

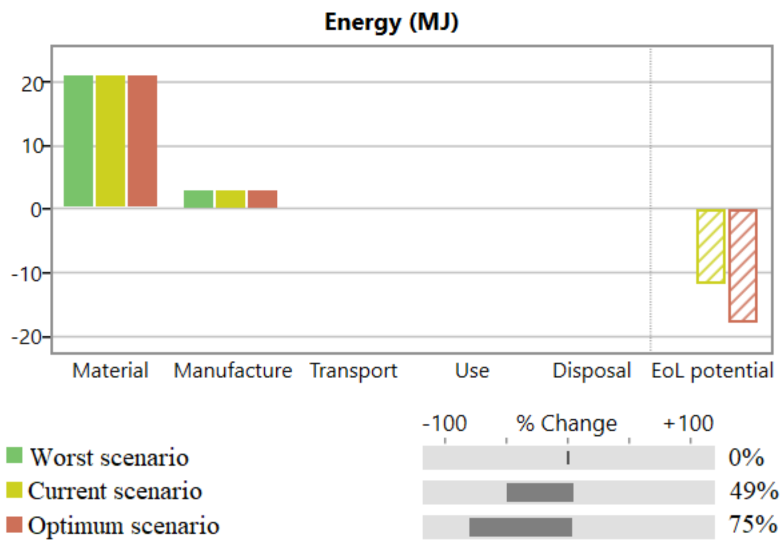


**Figure 4**. Values of energy consumption at each stage of the life cycle of the power socket for three scenarios: worst, current and optimum

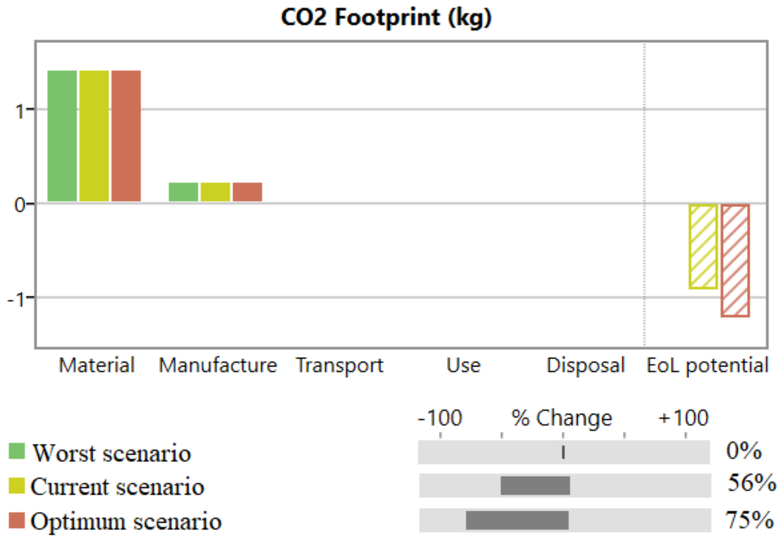


**Figure 5**. Values of carbon footprint at each stage of the life cycle of the power socket for three scenarios: worst, current and optimum

# 5 Recommendations to reduce the carbon footprint and enhance recyclability

All the components of the power socket are made of recyclable materials except the NFC Tag (Silicon) in addition to the Fascia Plate and Fascia Button (Urea-formaldehyde). It is worth mentioning that Urea-formaldehyde contributes 8.4% while Silicon contributes 12.7% of the carbon footprint, providing that 21% of the power socket is non-recyclable (**Tables 19, 24**). This indicates the high potential of the socket recyclability, 79% of the carbon footprint can be offset by the end of life potential.

Despite that fact the 21% is non-recyclable, the downcycle option should be considered at an alternative option to landfill for Silicon and Urea-formaldehyde. Downcycle is a process that is used in case recycling is not possible, in this operation the material losses many of its features, for example, marked drop in strength, but the material is still suitable for other applications. In case of Silicon, it can be downcycled into the following: playground mulch, insulation, and lubricant oils.

Considering plastics, Polypropylene, Polyoxymethylene and Polycarbonate, they are all recyclable but their recycle fraction in the current supply is low, <6%, (**Tables 17, 18, 20**). However, there are two things to consider. Firstly, the carbon footprint of the three plastics is low in fraction, around 4.5% (**Table 10**). Secondly, downcycling is a potential option, Maike Illner, a researcher at Fraunhofer Institute for Building Physics has emphasised the high potential of polypropylene for use in lower-quality products after downcycling.

Metals, copper and steel, have the biggest fraction of the carbon footprint due to their weight in comparison with plastic (**Table 10**), but this is associated with the biggest recycle fraction in the current supply, around 43% and 42% of copper and steel are recycled, respectively. Based on the datasheets of the materials and the options available, the power socket has a very positive end of life potential, given that most of the components can be recycled and the rest are suitable for downcycling so avoiding the landfill option and contributing into the circular economy.

It is worth mentioning that although 86% of the carbon footprint is caused during the material phase, **Figure 1**, this is ascribed to metals (copper and steel) which require high energy for extraction (**Table 3**). However, this energy will drop in the subsequent cycles as the metal will go through recycling rather than extraction, which would require much lower energy (**Tables 21 - 23**). Taking copper as an example, **Table 21**, the primary production energy requires around 59 MJ/kg leading to carbon footprint of 3.6 kg/kg. However, at the next cycle recycling consumes 13.5 MJ/kg leading to carbon footprint of 1.5 kg/kg. Therefore, measurable energy is strongly recommended to use recycled metals to supress the carbon footprint.

It is also important to mention that the life span of a product has an impact on the life cycle assessment, for example, a water bottle made of plastic is only used once and so its short life span results in an increase in the carbon footprint which its intensity is distributed over the life span of the product. However, in case of the power socket, it is made to last a long-life span, 15 – 25 years, and so plastic use is justified, and the carbon intensity become negligible.

Moreover, the use of plastic in the power socket is necessary and not an option for safety purposes, although metals are highly recyclable, they cannot be used in components where users can have a direct contact to avoid electric shock, for example, in the fascia plate.

Although it could be challenging to move from plastic completely, using recycled plastic is another option. Plastic is difficult to recycle so it is normally mixed with virgin plastic to fulfil the requirements. 30% recycled plastic is widely available after introducing the plastic tax in the UK. In numbers, the production of 1kg of virgin polypropylene consumes 1.76kg of $CO_2$, while this value drops to 1.12 kg of $CO_2$ for recycled polypropylene (**Table 17**).

Although we covered the end of life phase, the manufacturing phase is an important factor. Most plastic components are produced using injection moulding, but when possible, extrusion is preferred as it is consumes less energy. In Polypropylene, see the processing energy section in **Table 17**, injection moulding consumes on average 23.45 MJ/kg resulting in 1.76 kg/kg $CO_2$. However, extrusion consumes on average 6.3 MJ/kg resulting in 0.46 kg/kg $CO_2$, so reducing $CO_2$ emission by 75%. It is interesting that water footprint is also  less for extrusion, 4.88 – 7.32 l/kg, in comparison with moulding, 14.1 – 21.1 l/kg.

# 6 Appendix

**Table 17.** Datasheet of Polypropylene

## General information

**Designation**

Polypropylene

**Typical uses**

Film, cast, packaging, food, film, household goods, parts, thin-walled, packaging, thin-walled, packaging, media, containers, sheet, medical applications, containers, thin-walled, closures, general purpose, molds/dies/tools, containers, food, sheet, clear, labware, parts, transparent or translucent, cups, lids, furniture, profiles, toys, pharmaceuticals, film, bi-axially oriented, blending, trays, support, parts, thick-walled, packaging, pharmaceutical, laminates, hinges, living, electrical/electronic applications, parts, industrial, video cassettes, food applications, non-specific, appliance components, filaments, non-wovens, containers, thermoformed, coating applications, fibers, wire & cable applications, kitchenware, handles, consumer applications, packaging, cosmetic, automotive applications, hospital goods, compounding, cosmetics, outdoor furnishings, trays, microwavable, carpet backing, strapping, yarn, bcf, fibers, staple, stationary supplies, bags, lawn and garden equipment, drinkware, disposable, buckets, bowls, general mechanical parts, bottle crates, washing machine drums, pipes, battery cases, bottles, bottle caps, bumpers, films for packaging, fibers for carpeting and artificial sports surfaces.

| | |
|---|---|
| Included in Materials Data for Simulation | ✓ |

## Composition overview

**Compositional summary**

(CH2-CH(CH3))n - isotactic

| | |
|---|---|
| Material family | Plastic (thermoplastic, semi-crystalline) |
| Base material | PP (Polypropylene) |
| Polymer code | PP |

## Composition detail (polymers and natural materials)

| | | | | |
|---|---|---|---|---|
| Polymer | 100 | | | % |

## Price

| | | | | |
|---|---|---|---|---|
| Price | * 1.72 | - | 2.07 | GBP/kg |
| Price per unit volume | * 1.54e3 | - | 1.88e3 | GBP/m^3 |

## Primary production energy, CO2 and water

| | | | | |
|---|---|---|---|---|
| Embodied energy, primary production | 66.6 | - | 73.4 | MJ/kg |

Sources
49.1 MJ/kg (Argonne National Laboratory); 64.7 MJ/kg (Potting and Blok, 1996); 77.9 MJ/kg (PlasticsEurope, 2014); 75.5 MJ/kg (Sullivan and Gaines, 2010); 83 MJ/kg (Thiriez and Gutowski, 2006)

| | | | | |
|---|---|---|---|---|
| CO2 footprint, primary production | 1.71 | - | 1.89 | kg/kg |

Sources
1.97 kg/kg (Kemna et al. 2005); 1.63 kg/kg (PlasticsEurope, 2014)

| | | | | |
|---|---|---|---|---|
| Water usage | * 37.3 | - | 41.2 | l/kg |

## Processing energy, CO2 footprint & water

| | | | | |
|---|---|---|---|---|
| Polymer extrusion energy | * 5.95 | - | 6.58 | MJ/kg |
| Polymer extrusion CO2 | * 0.446 | - | 0.493 | kg/kg |
| Polymer extrusion water | * 4.88 | - | 7.32 | l/kg |
| Polymer molding energy | * 22.3 | - | 24.6 | MJ/kg |
| Polymer molding CO2 | * 1.67 | - | 1.85 | kg/kg |
| Polymer molding water | * 14.1 | - | 21.1 | l/kg |
| Coarse machining energy (per unit wt removed) | * 0.937 | - | 1.04 | MJ/kg |
| Coarse machining CO2 (per unit wt removed) | * 0.0703 | - | 0.0777 | kg/kg |
| Fine machining energy (per unit wt removed) | * 5.09 | - | 5.63 | MJ/kg |
| Fine machining CO2 (per unit wt removed) | * 0.382 | - | 0.422 | kg/kg |
| Grinding energy (per unit wt removed) | * 9.71 | - | 10.7 | MJ/kg |
| Grinding CO2 (per unit wt removed) | * 0.729 | - | 0.805 | kg/kg |

## Recycling and end of life

| | | | | |
|---|---|---|---|---|
| Recycle | ✓ | | | |
| Embodied energy, recycling | * 24.6 | - | 27.2 | MJ/kg |
| CO2 footprint, recycling | * 1.06 | - | 1.17 | kg/kg |
| Recycle fraction in current supply | 5.26 | - | 5.81 | % |
| Downcycle | ✓ | | | |
| Combust for energy recovery | ✓ | | | |
| Heat of combustion (net) | * 44 | - | 46.2 | MJ/kg |
| Combustion CO2 | * 3.06 | - | 3.22 | kg/kg |
| Landfill | ✓ | | | |
| Biodegrade | ✗ | | | |

**Table 18.** Datasheet of Polyoxymethylene

## General information

**Designation**

Polyoxymethylene

**Tradenames**

Aartel; Accucomp; Alcolor; Alcom; Altech; API; ARC; Ashlene; Bergaform; Bluestar; Cabelec; Celcon; Cheng; Clariant; Colorrx; Cp Pryme; Delrin; Delta; Deniform; Denistat; Dinaform; Duracon; Duratel; Duratuf; Dynamix; Dynapath; Dynastat; Edgetek; Ekatal; Electrafil; Enpom; Enviropom; Epimix; Estoplast; Formocon; Germaform; GLS; Heraform; Hifill; Hival; Hoegerin; Hostaform; Icorene; Inelec; Isotal; Iupital; Kebaform; Kepital; Kocetal; Lamigamid; Latan; Latistat; LCA; Lnp Stat-Loy; LTP; Lubrione; Lucel; Lucent; Lucet; Luvocom; Majoris; Maxatel; Next; Next Signature; Niform; Niuk; Omnitech; Optital; Palform; Permastat; Plaslube; Polipom; Polyform; Pomalux; Poticon; PPR; PTS; Quadrant; Ramtal; Resform; Resmart; RJM; Rotoun; RTP; Sabic; Saxaform; Schulaform; Schularec; Semitron; Stat-Tech; Sustarin; Tarnoform; Tecacomp; Tecaform; Tecoform; Tekuform; Tenac-C; Tenopom; Tepcon; Terez; TES; Texres; Titacon; Tynea; Ultraform; Unital; Witcom; Yuncon; Yuntianhua

**Typical uses**

Bearings, gears, electrical kettles, snap-fit components, chemical pumps, bathroom scales, pulley wheels, domestic appliance housings, shower heads, fuel expansion tanks, toys.

| | | | | |
|---|---|---|---|---|
| Included in Materials Data for Simulation | ✓ | | | |

## Composition overview

**Compositional summary**

Copolymer of (CH2-O)n (from formaldehyde or trioxane) with small amounts (<5%) of a comonomer such as -(CH2-CH2-O)- (from ethylene oxide or dioxolane)

| | |
|---|---|
| Material family | Plastic (thermoplastic, semi-crystalline) |
| Base material | POM(co) (Polyoxymethylene / acetal coplymer) |
| Polymer code | POM (co) |

## Composition detail (polymers and natural materials)

| | | | | |
|---|---|---|---|---|
| Polymer | 100 | | | % |

## Price

| | | | | |
|---|---|---|---|---|
| Price | * 1.23 | - | 1.37 | GBP/kg |
| Price per unit volume | * 1.72e3 | - | 1.93e3 | GBP/m^3 |

## Primary production energy, CO2 and water

| | | | | |
|---|---|---|---|---|
| Embodied energy, primary production<br>Sources<br>86 MJ/kg (PlasticsEurope, 2014) | 81.8 | - | 90.2 | MJ/kg |
| CO2 footprint, primary production<br>Sources<br>3.2 kg/kg (PlasticsEurope, 2014) | 3.04 | - | 3.36 | kg/kg |
| Water usage | * 240 | - | 265 | l/kg |

## Processing energy, CO2 footprint & water

| | | | | |
|---|---|---|---|---|
| Polymer extrusion energy | * 5.7 | - | 6.3 | MJ/kg |
| Polymer extrusion CO2 | * 0.427 | - | 0.472 | kg/kg |
| Polymer extrusion water | * 4.78 | - | 7.16 | l/kg |
| Polymer molding energy | * 15.2 | - | 16.8 | MJ/kg |
| Polymer molding CO2 | * 1.14 | - | 1.26 | kg/kg |
| Polymer molding water | * 11.2 | - | 16.7 | l/kg |
| Coarse machining energy (per unit wt removed) | * 1.22 | - | 1.35 | MJ/kg |
| Coarse machining CO2 (per unit wt removed) | * 0.0918 | - | 0.101 | kg/kg |
| Fine machining energy (per unit wt removed) | * 7.96 | - | 8.8 | MJ/kg |
| Fine machining CO2 (per unit wt removed) | * 0.597 | - | 0.66 | kg/kg |
| Grinding energy (per unit wt removed) | * 15.5 | - | 17.1 | MJ/kg |
| Grinding CO2 (per unit wt removed) | * 1.16 | - | 1.28 | kg/kg |

## Recycling and end of life

| | | | | |
|---|---|---|---|---|
| Recycle | ✓ | | | |
| Embodied energy, recycling | * 34.5 | - | 38.2 | MJ/kg |
| CO2 footprint, recycling | * 1.52 | - | 1.68 | kg/kg |
| Recycle fraction in current supply | 0.1 | | | % |
| Downcycle | ✓ | | | |
| Combust for energy recovery | ✓ | | | |
| Heat of combustion (net) | * 15.8 | - | 16.6 | MJ/kg |
| Combustion CO2 | * 1.45 | - | 1.52 | kg/kg |
| Landfill | ✓ | | | |
| Biodegrade | ✗ | | | |

**Table 19.** Datasheet of Urea-formaldehyde

## General information

**Designation**

UF Urea formaldehyde

**Tradenames**

Beetle; Pollopas

**Typical uses**

Industrial laminating, decorative laminating, adhesives, protective coatings, textile treatment, paper manufacture

## Composition overview

**Compositional summary**

Cross-linked polymer from urea and formaldehyde, resulting in formula of approx. (O=CN2(CH2)2)n

| | | | | |
|---|---|---|---|---|
| Material family | Plastic (thermoset) | | | |
| Base material | UF (Urea formaldehyde resin) | | | |
| % filler (by weight) | * 30 | - | 60 | % |
| Filler/reinforcement | Cellulose | | | |
| Filler/reinforcement form | Particulate | | | |
| Polymer code | UF-NX45 | | | |

## Composition detail (polymers and natural materials)

| | | | | |
|---|---|---|---|---|
| Polymer | * 40 | - | 70 | % |
| Woodflour / cellulose | * 30 | - | 60 | % |

## Price

| | | | | |
|---|---|---|---|---|
| Price | * 0.753 | - | 0.944 | GBP/kg |
| Price per unit volume | * 1.11e3 | - | 1.44e3 | GBP/m^3 |

## Primary production energy, CO2 and water

| | | | | |
|---|---|---|---|---|
| Embodied energy, primary production | * 38 | - | 41.9 | MJ/kg |
| CO2 footprint, primary production | * 1.67 | - | 1.84 | kg/kg |
| Water usage | * 164 | - | 181 | l/kg |

## Processing energy, CO2 footprint & water

| | | | | |
|---|---|---|---|---|
| Polymer molding energy | * 14 | - | 15.5 | MJ/kg |
| Polymer molding CO2 | * 1.05 | - | 1.16 | kg/kg |
| Polymer molding water | * 10.6 | - | 16 | l/kg |
| Coarse machining energy (per unit wt removed) | * 1.94 | - | 2.15 | MJ/kg |
| Coarse machining CO2 (per unit wt removed) | * 0.146 | - | 0.161 | kg/kg |
| Fine machining energy (per unit wt removed) | * 15.2 | - | 16.7 | MJ/kg |
| Fine machining CO2 (per unit wt removed) | * 1.14 | - | 1.26 | kg/kg |
| Grinding energy (per unit wt removed) | * 29.8 | - | 33 | MJ/kg |
| Grinding CO2 (per unit wt removed) | * 2.24 | - | 2.47 | kg/kg |

## Recycling and end of life

| | | | | |
|---|---|---|---|---|
| Recycle | ✗ | | | |
| Recycle fraction in current supply | 0.1 | | | % |
| Downcycle | ✓ | | | |
| Combust for energy recovery | ✓ | | | |
| Heat of combustion (net) | * 16.9 | - | 17.8 | MJ/kg |
| Combustion CO2 | * 1.44 | - | 1.52 | kg/kg |
| Landfill | ✓ | | | |
| Biodegrade | ✗ | | | |

**Table 20.** Datasheet of Polycarbonate

## General information

**Designation**

PC Polycarbonate

**Tradenames**

Alcom, Bestpolux, Clariant, Latilub, LNP Lubricomp, LNP Lubriloy, Lubricomp, Lubrione, Luvocom, Plaslube, Radici, Spartech, Stat-Kon, Vamplub, Witcom

**Typical uses**

Electrical components, appliances, electronic displays, connectors, switches, housings, casings.

## Composition overview

**Compositional summary**

polycarbonate (BPA, bis-phenol A based), PTFE (CF2CF2)n powder

| | |
|---|---|
| Material family | Plastic (thermoplastic, amorphous) |
| Base material | PC (Polycarbonate) |
| Additive | Anti-friction/wear lubricant |
| Polymer code | PC-L |

## Composition detail (polymers and natural materials)

| | | | | | |
|---|---|---|---|---|---|
| Polymer | | 85 | - | 90 | % |
| PTFE (lubricant) | | 10 | - | 15 | % |

## Price

| | | | | | |
|---|---|---|---|---|---|
| Price | * | 3.6 | - | 4.62 | GBP/kg |
| Price per unit volume | * | 4.53e3 | - | 5.96e3 | GBP/m^3 |

## Primary production energy, CO2 and water

| | | | | | |
|---|---|---|---|---|---|
| Embodied energy, primary production | * | 107 | - | 118 | MJ/kg |
| CO2 footprint, primary production | * | 5.02 | - | 5.53 | kg/kg |
| Water usage | * | 199 | - | 219 | l/kg |

## Processing energy, CO2 footprint & water

| | | | | | |
|---|---|---|---|---|---|
| Polymer extrusion energy | * | 5.98 | - | 6.61 | MJ/kg |
| Polymer extrusion CO2 | * | 0.449 | - | 0.496 | kg/kg |
| Polymer extrusion water | * | 4.89 | - | 7.34 | l/kg |
| Polymer molding energy | * | 23.2 | - | 25.6 | MJ/kg |
| Polymer molding CO2 | * | 1.74 | - | 1.92 | kg/kg |
| Polymer molding water | * | 14.5 | - | 21.7 | l/kg |
| Coarse machining energy (per unit wt removed) | * | 1.04 | - | 1.15 | MJ/kg |
| Coarse machining CO2 (per unit wt removed) | * | 0.078 | - | 0.0862 | kg/kg |
| Fine machining energy (per unit wt removed) | * | 6.12 | - | 6.77 | MJ/kg |
| Fine machining CO2 (per unit wt removed) | * | 0.459 | - | 0.508 | kg/kg |
| Grinding energy (per unit wt removed) | * | 11.8 | - | 13 | MJ/kg |
| Grinding CO2 (per unit wt removed) | * | 0.883 | - | 0.976 | kg/kg |

## Recycling and end of life

| | | | | | |
|---|---|---|---|---|---|
| Recycle | | ✓ | | | |
| Embodied energy, recycling | * | 36.9 | - | 40.8 | MJ/kg |
| CO2 footprint, recycling | * | 2.38 | - | 2.64 | kg/kg |
| Recycle fraction in current supply | | 0.672 | - | 0.742 | % |
| Downcycle | | ✓ | | | |
| Combust for energy recovery | | ✓ | | | |
| Heat of combustion (net) | * | 30.3 | - | 31.8 | MJ/kg |
| Combustion CO2 | * | 2.7 | - | 2.84 | kg/kg |
| Landfill | | ✓ | | | |
| Biodegrade | | ✗ | | | |

**Table 21**. Datasheet of Copper

### General information

**Designation**

Copper

| | |
|---|---|
| Condition | Hard |
| UNS number | C12200 |
| EN name | CW024A |
| ISO name | Cu-DHP |
| GB (Chinese) name | TP2 |
| JIS (Japanese) name | C1220 / C1221 |

**Typical uses**

Hot & cold water pipes, storage tanks, heat exchangers, automobile radiators, stills, vats, anodes for electroplating & electroforming.

| | |
|---|---|
| Included in Materials Data for Simulation | ✓ |

### Composition overview

**Compositional summary**

Cu100 / P0.015-0.04

| | |
|---|---|
| Material family | Metal (non-ferrous) |
| Base material | Cu (Copper) |

### Composition detail (metals, ceramics and glasses)

| | | | | |
|---|---|---|---|---|
| Cu (copper) | 100 | | | % |
| P (phosphorus) | 0.015 | - | 0.04 | % |

### Price

| | | | | |
|---|---|---|---|---|
| Price | * 5.06 | - | 5.15 | GBP/kg |
| Price per unit volume | * 4.52e4 | - | 4.6e4 | GBP/m^3 |

### Primary production energy, CO2 and water

| | | | | |
|---|---|---|---|---|
| Embodied energy, primary production | 56.1 | - | 61.9 | MJ/kg |

Sources

17.4 MJ/kg (Fthenakis, Wang, Kim, 2009); 33 MJ/kg (Norgate, Jahanshahi, Rankin, 2007); 34.5 MJ/kg (Ecoinvent v2.2); 36.1 MJ/kg (Ecoinvent v2.2); 43 MJ/kg (Ecoinvent v2.2); 54.2 MJ/kg (Ecoinvent v2.2); 57 MJ/kg (Hammond and Jones, 2008); 60.4 MJ/kg (Ecoinvent v2.2); 61 MJ/kg (Ecoinvent v2.2); 64 MJ/kg (Norgate, Jahanshahi, Rankin, 2007); 64.6 MJ/kg (Ecoinvent v2.2); 93.1 MJ/kg (Ecoinvent v2.2); 95.4 MJ/kg (Ecoinvent v2.2); 111 MJ/kg (Sullivan and Gaines, 2010)

| | | | | |
|---|---|---|---|---|
| CO2 footprint, primary production | 3.44 | - | 3.79 | kg/kg |

Sources

1.85 kg/kg (Ecoinvent v2.2); 2 kg/kg (Ecoinvent v2.2); 2.18 kg/kg (Ecoinvent v2.2); 2.87 kg/kg (Ecoinvent v2.2); 3.15 kg/kg (Ecoinvent v2.2); 3.23 kg/kg (Ecoinvent v2.2); 3.3 kg/kg (Norgate, Jahanshahi, Rankin, 2007); 3.81 kg/kg (Hammond and Jones, 2008); 4.79 kg/kg (Ecoinvent v2.2); 4.87 kg/kg (Ecoinvent v2.2); 5.05 kg/kg (Ecoinvent v2.2); 6.2 kg/kg (Norgate, Jahanshahi, Rankin, 2007)

| | | | | |
|---|---|---|---|---|
| Water usage | * 293 | - | 324 | l/kg |

### Processing energy, CO2 footprint & water

| | | | | |
|---|---|---|---|---|
| Roll forming, forging energy | * 2.06 | - | 2.28 | MJ/kg |
| Roll forming, forging CO2 | * 0.155 | - | 0.171 | kg/kg |
| Roll forming, forging water | * 2.43 | - | 3.65 | l/kg |
| Extrusion, foil rolling energy | * 3.84 | - | 4.24 | MJ/kg |
| Extrusion, foil rolling CO2 | * 0.288 | - | 0.318 | kg/kg |
| Extrusion, foil rolling water | * 3.19 | - | 4.79 | l/kg |
| Wire drawing energy | * 13.6 | - | 15 | MJ/kg |
| Wire drawing CO2 | * 1.02 | - | 1.13 | kg/kg |
| Wire drawing water | * 5.13 | - | 7.69 | l/kg |
| Metal powder forming energy | * 24.9 | - | 27.5 | MJ/kg |
| Metal powder forming CO2 | * 1.99 | - | 2.2 | kg/kg |
| Metal powder forming water | * 27.2 | - | 40.7 | l/kg |
| Vaporization energy | * 8.14e3 | - | 8.99e3 | MJ/kg |
| Vaporization CO2 | * 610 | - | 675 | kg/kg |
| Vaporization water | * 3.39e3 | - | 5.09e3 | l/kg |
| Coarse machining energy (per unit wt removed) | * 0.742 | - | 0.82 | MJ/kg |
| Coarse machining CO2 (per unit wt removed) | * 0.0556 | - | 0.0615 | kg/kg |
| Fine machining energy (per unit wt removed) | * 3.14 | - | 3.47 | MJ/kg |
| Fine machining CO2 (per unit wt removed) | * 0.236 | - | 0.26 | kg/kg |
| Grinding energy (per unit wt removed) | * 5.81 | - | 6.42 | MJ/kg |
| Grinding CO2 (per unit wt removed) | * 0.435 | - | 0.481 | kg/kg |
| Non-conventional machining energy (per unit wt removed) | * 81.4 | - | 89.9 | MJ/kg |
| Non-conventional machining CO2 (per unit wt removed) | * 6.1 | - | 6.75 | kg/kg |

### Recycling and end of life

| | | | | |
|---|---|---|---|---|
| Recycle | ✓ | | | |
| Embodied energy, recycling | * 12.8 | - | 14.1 | MJ/kg |
| CO2 footprint, recycling | * 1 | - | 1.11 | kg/kg |
| Recycle fraction in current supply | 40.8 | - | 45 | % |
| Downcycle | ✓ | | | |
| Combust for energy recovery | ✗ | | | |
| Landfill | ✓ | | | |
| Biodegrade | ✗ | | | |

**Table 22.** Datasheet of Copper-Co-Be alloy

## General information

**Designation**

Copper-Co-Be alloy

| | | |
|---|---|---|
| UNS number | | C82000 |
| ISO name | | CuBe |

**Typical uses**

High-conductivity/high-strength castings for electrical items & those having good thermal conductance such as molds & dies.

## Composition overview

**Compositional summary**

Cu96-97 / Co2.4-2.7 / Be0.45-0.8 (impurities: Ni<0.2, Si<0.15, Al<0.1, Cr<0.1, Fe<0.1, Sn<0.1, Zn<0.1, Pb<0.01)

| | | |
|---|---|---|
| Material family | | Metal (non-ferrous) |
| Base material | | Cu (Copper) |

## Composition detail (metals, ceramics and glasses)

| | | | | | |
|---|---|---|---|---|---|
| Al (aluminum) | | 0 | - | 0.1 | % |
| Be (beryllium) | | 0.45 | - | 0.8 | % |
| Co (cobalt) | | 2.4 | - | 2.7 | % |
| Cr (chromium) | | 0 | - | 0.1 | % |
| Cu (copper) | | 95.6 | - | 97.2 | % |
| Fe (iron) | | 0 | - | 0.1 | % |
| Ni (nickel) | | 0 | - | 0.2 | % |
| Pb (lead) | | 0 | - | 0.01 | % |
| Si (silicon) | | 0 | - | 0.15 | % |
| Sn (tin) | | 0 | - | 0.1 | % |
| Zn (zinc) | | 0 | - | 0.1 | % |

## Price

| | | | | | |
|---|---|---|---|---|---|
| Price | | * 8.74 | - | 9.44 | GBP/kg |
| Price per unit volume | | * 7.56e4 | - | 8.19e4 | GBP/m^3 |

## Primary production energy, CO2 and water

| | | | | | |
|---|---|---|---|---|---|
| Embodied energy, primary production | | * 89.4 | - | 98.6 | MJ/kg |
| CO2 footprint, primary production | | * 7.84 | - | 8.64 | kg/kg |
| Water usage | | * 300 | - | 332 | l/kg |

## Processing energy, CO2 footprint & water

| | | | | | |
|---|---|---|---|---|---|
| Casting energy | | * 8.81 | - | 9.74 | MJ/kg |
| Casting CO2 | | * 0.661 | - | 0.731 | kg/kg |
| Casting water | | * 16.7 | - | 25 | l/kg |
| Vaporization energy | | * 9.17e3 | - | 1.01e4 | MJ/kg |
| Vaporization CO2 | | * 688 | - | 760 | kg/kg |
| Vaporization water | | * 3.82e3 | - | 5.73e3 | l/kg |
| Coarse machining energy (per unit wt removed) | | * 0.994 | - | 1.1 | MJ/kg |
| Coarse machining CO2 (per unit wt removed) | | * 0.0746 | - | 0.0824 | kg/kg |
| Fine machining energy (per unit wt removed) | | * 5.67 | - | 6.27 | MJ/kg |
| Fine machining CO2 (per unit wt removed) | | * 0.425 | - | 0.47 | kg/kg |
| Grinding energy (per unit wt removed) | | * 10.9 | - | 12 | MJ/kg |
| Grinding CO2 (per unit wt removed) | | * 0.815 | - | 0.9 | kg/kg |
| Non-conventional machining energy (per unit wt removed) | | * 91.7 | - | 101 | MJ/kg |
| Non-conventional machining CO2 (per unit wt removed) | | * 6.88 | - | 7.6 | kg/kg |

## Recycling and end of life

| | | | | | |
|---|---|---|---|---|---|
| Recycle | | ✓ | | | |
| Embodied energy, recycling | | * 18.2 | - | 20.1 | MJ/kg |
| CO2 footprint, recycling | | * 1.43 | - | 1.58 | kg/kg |
| Recycle fraction in current supply | | 40.8 | - | 45 | % |
| Downcycle | | ✓ | | | |
| Combust for energy recovery | | ✗ | | | |
| Landfill | | ✓ | | | |
| Biodegrade | | ✗ | | | |

**Table 23.** Datasheet of Low alloy steel

### General information

**Designation**

Low alloy steel

| | |
|---|---|
| Condition | Normalized & tempered |
| UNS number | J13345 |
| US name | ASTM A487 Grade 9, AMS 5336 |
| EN name | 18CrMo4, 20CrMo4 |
| EN number | 1.3567, 1.7243 |

**Typical uses**

AISI 4130 is treated as a general purpose low-alloy casting steel, for applications that require higher hardenability and tensile strength (ie. thinner walls) than a low-carbon steel but also require good toughness.
ASTM A487 designates steel castings suitable for pressure service.

| | |
|---|---|
| Included in Materials Data for Simulation | ✓ |

### Composition overview

**Compositional summary**

Fe95-98 / Cr0.75-1.1 / Mn0.6-1 / Mo0.15-0.3 / C0.05-0.33 (impurities: Si<0.8, Cu<0.5, Ni<0.5, W<0.1, S<0.045, P<0.04, V<0.03)

| | |
|---|---|
| Material family | Metal (ferrous) |
| Base material | Fe (Iron) |

### Composition detail (metals, ceramics and glasses)

| | | | | | |
|---|---|---|---|---|---|
| C (carbon) | | 0.05 | - | 0.33 | % |
| Cr (chromium) | | 0.75 | - | 1.1 | % |
| Cu (copper) | | 0 | - | 0.5 | % |
| Fe (iron) | * | 95.3 | - | 98.4 | % |
| Mn (manganese) | | 0.6 | - | 1 | % |
| Mo (molybdenum) | | 0.15 | - | 0.3 | % |
| Ni (nickel) | | 0 | - | 0.5 | % |
| P (phosphorus) | | 0 | - | 0.04 | % |
| S (sulfur) | | 0 | - | 0.045 | % |
| Si (silicon) | | 0 | - | 0.8 | % |
| V (vanadium) | | 0 | - | 0.03 | % |
| W (tungsten) | | 0 | - | 0.1 | % |

### Price

| | | | | | |
|---|---|---|---|---|---|
| Price | * | 0.747 | - | 0.827 | GBP/kg |
| Price per unit volume | * | 5.83e3 | - | 6.48e3 | GBP/m^3 |

### Primary production energy, CO2 and water

| | | | | | |
|---|---|---|---|---|---|
| Embodied energy, primary production | | 30.8 | - | 33.9 | MJ/kg |

Sources
19.4 MJ/kg (Dhingra, Overly, Davis, 1999); 23 MJ/kg (Norgate, Jahanshahi, Rankin, 2007); 27.9 MJ/kg (Ecoinvent v2.2); 29.2 MJ/kg (Hammond and Jones, 2008); 32.8 MJ/kg (Hammond and Jones, 2008); 34.7 MJ/kg (Hammond and Jones, 2008); 35.4 MJ/kg (Hammond and Jones, 2008); 37.2 MJ/kg (Sullivan and Gaines, 2010); 38 MJ/kg (Hammond and Jones, 2008); 45.4 MJ/kg (Hammond and Jones, 2008)

| | | | | | |
|---|---|---|---|---|---|
| CO2 footprint, primary production | | 2.26 | - | 2.49 | kg/kg |

Sources
0.396 kg/kg (Voet, van der and Oers, van, 2003); 1.75 kg/kg (Ecoinvent v2.2); 1.81 kg/kg (Voet, van der and Oers, van, 2003); 2.23 kg/kg (Voet, van der and Oers, van, 2003); 2.3 kg/kg (Norgate, Jahanshahi, Rankin, 2007); 2.74 kg/kg (Hammond and Jones, 2008); 2.77 kg/kg (Hammond and Jones, 2008); 2.87 kg/kg (Hammond and Jones, 2008); 2.89 kg/kg (Hammond and Jones, 2008); 3.03 kg/kg (Hammond and Jones, 2008); 3.27 kg/kg (Hammond and Jones, 2008)

| | | | | | |
|---|---|---|---|---|---|
| Water usage | * | 48.8 | - | 53.9 | l/kg |

### Processing energy, CO2 footprint & water

| | | | | | |
|---|---|---|---|---|---|
| Casting energy | * | 10.8 | - | 12 | MJ/kg |
| Casting CO2 | * | 0.65 | - | 0.719 | kg/kg |
| Casting water | * | 20.5 | - | 30.8 | l/kg |
| Vaporization energy | * | 1.09e4 | - | 1.2e4 | MJ/kg |
| Vaporization CO2 | * | 652 | - | 721 | kg/kg |
| Vaporization water | * | 4.53e3 | - | 6.8e3 | l/kg |
| Coarse machining energy (per unit wt removed) | * | 1.08 | - | 1.2 | MJ/kg |
| Coarse machining CO2 (per unit wt removed) | * | 0.0649 | - | 0.0717 | kg/kg |
| Fine machining energy (per unit wt removed) | * | 6.54 | - | 7.23 | MJ/kg |
| Fine machining CO2 (per unit wt removed) | * | 0.392 | - | 0.434 | kg/kg |
| Grinding energy (per unit wt removed) | * | 12.6 | - | 13.9 | MJ/kg |
| Grinding CO2 (per unit wt removed) | * | 0.756 | - | 0.836 | kg/kg |
| Non-conventional machining energy (per unit wt removed) | * | 109 | - | 120 | MJ/kg |
| Non-conventional machining CO2 (per unit wt removed) | * | 6.52 | - | 7.21 | kg/kg |

### Recycling and end of life

| | | | | | |
|---|---|---|---|---|---|
| Recycle | | ✓ | | | |
| Embodied energy, recycling | * | 8.1 | - | 8.96 | MJ/kg |
| CO2 footprint, recycling | * | 0.636 | - | 0.703 | kg/kg |
| Recycle fraction in current supply | | 39.9 | - | 44 | % |
| Downcycle | | ✓ | | | |
| Combust for energy recovery | | ✗ | | | |
| Landfill | | ✓ | | | |
| Biodegrade | | ✗ | | | |

**Table 24.** Datasheet of Silicon

## General information

**Designation**

Silicon, pure silicon

**Typical uses**

Microcircuits, precision instruments, glass, concrete, bricks, lubricants

| | |
|---|---|
| Included in Materials Data for Simulation | ✓ |

## Composition overview

**Compositional summary**

100% Si

| | |
|---|---|
| Material family | Ceramic (technical) |
| Base material | Si (Silicon) |

## Composition detail (metals, ceramics and glasses)

| | | |
|---|---|---|
| Si (silicon) | 100 | % |

## Price

| | | | | |
|---|---|---|---|---|
| Price | * 7.11 | - | 11.8 | GBP/kg |
| Price per unit volume | * 1.62e4 | - | 2.81e4 | GBP/m^3 |

## Primary production energy, CO2 and water

| | | | | |
|---|---|---|---|---|
| Embodied energy, primary production | 116 | - | 128 | MJ/kg |
| Sources: 46.3 MJ/kg (Williams, Ayres, Heller, 2002); 142 MJ/kg (Ecoinvent v2.2); 176 MJ/kg (Boustead, 2002) | | | | |
| CO2 footprint, primary production | 4.78 | - | 5.27 | kg/kg |
| Sources: 5.02 kg/kg (Ecoinvent v2.2) | | | | |
| Water usage | * 23.2 | - | 25.7 | l/kg |

## Processing energy, CO2 footprint & water

| | | | | |
|---|---|---|---|---|
| Grinding energy (per unit wt removed) | * 272 | - | 300 | MJ/kg |
| Grinding CO2 (per unit wt removed) | * 20.4 | - | 22.5 | kg/kg |

## Recycling and end of life

| | | | | |
|---|---|---|---|---|
| Recycle | ✗ | | | |
| Recycle fraction in current supply | 0.672 | - | 0.742 | % |
| Downcycle | ✓ | | | |
| Combust for energy recovery | ✗ | | | |
| Landfill | ✓ | | | |
| Biodegrade | ✗ | | | |