**Sustainability Assessment of Additive Manufacturing End-of-Life Material Management**

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**Data**

Figure 2. GREENSCOPE score indicator results for (a) efficiency, (b) environment, (c) energy, and (d) economic indicators. Calculated indicators with maximized radius value correspond to a 100% sustainability score (best) in their respective categories

|  |  |
| --- | --- |
| 1. Efficiency Indicators | 1. Environmental Indicators |
|  |  |
| 1. Energy Indicators | 1. Economic Indicators |
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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Indicators** | | | **Symbol** | **Value** | | | **Unit** | | **Best Value** | **Worst Value** | | **Score** | |
|  | **Efficiency** | | | | | | | | | | | | |
| Total Material Consumption | | | mmat,tot | 3,984 | | | kg/hr | | 344 | 13,760 | | 72.9 | |
| Mass Intensity | | | MI | 11.6 | | | kg input/kg product | | 1 | 40 | | 72.9 | |
| Mass Productivity | | | MP | 0.086 | | | kg product/kg material input | | 1 | 0 | | 8.6 | |
| Environmental Factor | | | *E* | 10.6 | | | kg waste/kg product | | 0 | 39 | | 72.9 | |
| Mass Loss Index | | | MLI | 10.6 | | | kg unconverted/kg valuable products | | 0 | 100 | | 89.4 | |
| Renewability-material index | | | RIM | 0.00053 | | | kg renewable/kg material input | | 1 | 0 | | 0.1 | |
| Breeding-material factor | | | BFM | 1.00053 | | | kg input/kg nonrenewable material | | 10 | 0 | | 10.0 | |
| Recycled material fraction | | | wrecycl,mat | 0.21 | | | kg recyclable material/kg material input | | 1 | 0 | | 21.3 | |
| Mass fraction of products designed for recycling | | | wrecov,prod | 1 | | | kg recyclable material/kg product | | 1 | 0 | | 100.0 | |
|  | **Environment** | | | | | | | | | | | | |
| Mass of hazardous materials input | | | mhaz,mat | 3,113 | | | kg/hr | | 0 | 3,984 | | 21.9 | |
| Specific hazardous raw materials input | | | mhaz,mat,spec | 9.05 | | | kg hazardous material/kg product | | 0 | 11.5 | | 21.9 | |
| Safety hazard, acute toxicity | | | SHacute tox | 592 | | | m3 polluted air/kg product | | 0 | 10,000 | | 94.1 | |
| Environmental Quotient | | | EQ | 221 | | | m3/kg | | 0 | 340 | | 34.9 | |
| Environmental hazard, air hazard | | | EHair | 417,890 | | | m3 polluted air/kg product | | 0 | 10,000,000 | | 95.8 | |
| Environmental hazard, water hazard | | | EHwater | 12,163 | | | m3 polluted water/kg product | | 0 | 100,000 | | 87.8 | |
| Environmental hazard, solid waste (inorganic pollutants) | | | EHsolid | 0.00030 | | | kg inorganic solid/kg product | | 0 | 1 | | 100.0 | |
| Environmental hazard, bioaccumulation (in food chain/soil) | | | EHbioacc | 31 | | | kg/kg product | | 0 | 100 | | 68.8 | |
| Total solid waste mass | | | ms,tot | 1,257 | | | kg solid waste/hr | | 0 | 1,282 | | 1.9 | |
| Specific solid waste mass | | | ms,spec | 3.66 | | | kg solid waste/kg product | | 0 | 3.7 | | 1.9 | |
| Solid waste mass for recovery | | | ms,recov | 347.5 | | | kg solid recoverable waste/hr | | 1,257 | 0 | | 27.6 | |
| Solid waste mass for disposal | | | ms,disp | 910 | | | kg nonrecoverable solid/hr | | 0 | 1,257 | | 27.6 | |
| Recycling mass fraction | | | ws,recycl | 0.28 | | | kg solid recovered/kg solid waste | | 1 | 0 | | 27.6 | |
| Disposal mass fraction | | | ws,non-recycl | 0.72 | | | kg nonrecoverable solid/kg solid waste | | 0 | 1 | | 27.6 | |
| Hazardous solid waste mass fraction | | | ws,haz | 0 | | | kg nonrecoverable hazardous solid/kg nonrecoverable solid waste | | 0 | 1 | | 100.0 | |
| Total hazardous solid waste disposal | | | ms,haz | 0 | | | kg nonrecoverable hazardous waste/hr | | 0 | 1,257 | | 100.0 | |
| Specific hazardous solid waste | | | ms,haz,spec | 0 | | | kg nonrecoverable hazardous waste/kg product | | 0 | 1 | | 100.0 | |
| Total non-hazardous solid waste disposal | | | ms,n-haz | 913 | | | kg non-hazardous waste/hr | | 910 | 0 | | 100.0 | |
| **Indicators** | | **Symbol** | | | **Value** | **Unit** | | **Best Value** | | | **Worst Value** | | **Score** |
|  | **Energy** | | | | | | | | | | | | |
| Total energy consumption | | Etotal | | | 63254 | MJ/h | | 44,769 | | | 447694 | | 95.4 |
| Specific energy intensity | | RSEI | | | 0.0230 | MJ/kg | | 0.016 | | | 0.16 | | 95.4 |
| Energy intensity | | REI | | | 0.0000427 | MJ/$ | | 0.000030 | | | 0.00030 | | 95.4 |
| Waste treatment energy | | WTE | | | -0.0185 | MJ/kg | | 0 | | | 0.0023 | | 100.0 |
| Solvent recovery energy | | SRE | | | 0 | MJ/kg | | 0 | | | 0.0023 | | 100.0 |
| Resource-energy efficiency | | ηE | | | 0.057 | MJ product/MJ feedstock | | 1 | | | 0 | | 5.7 |
| Renewability-energy index | | RIE | | | 0.00250 | MJ renewable/MJ total supplied | | 1 | | | 0 | | 0.2 |
| Breeding-energy factor | | BFE | | | 0.057 | MJ total output/MJ nonrenewable input | | 10 | | | 0 | | 0.6 |
| Energy for recycling | | Erecycl | | | 0.02 | MJ/kg | | 0.0 | | | 0.002298 | | 0.0 |
|  | **Economic** | | | | | | | | | | | | |
| Total process cost (end-of-life) | | TPC | | | 25,793,470 | $/yr | | 22,631,358 | | | 35,203,909 | | 74.8 |
| Annual operation of EoL Processes (COM) | | COM | | | 20,634,776 | $/yr | | 9,801,518 | | | 43,848,898 | | 68.2 |
| Specific raw material cost | | CSRM | | | 2.16 | $/kg | | 1 | | | 11 | | 85.6 |
| Total material cost | | Cmat. tot. | | | 5,945,864 | $/yr | | 2,020,657 | | | 29,336,591 | | 85.6 |
| Total energy cost | | CE, tot. | | | 1,774,922 | $/yr | | 821,013 | | | 8,019,199 | | 86.7 |
| Average cost of energy source | | CE, source | | | 0.000004 | $/kJ | | 0.00000172 | | | 0.0000168 | | 86.7 |
| Specific energy cost | | CE, spec. | | | 0.07 | $ energy cost/$ total | | 0.041 | | | 0.22 | | 84.2 |
| Total solid waste cost | | Cs tot. | | | 1,635,394 | $/yr | | 0 | | | 20,463,520 | | 92.0 |
| Solid waste cost fraction | | Cs, spec. | | | 0.06 | $ solid waste cost/$ total | | 0 | | | 0.79 | | 92.0 |
| Total liquid waste cost | | Cl tot. | | | 3,391,849 | $/yr | | 0 | | | 42,441,849 | | 92.0 |
| Liquid waste cost fraction | | Cl, spec. | | | 0.13 | $ liquid waste cost/$ total | | 0 | | | 1.65 | | 92.0 |
| Revenues from eco-products | | REV | | | 762,741 | $/yr | | 762,741 | | | 0 | | 100.0 |
| Revenues fraction of eco-products | | REVeco-prod | | | 1 | $/$ | | 1 | | | 0 | | 100.0 |