How Can Sustainable Manufacturing Save you Money and Help the Planet

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Introduction

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Learning Objectives

1. Compare different metal additive, subtractive and hybrid workflows.

2. Learn about sustainability metrics within manufacturing and how they impact the embodied carbon of manufactured components.

3. Learn about applying sustainability metrics to assess three manufacturing workflows to select the most sustainable methodology.

4. Evaluate how sustainability metrics can be predicted to enable the decision-making process within the design phase.
Presentation Agenda

1. Manufacturing’s Impact
2. What is Sustainable Manufacturing
3. The Case Study – Set Up
4. The Case Study – Manufacturing
5. The Case Study – Evaluation
6. Looking to the Future
Manufacturing’s Impact

Small Scalable Changes...

CO2 emissions from the: Metallurgy, Machinery and other Manufacturing based industries correspond to 9 Billion Tonnes of CO2eq
Manufacturing changes can have a big impact.
What is Sustainable Manufacturing?

“The creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources”

- Evaluating and reducing manufacturing costs
- Understanding and reducing manufacturing energy consumption
- Minimising raw material consumption and reducing waste
How to measure sustainability in manufacturing?
Leveraging an LCA to determine an embodied carbon value of a component
What problem are we trying to solve?

How do we Tackle Carbon Early with Smart and Efficient Production?

- **Produce Nothing** – Challenge the root cause for the need and explore alternative approaches
- **Produce Less** – Maximise the use of existing assets whilst optimising the operation / management to extend current lifespans
- **Produce Smart** – Optimise designed geometries to reduce resource consumption, whilst leveraging low carbon materials
- **Produce Efficiently** – Embrace new manufacturing technologies to reduce waste and operational carbon emissions

Adapted from: HM Treasury, 2013. *Infrastructure Carbon Review*
The Case study - Setup
Manufacturing Methods

Manufacturing Technologies Used

Additive Manufacturing
Laser Powder Bed Fusion (L-PBF)

Subtractive Manufacturing
CNC Milling

Additive Manufacturing
Direct Energy Deposition

https://www.ge.com/news/reports/these-engineers-3d-printed-a-mini-jet-engine
https://meltio3d.com/technology/
Manufacturing Methods

Additive Manufacturing
Laser Powder Bed Fusion (L-PBF)

Subtractive Manufacturing
CNC Milling

Hybrid Manufacturing
Direct Energy Deposition + CNC Milling

Manufacturing Machines Used

[Images of manufacturing machines]
Generative Design
Geometry Optimisation for mass reduction

Define
Create a generative design set up by:
• Defining Preserve Regions
• Defining Obstacle Geometries
• Applying Load Cases
• Select Manufacturing Methods and materials
• Select Outcome Goals

Generate
Wait for Generated Outcomes:
• Allow Generative Design to create optimized outcomes for your defined set up

Explore
Explore Outcomes:
• Explore the different generated outcomes for different manufacturing methods and materials selected
The Component

The Classic Triple Clamp Generative Example

Generative Design Set Up Defined

Original Design

Material = Stainless Steel 316
Part Mass = 2.28 kg

Generative Design Generated Outcomes Explored

2.5 Axis Outcome

Material = Stainless Steel 316
Part Mass = 1.71 kg

3 Axis Outcome

Material = Stainless Steel 316
Part Mass = 1.62 kg

Additive Outcome

Material = Stainless Steel 316
Part Mass = 1.53 kg
Component + Manufacturing Variations

Manufacturing processes

Original Design → CNC Machining → DED Hybrid → CNC Machining

GD 2.5 Axis Y+/− → CNC Machining → DED Hybrid → CNC Machining

GD 3 Axis Y+ → Paper Study → CNC Machining → DED Hybrid → CNC Machining

GD Additive Z+ → L-PBF (Solid) Finishing → CNC Machining → L-PBF (Lattice) Finishing → CNC Machining
Evaluating the Manufacturing Outcomes
Tracking manufacturing consumption through a tailor-made LCA

Energy + Consumables + Materials = Total CO2

- **Energy**: Operational energy consumption, monitored through IoT power monitors connected to the power inputs of the different machinery.
- **Consumables**: Volume of Argon gas, coolant liquid, and tools consumed during the manufacturing of the finished component.
- **Materials**: Raw materials used for the manufacturing of the finished component.
- **Total CO2**: Carbon equivalent values for Energy, Gas, Water, and Materials identified through leveraging LCA data bases and research papers.
Evaluating the Manufacturing Outcomes
Tracking Operational Energy Consumption

HAAS UMC - 1000

Power Monitor

IoT Base Station

Power Consumption Dashboarding

1. Current clamps connected to the HAAS and Meltio Power Inputs
2. Power Monitor communicates and transfers power consumption data to the base station
3. Base station uploads live power data to cloud data visualisation platform
Evaluating the Manufacturing Outcomes

Tracking Manufacturing Consumables

**Material Consumption**
- Calculated the ‘unprocessed’ Stainless Steel 316 required to manufacture each operations stock material*
- Measuring total stock material required to manufacture the component (Waste)

**Tool Consumption**
- Number of tools worn through during the manufacturing process
- Measured number and size of tools and inserts replaced during the milling operations

**Argon Consumption**
- Calculated the Argon consumption for the processing of steel to produce stock material*
- Measured Argon consumption during the manufacturing process

*Note: Consumption data marked with an asterisk are estimated or calculated values.
Calculating Embodied Carbon of Stock Materials

### Material Processing
- **Process Yield** = 100% (Start)
- **CO₂ / kg Steel** = 5.738 kg

### Continuous Casting
- **Process Yield** = 90%
- **CO₂ / kg Steel** = 0.672 kg

### Hot Rolling
- **Process Yield** = 95%
- **CO₂ / kg Steel** = 0.176 kg

### Wire Drawing
- **Process Yield** = 92%
- **CO₂ / kg Steel** = 0.362 kg

### Gas Atomisation
- **Process Yield** = 85%
- **CO₂ / kg Steel** = 1.299 kg

### Raw Material Required
- **CNC**
  - **Raw Material Required / kg** = 1.17 kg
  - **CO₂ / kg of Steel** = 7.683 kg CO₂e / 316 Stainless kg

- **DED**
  - **Raw Material Required / kg** = 1.27 kg
  - **CO₂ / kg of Steel** = 8.745 CO₂e / 316 Stainless kg

- **L-PBF**
  - **Raw Material Required / kg** = 1.31 kg
  - **CO₂ / kg of Steel** = 9.907 CO₂e / 316 Stainless kg

Values have been determined through collating research papers and accessing data from the LCA database ‘Ecoinvent’
The Case study - Manufacturing
Design & Manufacturing

Generating Additive & Subtractive Tool Paths – Milling Manufacturing Plan

Starting stock

Milling setup 1

Soft jaw fixture

Milling setup 2
Design & Manufacturing

Generating Additive & Subtractive Tool Paths – Hybrid Manufacturing Plan

- Original design
- Manufacturing design
- Deposition process
- Milling setup 1
- Milling setup 2
Design & Manufacturing

Generating Additive & Subtractive Tool Paths – Additive Toolpaths in Fusion 360

- Multi Axis Deposition Toolpaths – Tech preview released Nov. 2021
- Deposit entire components or add features to existing parts
- Create deposition conformal to planar, cylindrical, revolved or arbitrary surfaces
- Currently supports all major DED technologies
- Pass deposited stock forward to subsequent milling process
Design & Manufacturing

Generating Additive & Subtractive Tool Paths – Powder Bed Fusion Manufacturing Plan

Original design

Manufacturing design

AM setup

AM process

Latticed Design in Netfabb with 0.75mm Beam, 4 mm Cell Size
Design & Manufacturing
Original Design – Milling (Carbon Evaluation)

Manufacturing

**Step 1: Subtractive (Machining)**

**Step 2: Subtractive (Machining)**

Carbon & Cost Evaluation

*Total Carbon (kg CO2)*

- Material (Embodied): 106.79 kg
- AM (Operational): 8.61 kg
- Total: 115.46 kg CO2

*Total Cost ($)*

- Material: $287.31
- Consumables: $24.00
- Energy: $5.82
- Machine Overhead: $109.92
- Carbon Offset: $1.85
- Total: $427.05
Design & Manufacturing

Original Design – Hybrid (Carbon Evaluation)

**Manufacturing (WIP)**

*Step 1: Additive (DED)*

*Step 2: Post Processing (Machining)*

**Carbon & Cost Evaluation***

**Total Carbon (kg CO2)**
- Material (Embodied): 36.55 kg
- AM (Operational): 8.56 kg
- SM (Operational): 1.01 kg

**Total Carbon: 46.12 kg of CO2**

**Total Cost ($)**
- Material: $45.27
- Consumables: $0.37
- Energy: $5.76
- Machine Overhead: $606.28
- Carbon Offset: $0.74

**Total Cost: $657.68**
Design & Manufacturing
2.5 Axis Outcome – Milling (Carbon Evaluation)

**Manufacturing**

**Step 1: Subtractive (Machining)**

**Step 2: Subtractive (Machining)**

**Carbon & Cost Evaluation**

**Total Carbon (kg CO2)**
- Material (Embodied): 106.79 kg
- AM (Operational): 12.92 kg
- SM (Operational): 119.71 kg

**Total Cost ($)**
- Material: $287.31
- Consumables: $24.00
- Energy: $8.73
- Machine Overhead: $142.88
- Carbon Offset: $1.92
- Total: $462.92
Design & Manufacturing

2.5 Axis Outcome – Hybrid (Carbon Evaluation)

**Manufacturing (WIP)**

**Step 1 : Additive (DED)**

**Step 2: Post Processing (Machining)**

**Carbon & Cost Evaluation**

**Total Carbon (kg CO2)**
- Material (Embodied): 34.98 kg
- AM (Operational): 7.95 kg
- SM (Operational): 1.82 kg

Total Carbon: 44.74 kg of CO2

**Total Cost ($)**
- Material: $43.32
- Consumables: $0.34
- Energy: $595.98
- Machine Overhead: $5.35
- Carbon Offset: $0.72

Total Cost: $644.99
Design & Manufacturing
Additive Outcome – Solid (Carbon Evaluation)

**Manufacturing**

**Step 1: Additive (L-PBF)**

**Step 2: Post Processing (Machining)**

**Carbon & Cost Evaluation**

**Total Carbon (kg CO2)**
- Material (Embodied): 26.70 kg
- AM (Operational): 90.67 kg
- SM (Operational): 1.15 kg

Total Carbon: 118.52 kg of CO2

**Total Cost ($)**
- Material: $151.59
- Consumables: $13.28
- Energy: $60.68
- Machine Overhead: $215.23
- Carbon Offset: $1.90

Total Cost: $440.78
Design & Manufacturing

Additive Outcome – Latticed (Carbon Evaluation)

**Manufacturing**

**Step 1: Additive (L-PBF)**

**Step 2: Post Processing (Machining)**

**Carbon Evaluation**

**Total Carbon (kg CO2)**
- Material (Embodied): 20.51 kg
- AM (Operational): 79.43 kg
- SM (Operational): 1.15 kg

Total Carbon: 101.10 kg of CO2

**Total Cost ($)**
- Material: $116.44
- Consumables: $10.67
- Energy: $53.21
- Machine Overhead: $207.35
- Carbon Offset: $1.62

Total Cost: $387.67
The Case study - Evaluation
Which Is The Most Sustainable Outcome?
From a Cradle to Gate Perspective
Which Is The Most Sustainable Outcome?

Extending the Scope...

Circular Economy Practices!

- Recycling swarf from the milling operations leads to ~60% in Product Carbon

Including Operational Carbon

- Light weighting is important for Fuel Efficiency!

Machines and Batching
Predicting the Future
Making More Informed Manufacturing Choices

Our goal is to help you manufacture more sustainably

- **Design**
  - Molding
  - Subtractive
  - Additive

- **Estimate**
  - Manufacturing Energy Consumption
    - Print Statistics
    - Cost and energy
    - Cost
      - Country: United States of America
      - 1 kWh cost: 0.14 USD
      - 1 kg filament cost: 40.00 USD
      - Predicted energy usage: 0.33 kWh
      - Predicted support energy: 0.04 kWh
      - Filament used: 36 g
      - Energy cost: 0.05 USD
      - Filament cost: 0.01 USD
      - Support mass: 4 g
    - Energy Consumption
      - Shell: 71%
      - Infill: 14%
      - Support: 11%
      - Adhesion: 0%
      - Other: 1%

- **Create**

Customers are given predicted energy consumption insights based on their manufacturing simulations.
Making More Informed Manufacturing Choices

FFFF Energy Prediction Tool
Manufacturing-Influenced Design Choices

How could we provide manufacturing sustainability Insights into your design phase?
How can you manufacture more sustainably?

Think about small changes in manufacturing operations, technology or materials which could save you money and help the planet!