About Environmental Impacts of Metal AM

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Pasi Puukko, VTT

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Introduction

- Reduction of CO_2 emissions is vital to combat climate change. Action from all industrial sectors are needed to limit temperature increase to 1.5°C above pre-industrial level
- Additive manufacturing (AM) has established itself as viable new manufacturing process for final components
- Due to the additive (rather than subtractive) nature of the process, it is often referred to as resource-efficient or environmentally sustainable manufacturing
  - We wanted to create fact-based information, if it is and how

VTT GREEF focus

- VTT focused on environmental impacts of selected AM technologies and case studies related to them
- Technical objective:
  - To create a holistic understanding of *life cycle environmental impacts* and *benefits* of selected novel manufacturing technologies and *demonstrate their capabilities for product enhancement*.

In this presentation

- How is material efficiency of metal AM?
- How is energy efficiency of metal AM?
- Can we effect on those with process parameter?
- How metal AM should be used for positive environmental impact?

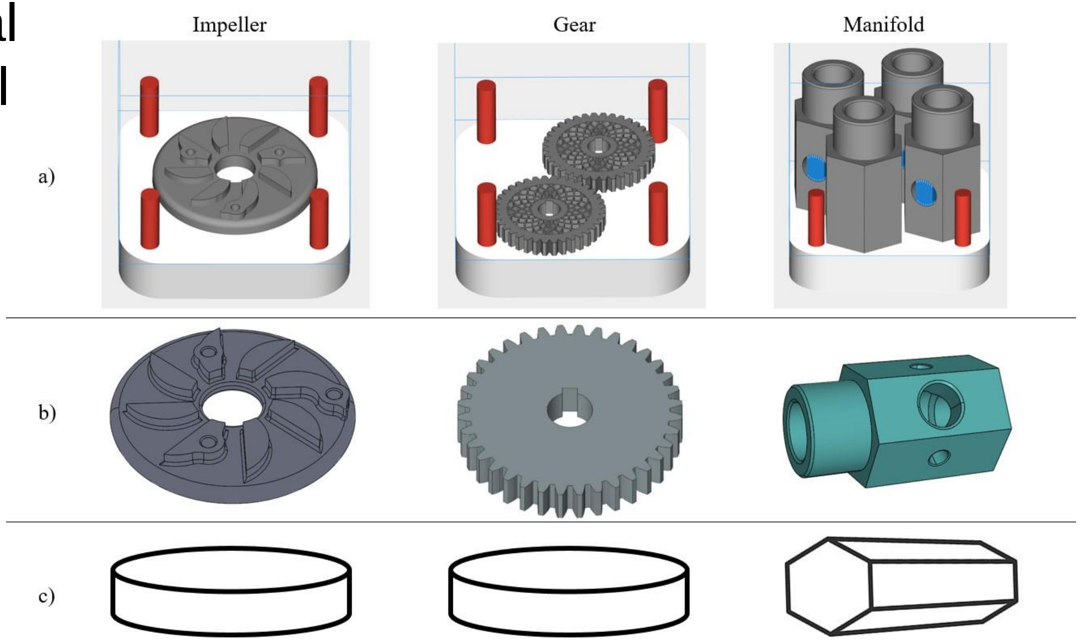
Scope of GREEF studies

- Metal additive manufacturing, **PBF-LB**, BJT, DED
  - SLM125HL & EOS M290
  - 316L Stainless steel
  - Measured **primary** data was used whenever possible
    - completed with data from ecoinvent, worldstainless and other databases when necessary
  - Electricity profile of Finland if not otherwise stated
  - Focus on using AM for final part production (not e.g. prototyping)
- Including material (processing), manufacturing and use phases
- Excluding design (as process) and end-of-life (recycling etc.)

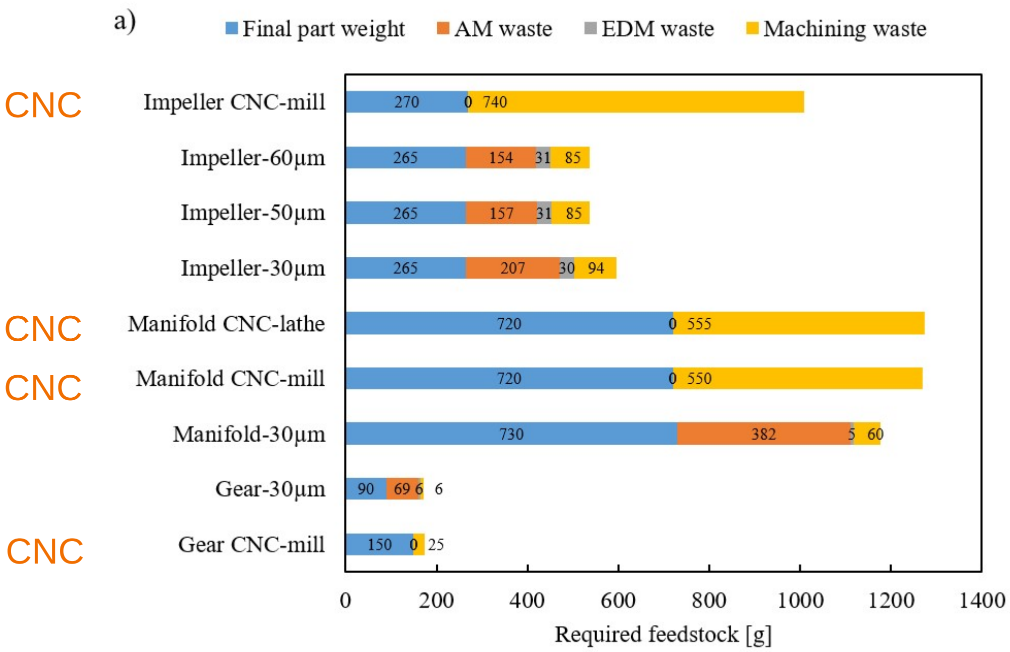
Material and energy efficiency

Comparison of PBF and CNC - geometries

- **Impeller** and **manifold** real components from industrial companies, **gear** just a generic gear, designed for this purpose
- Feedstock dimensions for CNC machining close to outer diameter to minimize waste
- PBF manufacturing at VTT, machining at Oulu University



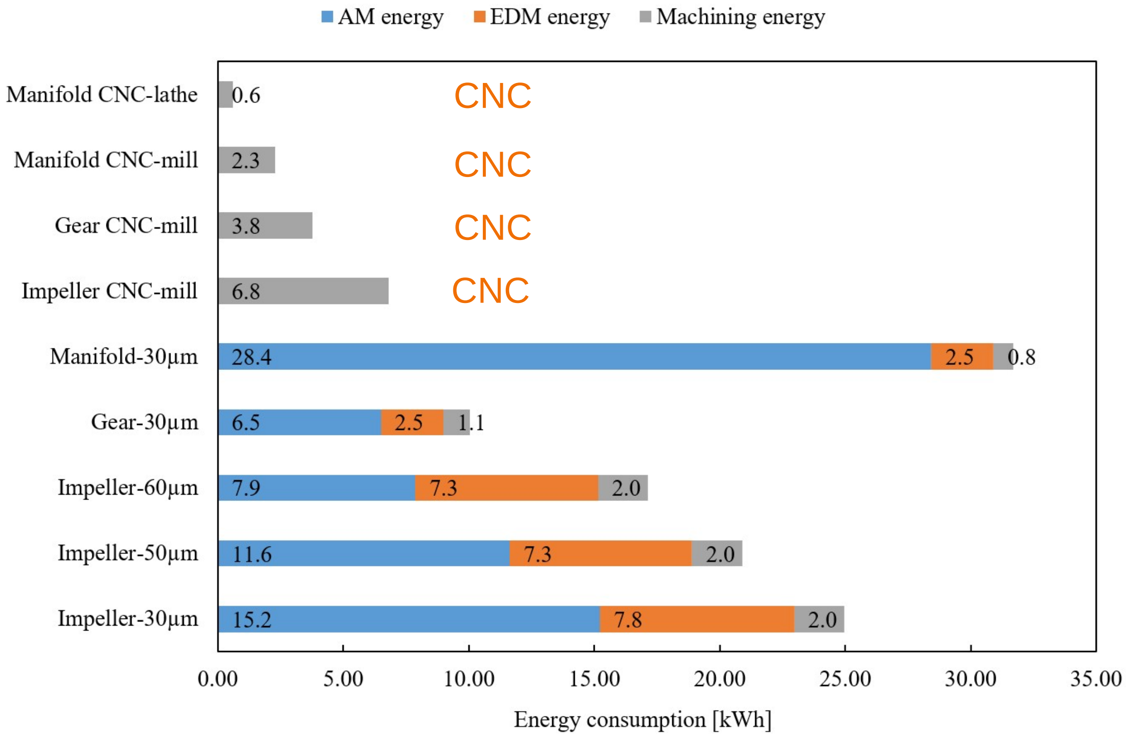
Material consumptions



- PBF-LB process required less feedstock:
  - impeller 41%
  - manifold 14%
  - gear 2%
- Powder waste in PBF to sieving and filters was surprisingly large (28-40% of printed part mass)

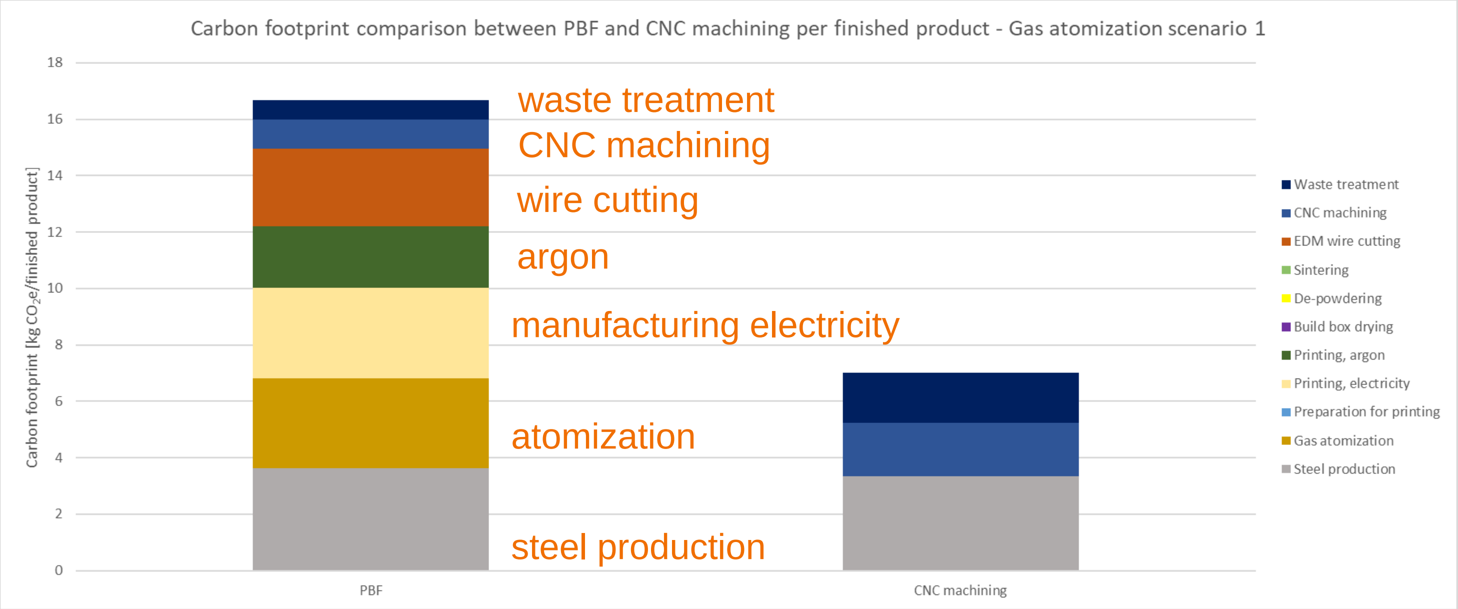
Energy consumptions

- PBF-LB consumed more energy than machining
  - manifold 14x
  - impeller 4x
  - gear 3x
- EDM energy consumption was surprisingly large



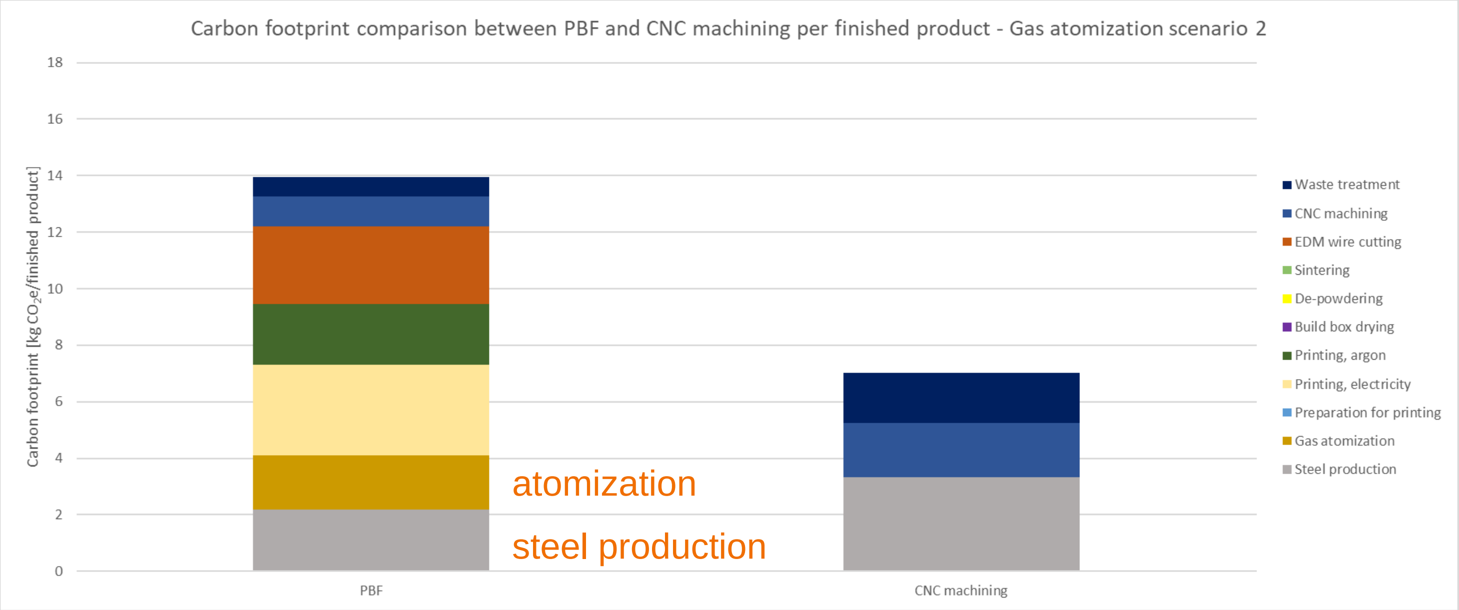
Impeller LCA - effect of feedstock material

Impeller – Carbon footprint – scenario 1



1) 60% of atomization is suitable for PBF-LB process and the rest i.e. 40% is scrap material
2) 60% of powder can be used for PBF-LB process but the rest of atomized powder is used in other processes

Impeller – Carbon footprint – scenario 2



1) 60% of atomization is suitable for PBF-LB process and the rest i.e. 40% is scrap material
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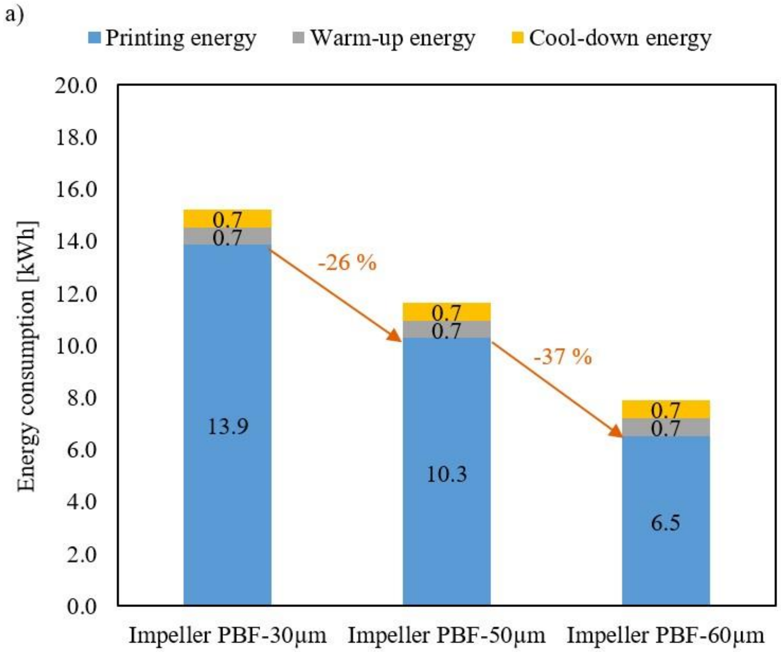
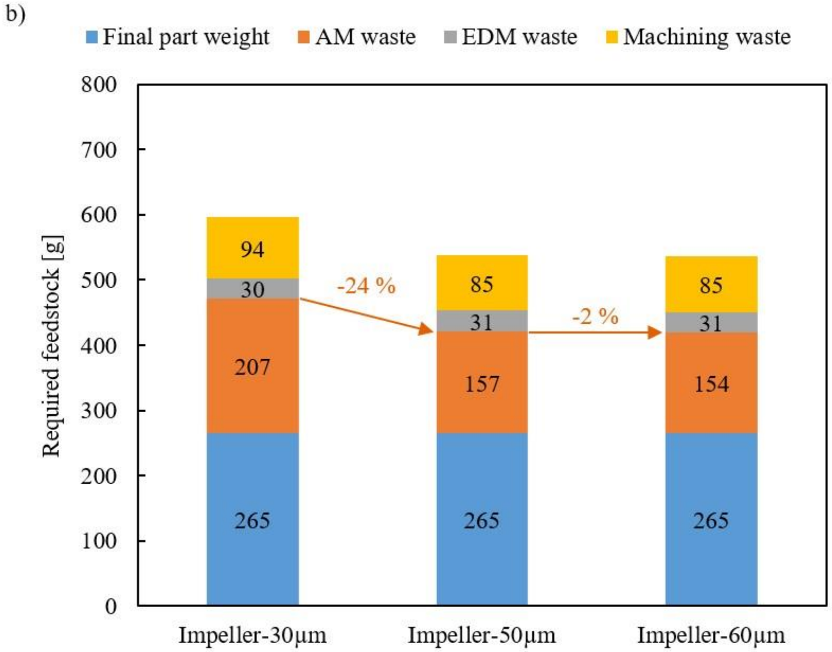
Some remarks about the feedstock materials

- As shown in previous slides, feedstock material production have significant effect on carbon footprint
- However, publicly available data related to atomization process is rather scarce
  - We have used measured data from our pilot scale atomizer
  - More information would be needed (energy, yield etc.)
- All our cases are based on stainless steel (316L) material
- From Ecoinvent (v. 3.9.1), GWP for stainless **steel** is **4.9** kg CO2/kg, while GWP for **titanium** production is **47.9** kg CO2/kg
  - Thus, one should be careful not to generalize results from one material group to another – without careful consideration

Process parameters

Effect of layer thickness on energy and material consumption in PBF





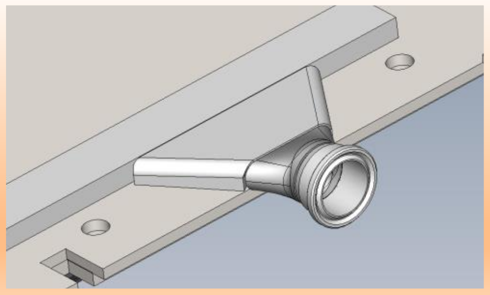
200W 250W 350W

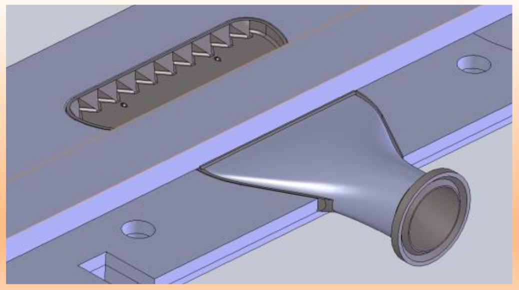
- Less scanning = faster process = less energy consumption

Use phase

Case filtrate nozzle

- essential part of machine used in the mining industry
- main purpose to increase the dry content of a slurry
- collects liquid from a filter plate and delivers it to output





Conventional:

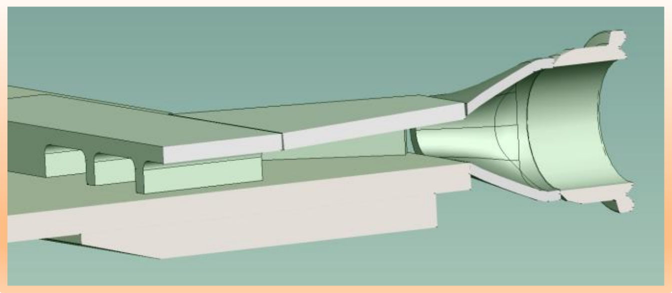
- consists of four separate pieces that are welded together
- manufactured from several blanks by cutting and flattening the pipe, machining the round bar with a lathe, laser-cutting and bending the steel sheet

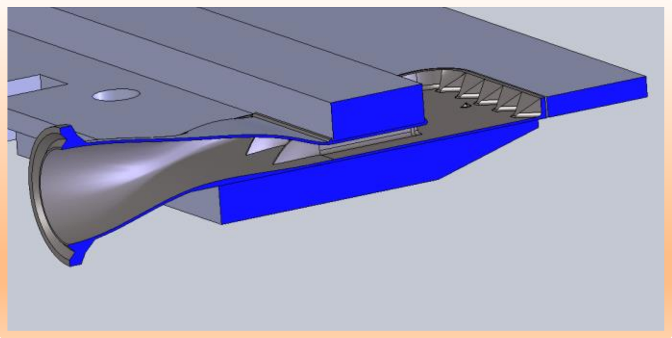
Additively manufactured:

- laser-based powder bed fusion (PBF-LB) using an EOS M 290 machine and AISI316L stainless steel at Delva Oy (Hämeenlinna, Finland)
- batch of 12 pieces, no assembly required.

Optimized structure of additively manufacture nozzle

- the number of parts decreased from four to one
- automated laser welding without additives became possible
- the pressure loss was reduced to approximately 70%, improving the product's performance





Data collection for carbon footprint (lifetime emissions) calculation

Conventional

- Input: mass of each used material blanks, transportation distance and mode, electricity consumption for each manufacturing process, as an input parameter.
- Output: mass of the components and mass of waste
- Neglected: effect of cutting fluids and machining tools

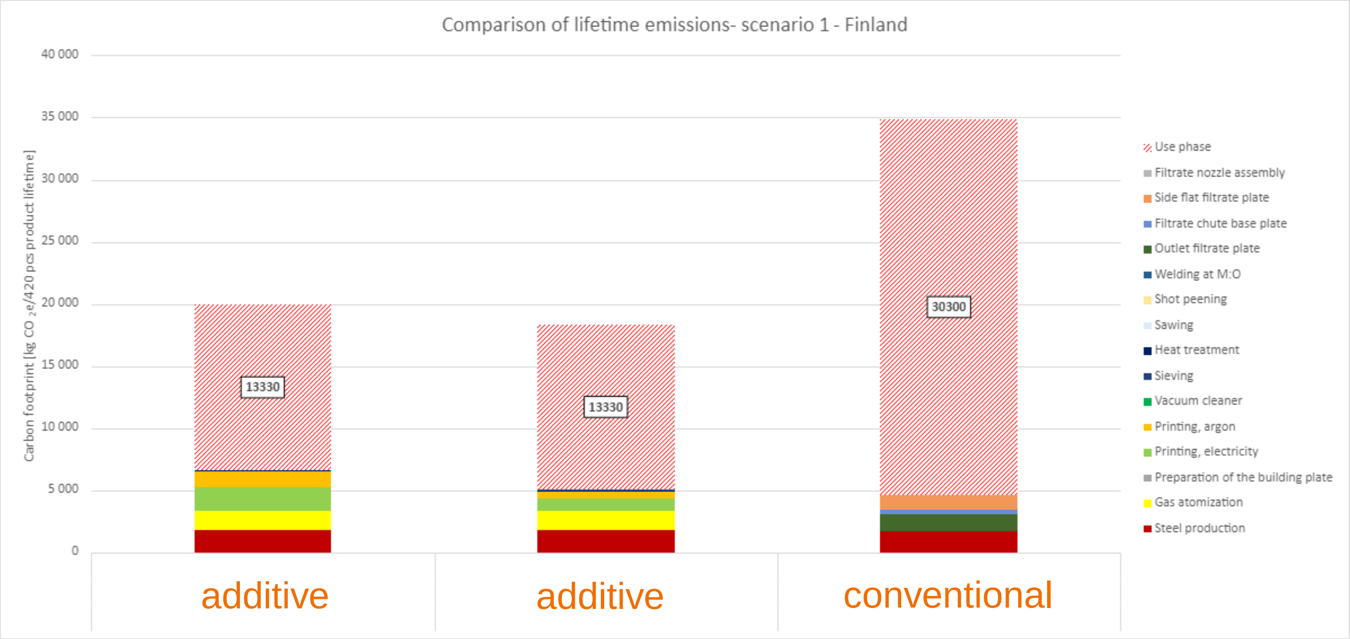
Additive

- Input: feedstock powder, Argon gas, electricity consumption for printing, heat treatment, sieving, band sawing, transportations
- Output: mass of manufactured parts, amount of waste
- Neglected: building plate, sawing oil, reusable balls for shot peening, vacuum cleaning, use of pressurized air

Use phase

- 20-year utilization period and 90% utilization rate
- Input values for energy consumption calculations based on (CFD) modelling, more precisely on pressure losses in the nozzles
- Other values (use cycles of pumps etc.), are based on real average values with machines consisting conventionally manufactured nozzles.

Comparison of lifetime emissions (carbon footprint) – scenario 1



Conclusions

- Additive Manufacturing can provide positive environmental impacts (i.e. reduce carbon footprint)

1. Utilizing design freedom of AM to improve component performance for better environmental sustainability – life cycle impacts
2. Utilizing capability to manufacture complex geometries, which traditionally require extreme machining and material removal – material efficiency
3. Running the AM processes such way they produce adequate quality with minimum negative environmental impacts - processing

- Environmental sustainability should not be taken for granted, but considered carefully case by case

beyond the obvious

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