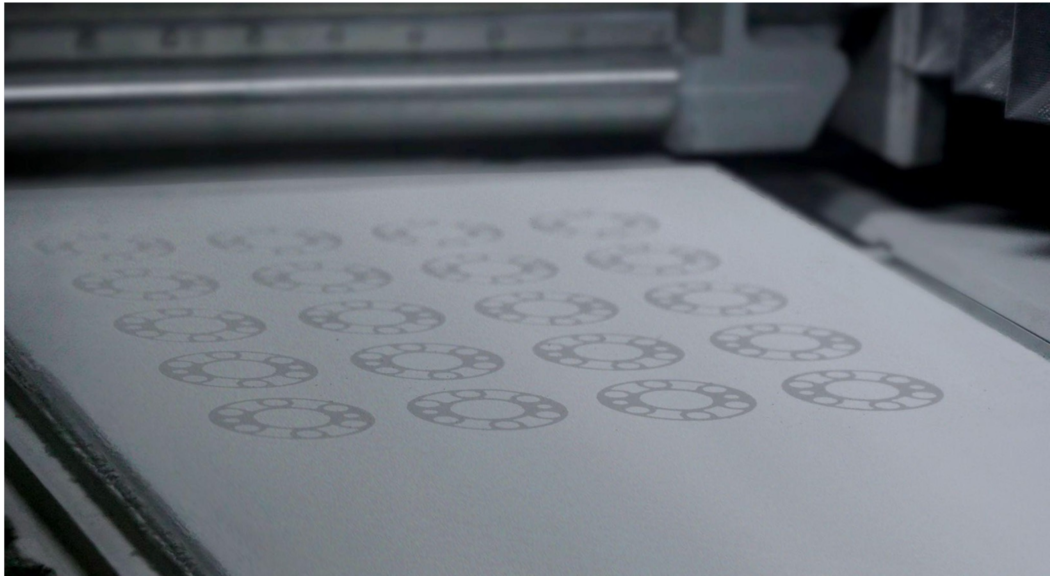
The Sustainability Case for Binder Jet 3D Printing – and AMGTA

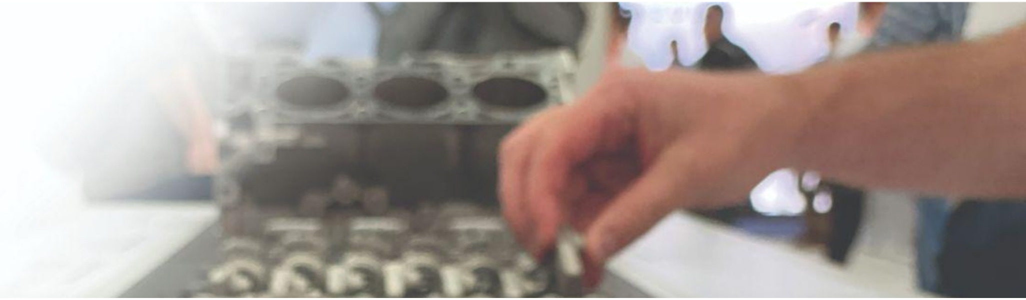
May 2023



Introduction

Jonah Myerberg

CTO, Co-founder



Desktop Metal (NYSE:DM) is driving **Additive Manufacturing 2.0**, a new era of sustainable, on-demand, digital mass production of industrial, medical, and consumer products. Our innovative 3D printers, materials, and software deliver the speed, cost, and part quality required for this transformation.

Binder Jet 3D Printing Life Cycle Analysis

September 2021

"The goal of this research is to **understand the environmental and economic impacts of binder jetting compared to conventional manufacturing**. Using LCA tools and modeling, the research will characterize impacts related to emissions of principal greenhouse gases and other associated impacts. Through robust and independent research studies, the AMGTA will continue to publish research reports that evaluate environmental sustainability within the additive manufacturing industry."

About the Center for Industrial Ecology. The Center for Industrial Ecology at the Yale School of the Environment was established in September 1998 to provide an organizational focus for research in industrial ecology. The Center brings together Yale staff, students, visiting scholars, and practitioners to develop new knowledge at the forefront of the field.

About Binder Jetting

Binder jetting is a method of 3D printing in which an industrial printhead quickly deposits a liquid bonding agent onto a thin layer of powdered particles, such as metals, foundry-grade silica, or ceramics. The process is repeated layer by layer using a map from a digital design file, until the object is complete.

Developed at MIT, commercialized by Desktop Metal and its Team DM brands, including ExOne. Fast and flexible, from materials to output types.

START LAYER: The recoater applies the first thin layers of powder — either ceramic, metal, or another material — in the print area or job box.

INKJET BINDER: A gantry of industrial printheads selectively applies binder to the powder to bind particles together where desired. Different binders work with different materials to achieve desired results.

LOWER & RECOAT: After each layer, the bed lowers for the next layer to be applied. Recoating is a critical step in binder jetting, as the consecutive powder layers must be precisely and compactly applied to deliver a high-quality precision part. Whether using coarse or fine particles, powder handling is a critical element of successful binder jetting.

RINSE & REPEAT: Once the next powder layer has been applied to the print area, the stage has been set for the next layer of binder to be selectively deposited. This recoating-and-binding sequence is repeated until the part is complete.

FAST LAYER SPEED: With a full sweep of printheads, a binder jet 3D printer can complete a full layer very quickly. This is one of the core benefits of binder jetting compared to other additive manufacturing methods.

PRINTING COMPLETE: Once the print job has finished, parts can be removed from the print area or job box. Depending on the material and binder used, additional curing and post-processing steps may be necessary. For certain sand binders, parts should be cured in an oven or microwave. Metal parts typically require curing and sintering.

Questions about the Sustainability of Metal Binder Jetting

We believed binder jetting was greener. But we needed to prove it.

Our customers – manufacturers – wanted and needed empirical evidence to make the right decisions.

1. Does binder jetting really reduce waste?
2. Does binder jetting really reduce greenhouse gas emissions?
3. Can binder jetting really enable more sustainable products through lightweighting or other design improvements?
4. Does binder jetting really matter when it comes to improving the sustainability of metal manufacturing?
5. What if you lightweighted a part and moved to a distributed manufacturing model, which our tech enables?

We also needed to say **how much better** binder jetting was than the status quo, to help manufacturers decide: was changing worth it?

AMGTA and researchers worldwide are helping us answer these questions with independent studies.

The World Needs Greener Metal Manufacturing

IRP, Global Resources Outlook 2019: Natural Resources for the Future We Want

A Report of the International Resources Panel, United Nations Environment Programme

2019

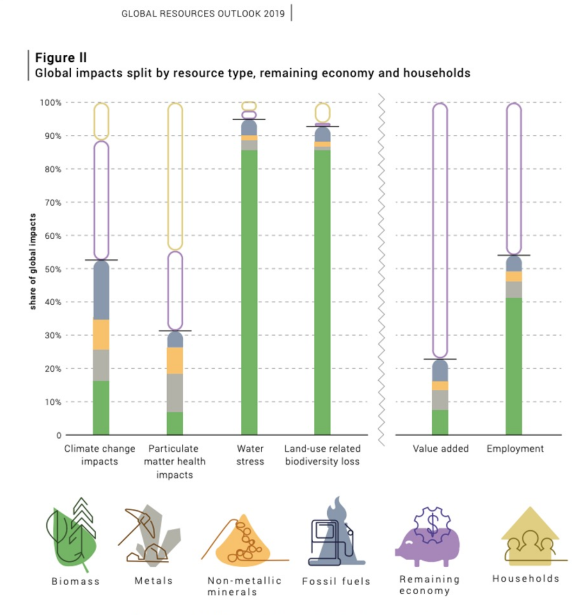
ISBN: 978-92-807-3741-7

Metal production accounts for approximately 10% of global GHG emissions.

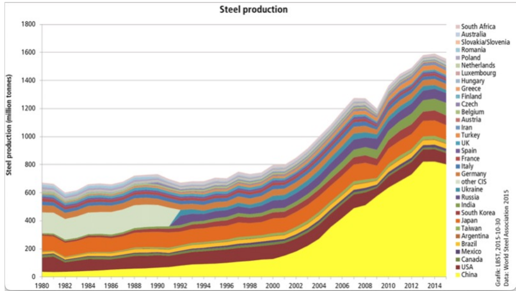
Between 2000 to 2015, the climate change and health impacts from **extraction and production of metals** approximately doubled.

Among metals, the global iron-steel production chain **causes the largest climate change impacts and represents around one quarter of global industrial energy demand**.

Due to considerable production amounts and high energy requirements, aluminium production is also a significant contributor to the climate change impacts of metals, while for copper and precious metals, **toxicity impacts are the major concern**.



Sources: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018), combined with land-use data (Chapter 2) and impact assessment methods (Section 3.1) of the Global Resources Outlook 2019, reference year 2011



The World Needs Greener Metal Manufacturing

Future greenhouse gas emissions from metal production: gaps and opportunities towards climate goals”

Research Institute of Science for Safety and Sustainability, National Institute of Advanced Industrial Science and Technology (AIST), Japan.

Published in Energy & Environmental Science, The Royal Society of Chemistry. 2022.

https://pubs.rsc.org/en/content/articlelanding/2022/ee/d1ee02165f

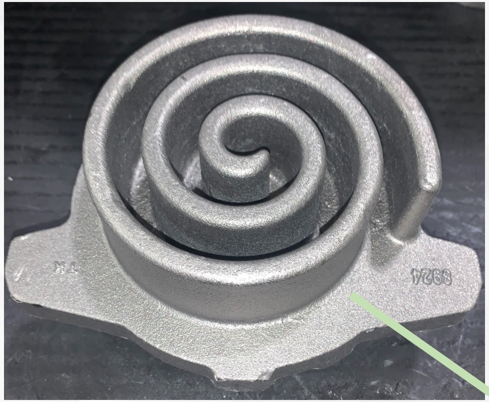
“Climate change is an urgent global challenge, and greenhouse gas (GHG) emissions from metal production contribute to a substantial part of total emissions. … Therefore, projecting future GHG emissions associated with metal production and exploring effective measures to alleviate GHG emissions are **essential for achieving climate goals**.”

“Lowering the saturation value of per capita in-use metal stock and improving emission intensity could be effective for reducing GHG emissions ...”

Project Goals

- Growth of binder jetting for cost advantages and potential for larger volume production
- Understand associated greenhouse gas emissions vs traditional methods
- Study an industrial part in production

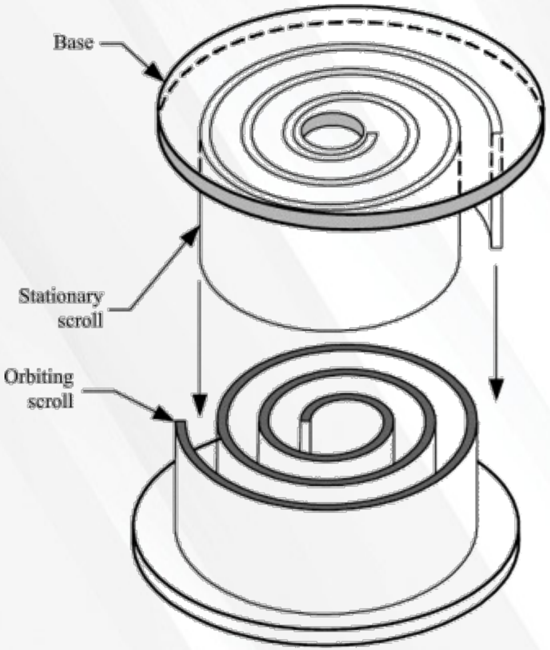
Evaluation Part



- Steel Scroll
- About 6-inches in diameter
- Used in Trane Technologies HVAC products, one shown here, 2 per set

Methodology – Scope & System Boundaries

- Evaluate emissions of scroll set in HVAC application
- Scroll Set includes orbiting and fixed scrolls



Methodology – Scope & System Boundaries

- **Traditional Manufacturing**
  - Sand casting - with machining
- **Additive Manufacturing**
  - Binder Jetting – with curing and sintering

- Both processes include plating and finishing

Methodology – Scope & System Boundaries

- **Functional Unit:**
  - One scroll set comprised of orbiting and fixed scrolls

- **Cradle-to-Gate manufacturing life-cycle inventory model**

- **Life cycle stages included:**
  - Raw material production and transportation

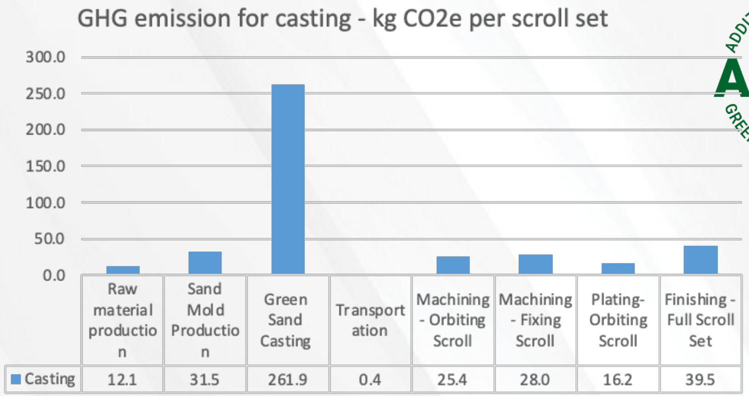
Methodology – Scope & System Boundaries

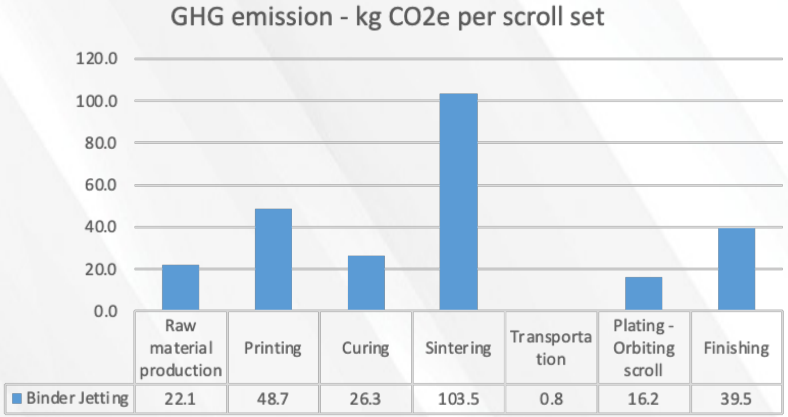
- **Leverage Life-Cycle Inventory (LCI) for Casting and Machining**
  - Adapted from existing literature, validated by comparing to Ecoinvent
- **Leverage Life-Cycle Inventory for Binder Jetting**
  - Provided by Desktop Metal / ExOne

Results and Discussion

- Sand casting (CO_2-eq)
  - 415 kg – total
  - 262 kg – casting
  - 40 kg – finishing
  - 53 kg – machining
  - 32 kg – sand mold
  - 12 kg – raw material production

- Binder jetting (CO_2-eq)
  - 257 kg – total
  - 103 kg – sintering
  - 41 kg – printing
  - 26 kg – curing
  - 22 kg – raw material production





Findings of the Yale LCA Study

FINDINGS

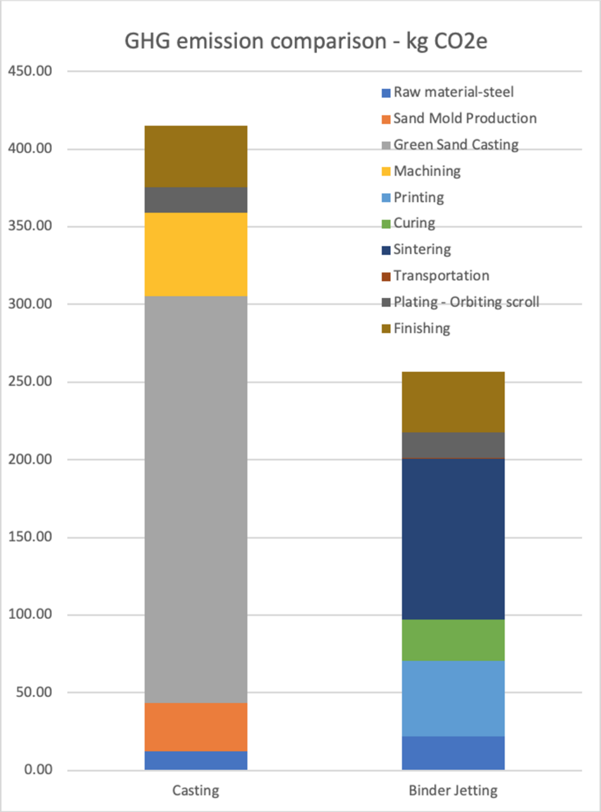
Cradle-to-gate life cycle:

- Metal casted part: 415 kg of C02
- Binder jetted part: 257 kg of C02

Conclusion: Binder jetting can reduce cradle-to-gate greenhouse gas emissions by 38% over traditional sand casting.

While the binder jetting process has the potential to reduce GHG emissions, its effectiveness depends on a variety of factors, such as electricity mix and unit volume of print job.

Both the sandcasting and binder jetting process were highly dependent on the electricity mix used for manufacturing.

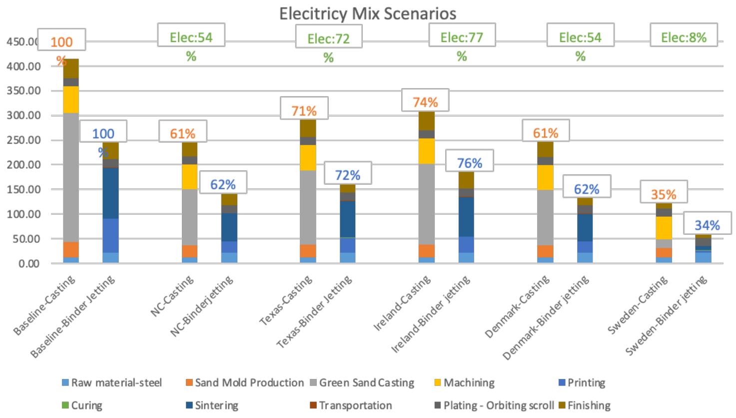


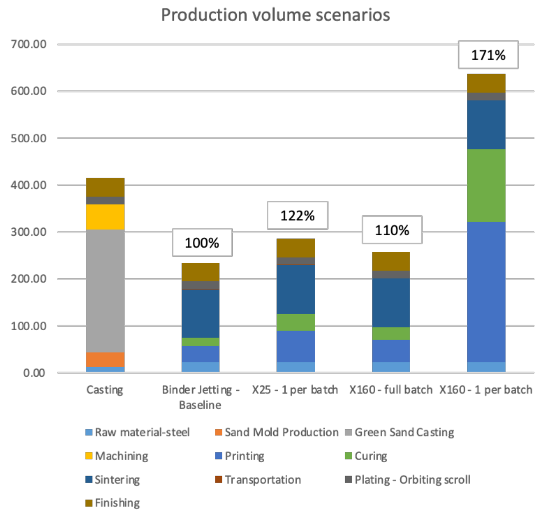
A Growing Understanding of Binder Jet’s Sustainability

FINDINGS

- Benefits were less pronounced, but still evident, in areas where cleaner energy is more common such as Sweden.

- The volume of the print job also played a key role in delivering a bigger benefit, with a larger print volume delivering the highest comparative benefit.





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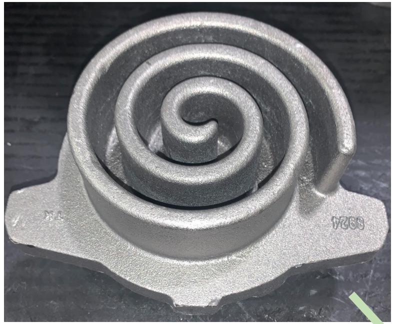

“Trane Technologies is committed to boldly challenging what's possible for a sustainable world. That includes designing advanced climate control solutions that can be manufactured and operated with reduced environmental impact. Metal additive manufacturing (AM) will become an increasingly viable tool in that pursuit, and binder jetting's comparably higher speed and lower cost among AM technologies make it particularly promising for manufacturing HVAC components at relevant production volumes.

Prior to this project, uncertainty about the life cycle emissions of binder jetting versus conventional manufacturing approaches was a barrier to AM adoption. With the results of this study, Trane Technologies is in a better position to comprehensively consider AM's cost, productivity and environmental impact earlier in a product's design cycle, when risk is lowest, and the potential benefits are highest.”

-- Kevin Klug, Lead Additive Manufacturing Engineer, Trane Technologies

Binder Jet Gets High Scores for Material Efficiency

Metal Powder Recyclability in Binder Jet Additive Manufacturing

School of Mechanical, Industrial and Manufacturing Engineering, Oregon State and Advanced Technology and Manufacturing Institute (ATAMI)

2020

https://doi.org/10.1007/s11837-020-04258-6

“The recyclability of 316L stainless steel powder in the binder jetting process has been determined. …

“SS 316L powder was **recycled 16 times**, with each recycling step occurring after a BJT cycle. The characteristics of the powder, including the PSD and morphology, had significant effects on its packing behavior (spreadability, flowability, and green density) in the print bed, and thereby on the densification behavior and mechanical properties of the BJT parts.

“It was found that, despite the slight changes in the powder characteristics, the **mechanical properties of the parts manufactured by BJT using the fresh and recycled powder were nearly equivalent**.

“During recycling up to 16 times, about 4 vol.% of the processed powder was collected as waste due to agglomeration, being oversized, and possible contamination with binder, indicating an **overall efficiency of material consumption of up to 96%.”**

Thank You to Yale, Trane Technologies, and AMGTA!