3D METAL PRINTING
EXPERIENCE AND TECH TOUR

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3D METAL PRINTING MAGAZINE

Environmental Impacts of Metal Additive Manufacturing

Sherry Handel

Executive Director

Additive Manufacturer Green Trade Association

www.amgta.org

Advancing Sustainability Through LCA Research

State of Knowledge: **Environmental Impacts of Metal Additive Manufacturing**

Dr. Jeremy Faludi, TU Delft, Faculty of Industrial Design Engineering

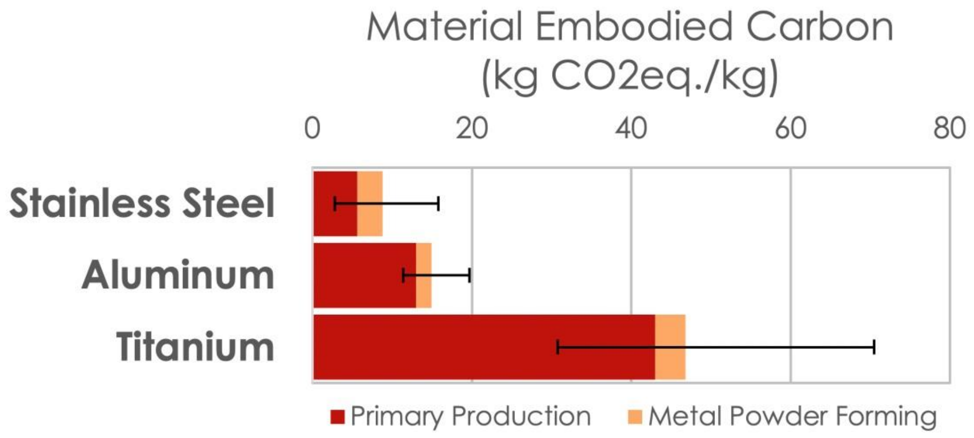
Corrie Van Sice, Dartmouth College, Thayer School of Engineering

Image courtesy of Airbus

Image from GE Aviation

Table of Contents

Impacts of material choice:



- Titanium has much higher embodied impacts (kg CO_2eq. / kg material production).
- Material choice also affects process energy (melting point, thermal conductivity, reflectivity).

Impacts of metal additive versus conventional manufacturing, excluding machining processes

Processing energy impacts per kg:

Stainless steel AM = **7 – 100x** CM
Aluminum AM = **20 – 700x** CM
Titanium AM: **5 – 50x** CM

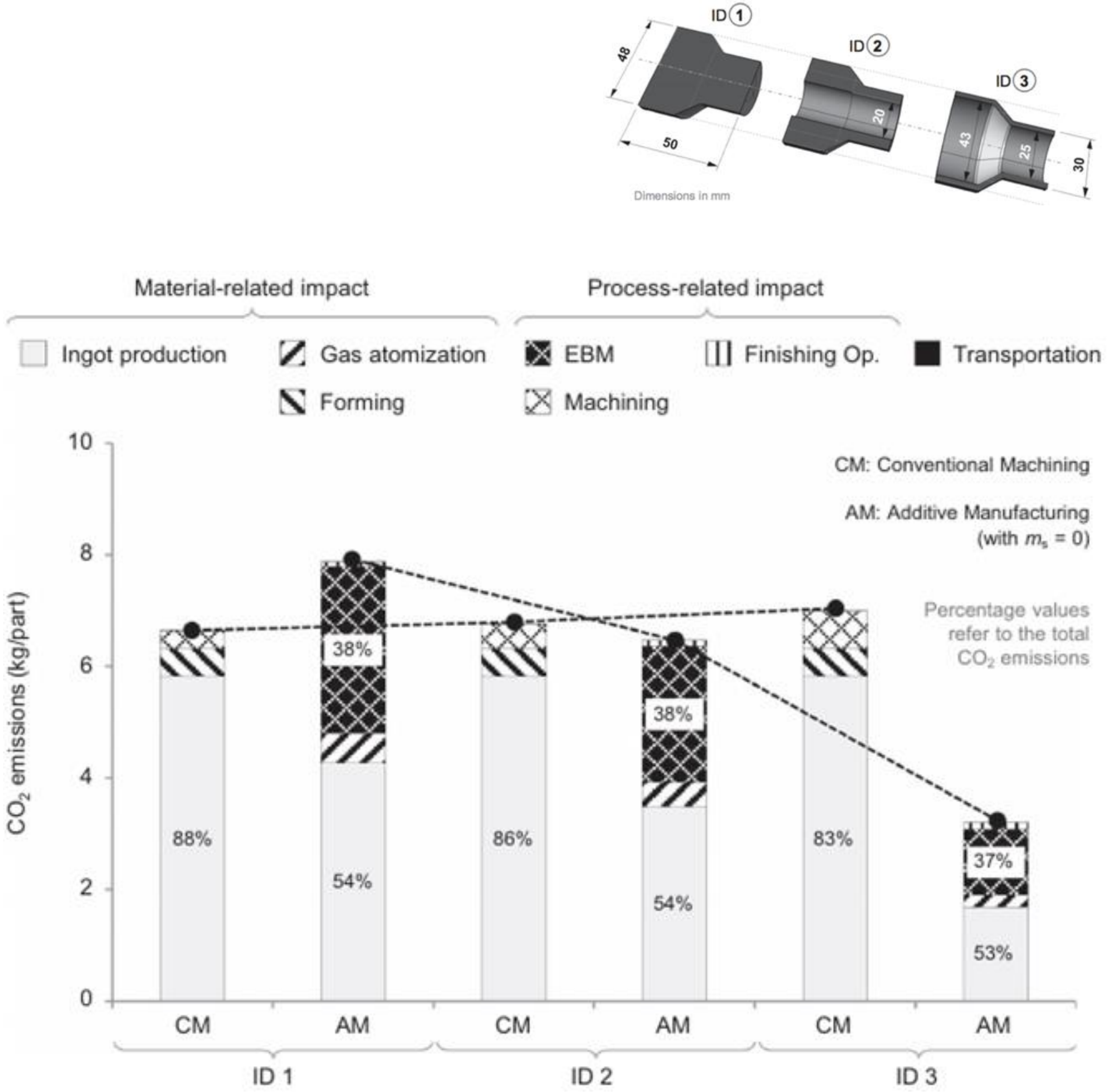
Processing + material impacts per kg:

Stainless steel AM: **4x – 8x** CM
Aluminum AM: **5x – 8x** CM
Titanium AM: **1.4x – 1.7x** CM

These ratios of kg CO_2-equivalent emissions per kg material processed (design and end use agnostic) come from comparing published life cycle assessments of metal additive mfg. (AM) to Granta EduPack data of conventional mfg. (CM) processes, including casting, extrusion, rolling, forging, and wire drawing (not machining). The large ranges mean further research is required.

Impacts of AM versus machining

- Cannot compare impacts per kg of material: AM impacts grow per kg of material added, machining impacts grow per kg removed.
- Analyzing 3 different part geometries showed crossover where AM is more sustainable than machining titanium.
- AM process energy was always higher than machining, but material impacts were lower. More research is needed.



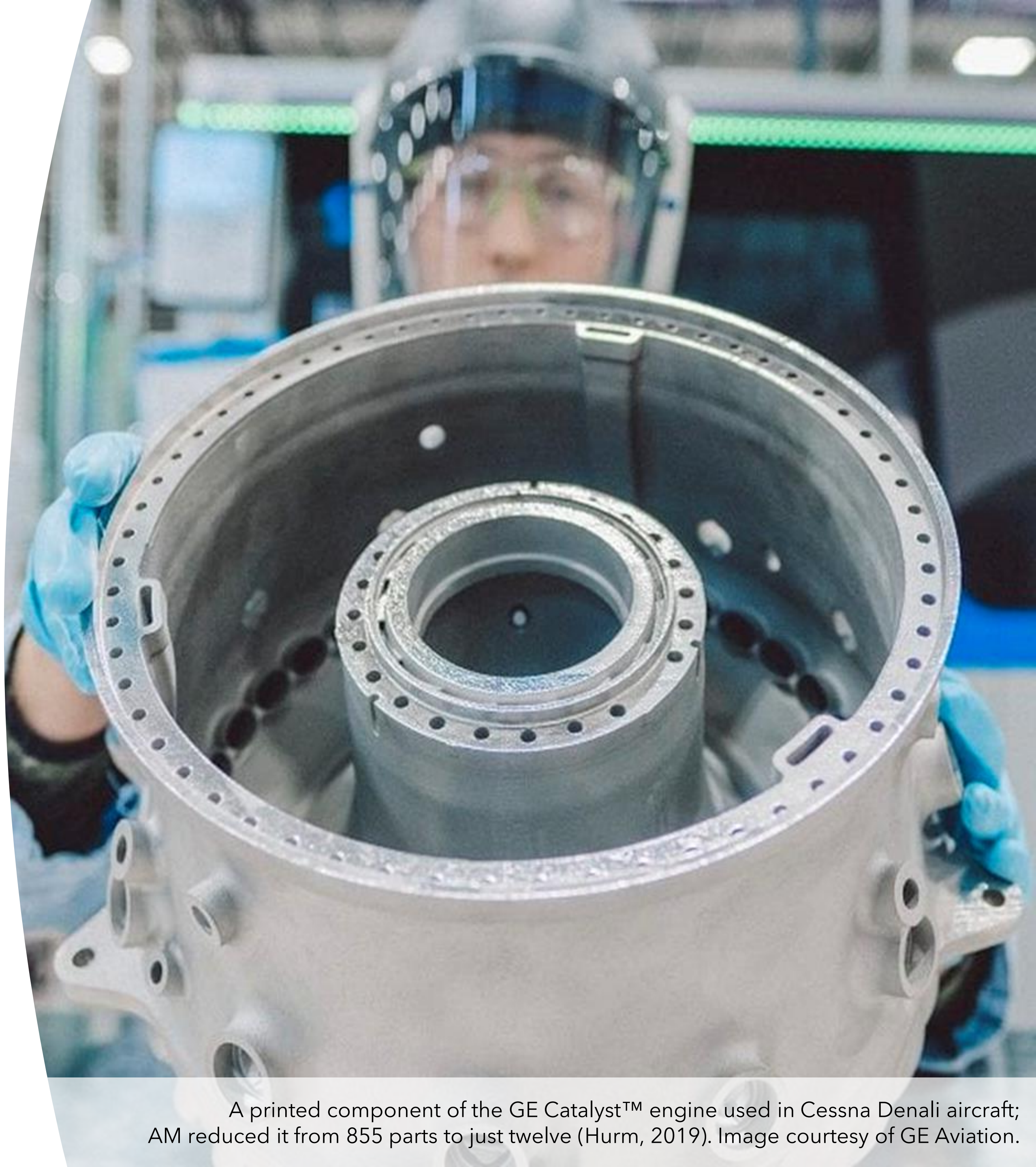
Images from Priarone, P.C., Ingarao, G., Lorenzo, R. di, Settineri, L., 2017. Influence of Material-Related Aspects of Additive and Subtractive Ti-6Al-4V Manufacturing on Energy Demand and Carbon Dioxide Emissions. *Journal of Industrial Ecology* 21, S191–S202.

Improving impacts of metal AM versus CM

AM can be more sustainable than CM if part designs are optimized to greatly:

- **Reduce material impacts**
  (usually by saving mass)
- **Consolidate parts**
  (avoid several manufacturing steps)
- **Optimize whole-lifetime impacts**
  (usually saving fuel during use via reduced mass)

More research could find crossover points and achieve benefits more easily.



A printed component of the GE Catalyst™ engine used in Cessna Denali aircraft;
AM reduced it from 855 parts to just twelve (Hurm, 2019). Image courtesy of GE Aviation.

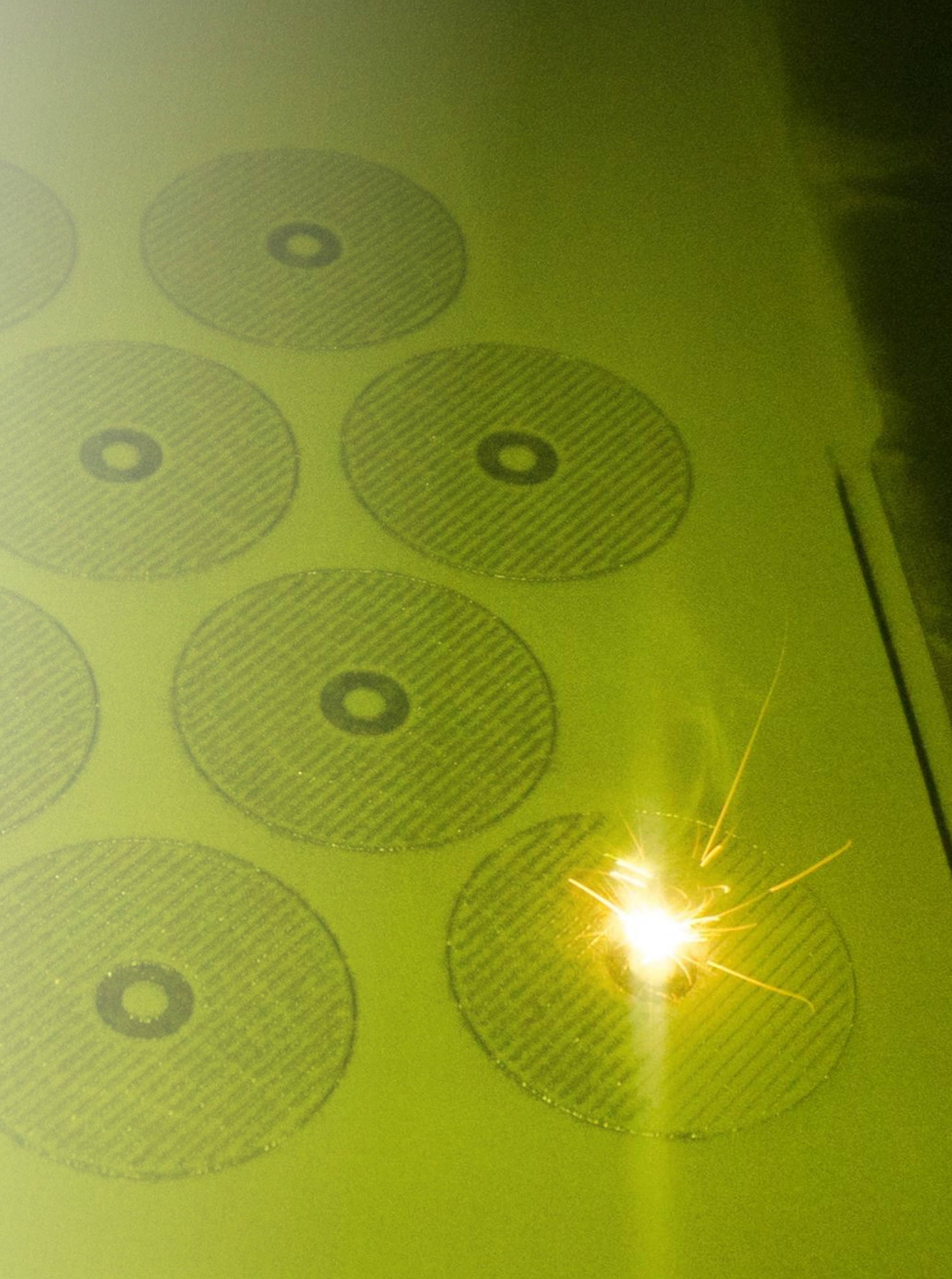
Improving process energy impacts

Utilization — Sharing printers to minimize idle space & time dramatically improves impacts per part.

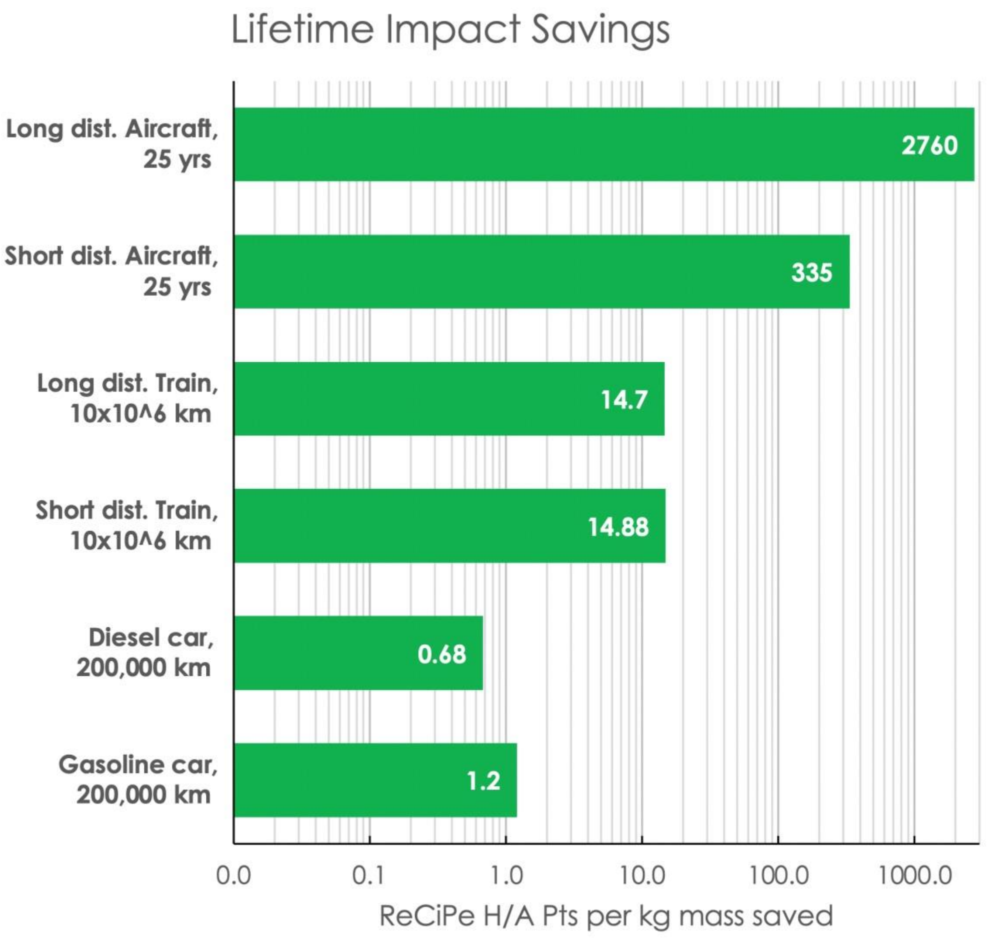
Material choice — Lower melting point, reflectance, thermal conductivity. Eliminate melting?

Post-processing — Minimize finishing steps (e.g., machining).

Avoid tooling — For low production quantities, AM avoids impacts of tooling.



Use phase: aerospace benefits from metal AM



- Reduced mass saves fuel during use, and fuel use greatly overshadows manufacturing impacts. (In aerospace only, not other vehicles.)

- Many aerospace parts are complex hollow shapes
  - Here, AM is lower manufacturing impact than machining
  - AM consolidates parts, saving manufacturing steps

Data for graph from Kellens, K., Baumers, M., Gutowski, T.G., Flanagan, W., Lifset, R., Duflou, J.R., 2017. Environmental Dimensions of Additive Manufacturing: Mapping Application Domains and Their Environmental Implications. *Journal of Industrial Ecology* 21, S49–S68.

AM powder recycling and reuse

- Reusing powder usually does not harm part performance, but more research required.
- Reliable powder recycling technologies are needed.

Health & safety

- Metal powders introduce workplace hazards, but PPE & safe material handling mitigate risk.
- Nano-particles are produced, with unknown effects. Recommend regular worker toxicity screening.

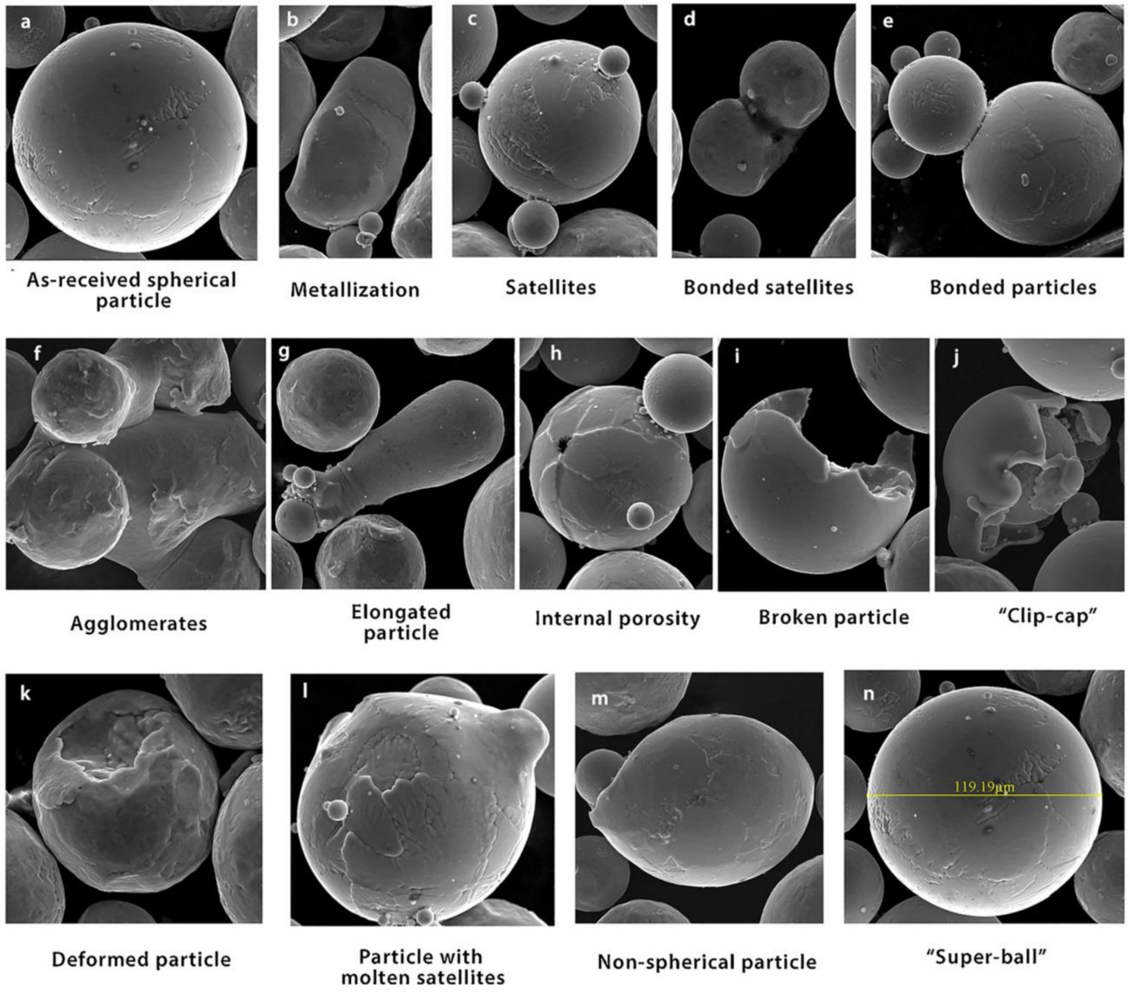


Image from Popov, V.V., Katz-Demyanetz, A., Garkun, A., Bamberger, M., 2018. The effect of powder recycling on the mechanical properties and microstructure of electron beam melted Ti-6Al-4 V specimens. *Additive Manufacturing* 22, 834–843.

Next steps for research

More research comparing AM to CM and showing how to improve.

Specifically, life cycle assessments that:

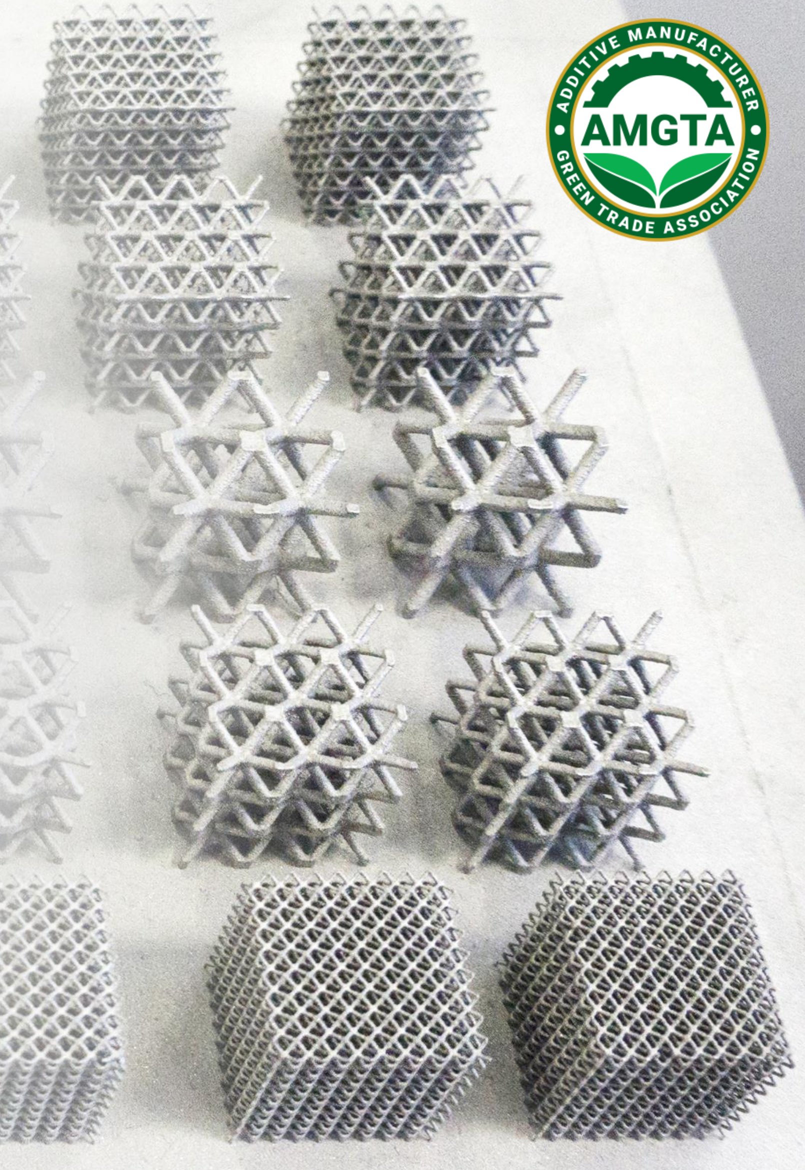
- Measure more printer technologies
- Model all life cycle stages
- Make fair comparisons with standard part(s) & scenarios
  - Varying geometries & utilization rates
  - Relevant to applications
  - Identify sustainability crossover points
- Measure many impact types (not merely CO_2)
- Make prioritized recommendations

Image from Sintavia

Next steps for development

Improve impacts of AM technologies by:

- Maximizing printer utilization (fewer printers, shared more)
- Improve material impacts & resource circularity
- Minimize print energy (efficiency & material choice)
- Check printer operators for hazard exposure
- Design for reduced failure rates



Other opportunities: process optimization, in-situ controls, use-phase performance, powder health & safety, recycling & end-of-life, AM for repair.

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Rusal America

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Advancing Sustainability Through Research

- November 2020 – Metal AM Sustainability Literature Review by researchers at Delft University of Technology and Dartmouth College.
- Summer 2021 – LCA Case Study comparing Binder Jet AM with conventional manufacturing of impeller parts.
- Fall 2021 – LCA Case Study comparing an aerospace part manufactured with LPBF AM as compared to manufacturing a cast part.
- Polymer LCA Research - TBD

Trends: Trade Press Attention

3D FEATURE

Additive Manufacturing

A Path to Sustainable Success

AM offers a viable alternative to traditional manufacturing, and a cleaner one. Formed to promote these views: the Additive Manufacturer Green Trade Association.

This Inconel 718 aircraft-engine bracket, redesigned and optimized for AM by Sintavia as a test project to explore the environmental impact of AM, offers a 20-percent weight reduction over the original part, with a 50-percent increase in durability. The longer-life part can cut jet-fuel usage dramatically, according to Brian Neff, Sintavia founder and CEO.

FOCUS ON THE NEW NORMAL FOR DESIGN

PROTOTYPE AND MANUFACTURE ||| 3D Printing

Sustaining the Future of 3D Printing

Experts share their sustainability approaches for manufacturing the way to a more planet-friendly future.

BY STEPHANIE SKERNIVITZ

3D printing has many merits, two of which are its ability to generate less waste in the final product compared to other manufacturing processes, and that it lends itself to functional design. Yet it's not enough to rest on past environmental achievements if companies expect to remain successful green leaders well into the 21st century. Manufacturers that anticipate not only surviving but thriving in the future are constantly seeking ground-breaking ways to "green" their processes. Under the sustainability umbrella, there's a push toward more recyclable materials, green-certified best practices and an enhanced global supply chain to name a few. In what follows, experts across the industry share their reci-

Sustainability in Additive Manufacturing

7 Ways 3D Printing Helps You Become Eco-Friendly

by Carolyn Schwaar
Published Jan 4, 2021

3dpbm | Insights

Sustainability

The vital role of sustainability across additive manufacturing

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HIGHLIGHT STORIES TALKING ABOUT INDUSTRY NEWS

THE ROLE OF SUSTAINABLE DESIGN

by Sherry Handel – 2020/11/02*

In many areas of additive manufacturing, sustainability is receiving increasing attention. With the Sustainable Design & Products Panel, Formnext Connect is focusing on this important topic even more.

On November 12 at 9:30am CET, Moderator Sherry Handel, Executive Director of the Additive Manufacturer Green Trade Association (AMGTA) will host an insightful discussion on the role of sustainable design in the additive manufacturing process. It brings diverse and thoughtful perspectives from entrepreneur, Romain Paul, founder of »Yuyo – the world's most sustainable surfboards made from biocomposites and 3D printed plastic waste«; academic researcher, Susan MacKay, Ph.D., Senior R&D Program Manager, Advanced Structures and Composites Center, University of Maine; and sustainable design expert Jeremy Faludi, Ph.D., principal of Faludi Design; Assistant Professor of Design Engineering, Technical University of Delft; and adjunct faculty of engineering at Dartmouth College.

Trends: Industry Talks on Sustainability

Jan. 27: TIPE 3D Printing 2021 Conference – Sustainability & Circular Economy Panel

Jan. 29: 3D Friday Talk Show – Sustainability: Myth or Reality Panel

Mar. 11: Danish AM Hub Webinar – How AM Battles the Corona and Climate Crisis

May 4: AMUG Conference (Orlando, FL) – Environmental Impacts of Metal AM

May 26: TCT Asia Summit (Shanghai, China) – Environmental Impacts of Metal AM

June 1: Zverse & 3D Printing Industry Media Webinar – Delivering on MRO Panel

June 17: ASME's AM Tech Tour – Fireside Chat on Sustainability with Marie Langer, CEO, EOS

June 24: 3D Metal Printing Experience & Tech Tour – Environmental Impacts of Metal AM

Sept. 28: TCT 3Sixty (Birmingham, UK) – Keynote Speaker: Update on the Environmental Impacts of Metal Additive Manufacturing

Sept. 29: TCT 3Sixty (Birmingham, UK) – Moderator, The Future of Sustainability in Additive Manufacturing Panel

Nov. 16-19: Formnext (Frankfurt, Germany) – Moderator, Executive Sustainability Panel

Sustainability in AM: Impact Industry-wide

Sustainability in AM: Impact Industry-wide

Questions?

Sherry Handel
Executive Director, AMGTA

Phone: 954-308-0888
Email: shandel@amgta.org
www.amgta.org