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How can we design sustainability into Additive Manufacturing?

PM500735

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Solution Engineers – Advanced Manufacturing
Autodesk

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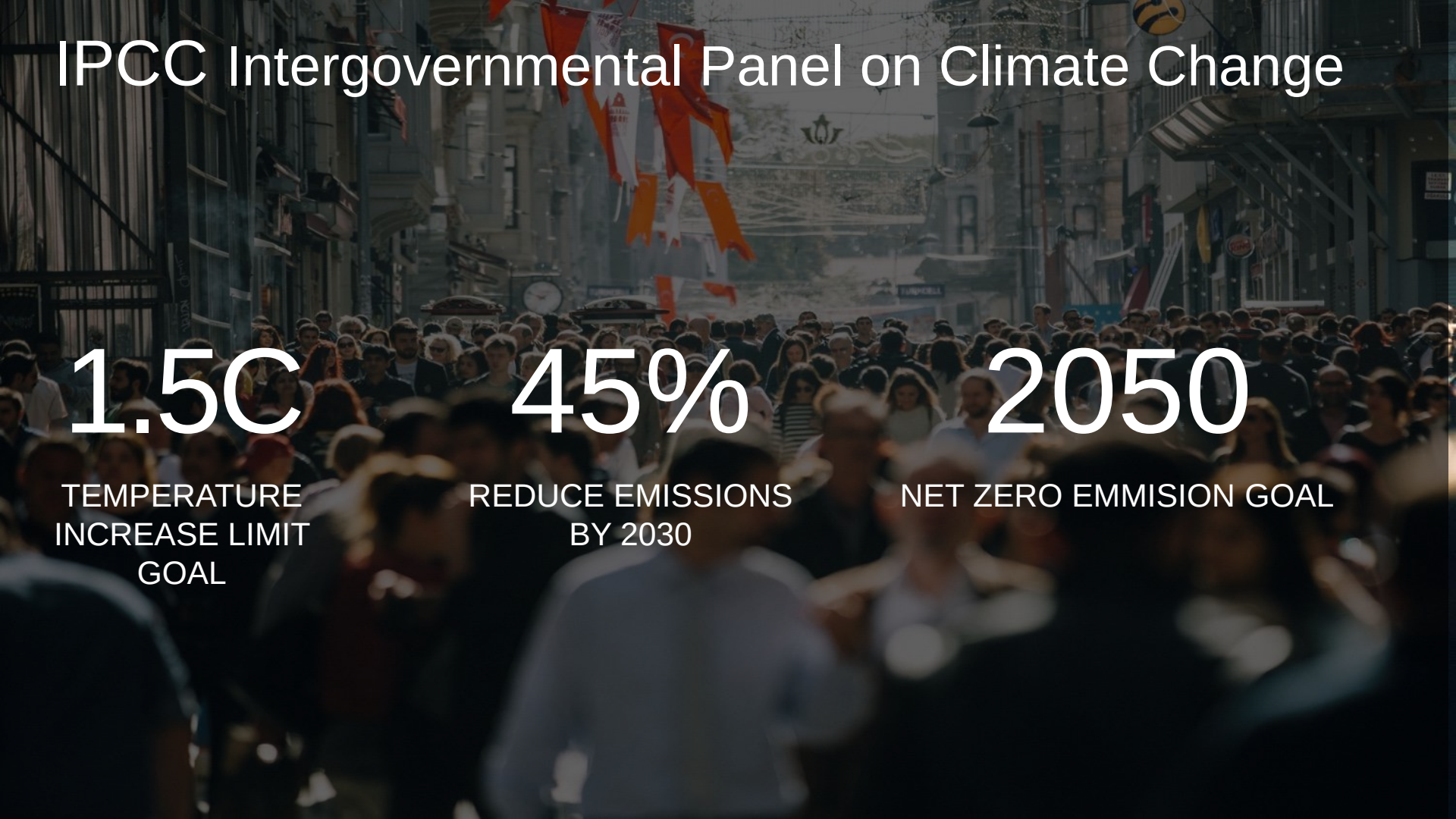
Is Additive Manufacturing Sustainable?



IPCC Intergovernmental Panel on Climate Change

1.5C

TEMPERATURE INCREASE LIMIT GOAL

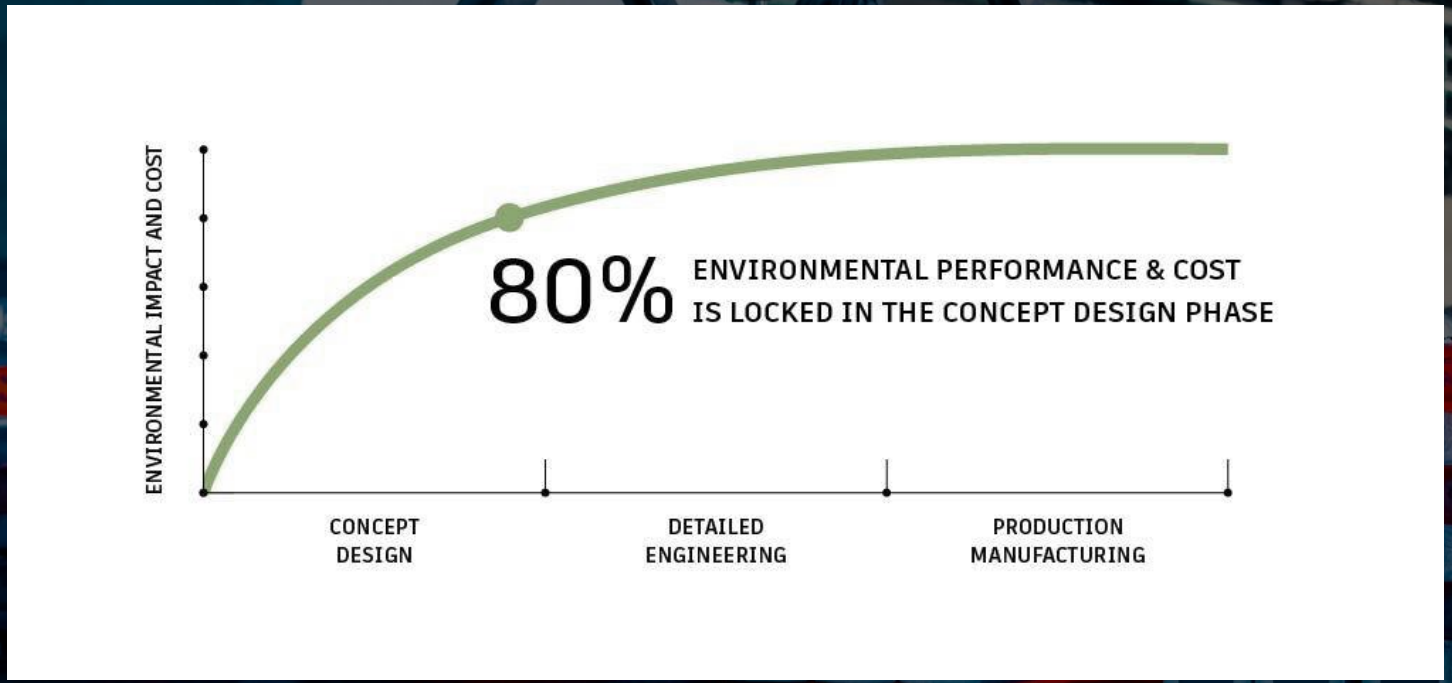
45%

REDUCE EMISSIONS BY 2030

2050

NET ZERO EMMISION GOAL

Reduce impact early in your process



Circularity

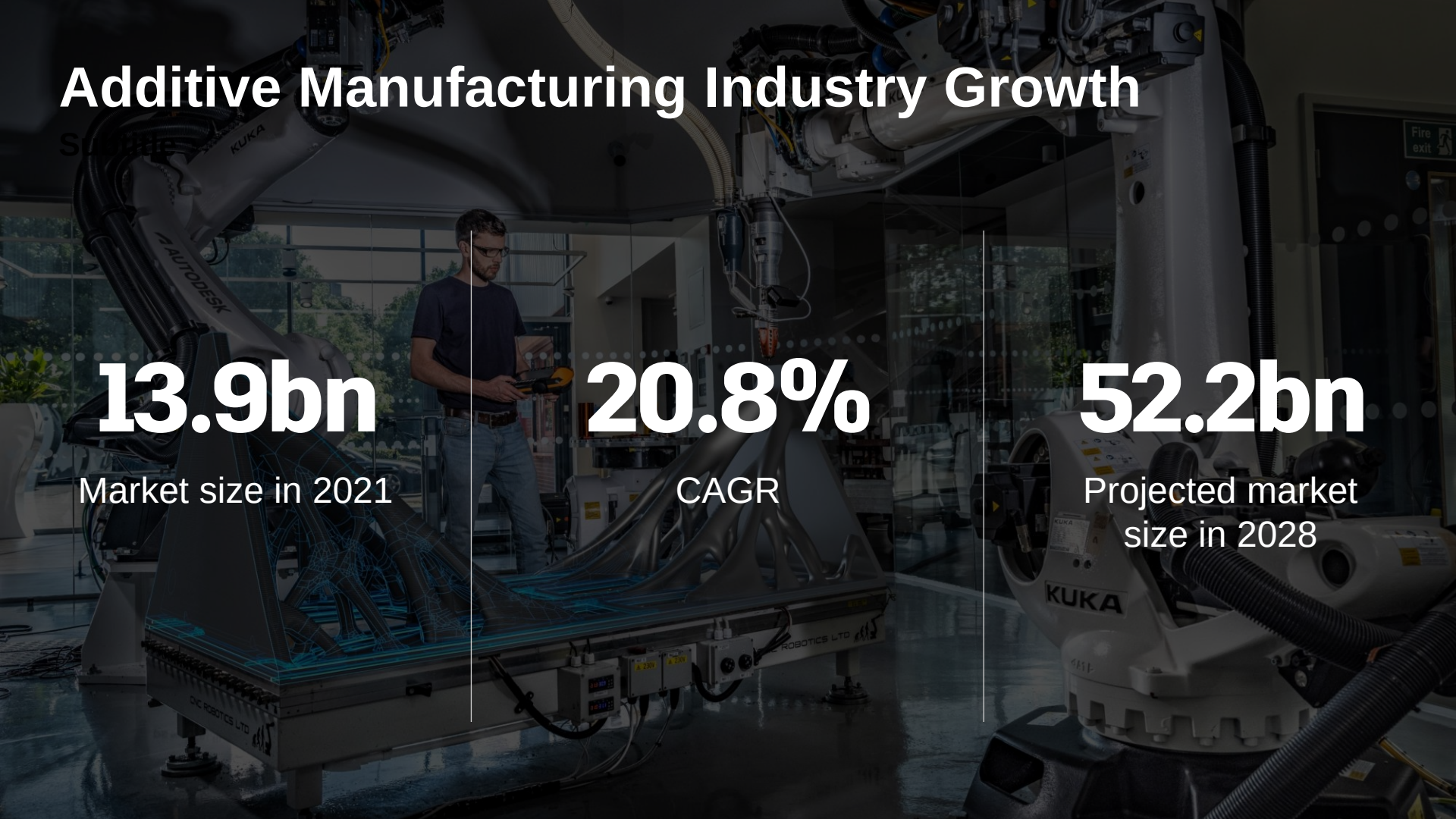
Maximizing value of resources by getting the most out of them

TRADITIONAL

Take **Make** **Waste**

CIRCULAR ECONOMY

Additive Manufacturing Industry Growth



13.9bn

Market size in 2021

20.8%

CAGR

52.2bn

Projected market size in 2028

Learning objectives

Technical Instruction

1. Identify applications where additive manufacturing provides business and sustainability benefits and where it doesn’t
2. Assess AM design trade-offs while avoiding common pitfalls
3. Apply DfAM techniques such as generative design, latticing, and part consolidation
4. Implement design workflows that drive more sustainable and higher performing part designs

Kieran Mak

Autodesk Solutions Engineer – Advanced Manufacturing

Education

- B.S. in Mechanical Engineering – McGill University

Experience

- Autodesk: Solutions Engineer – Advanced Manufacturing
- Application & Design Engineer @ Carbon 3D
- 7+ Years in Product Design and Manufacturing

Specialities

- Additive Manufacturing (3D Printing)
- Product Development
- Mass customization
- Computational Design

Ryan Abel

Autodesk Solutions Engineer – Advanced Manufacturing

Education

- M.S. in Mechanical Engineering – Lehigh University

Experience

- 22+ Years in Product Design and Manufacturing
  - Design Engineer Leader @ Lutron Electronic
  - CFD Applications Engineer @ Blue Ridge Numerics
  - Upfront Simulation Specialist @ Autodesk

Specialities

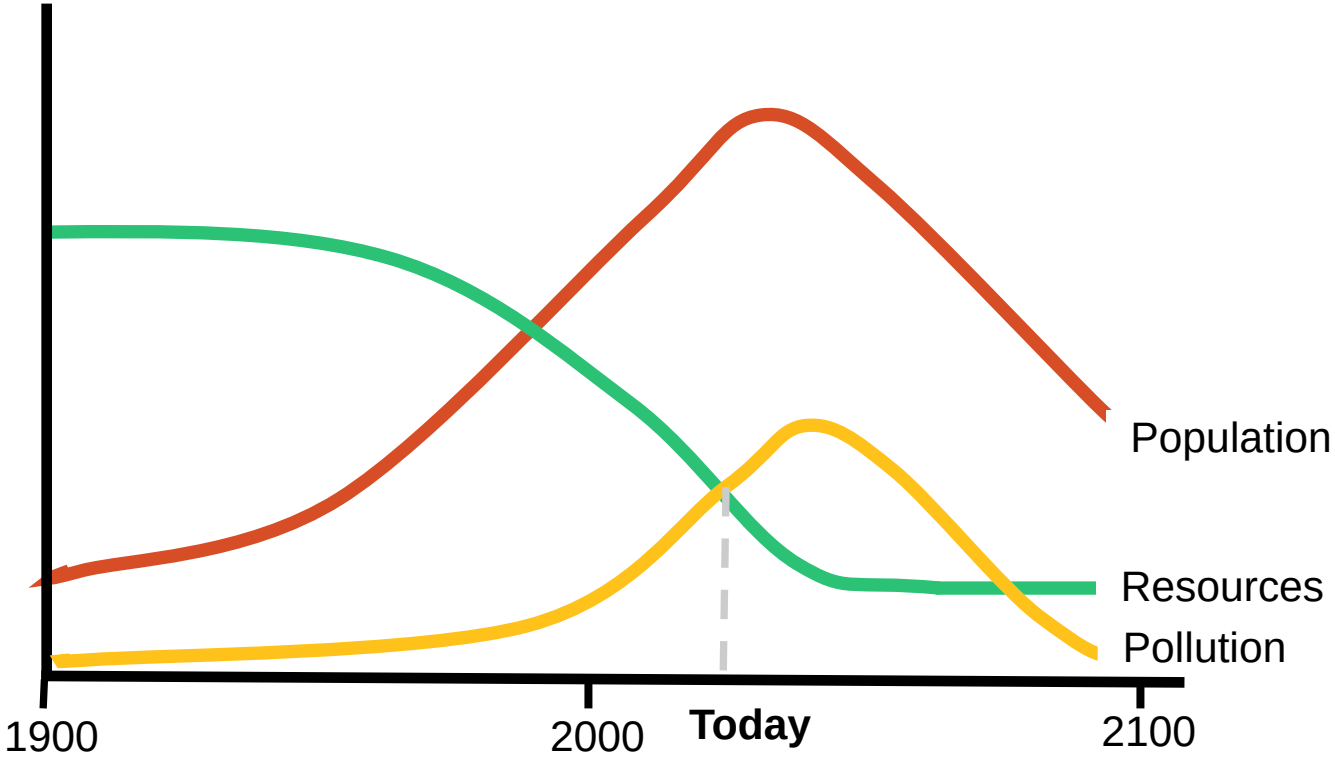
- Upfront Simulation
- Generative Design
- New Product Introduction
- Remanufacturing

"Meeting the needs of the present without compromising the ability of future generations to meet their own needs"

The UN Brundtland commission

Achieving 2050 Net Zero Looks Like

Building a sustainable future for all




SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

Sustainable Development Indicators

Indicators

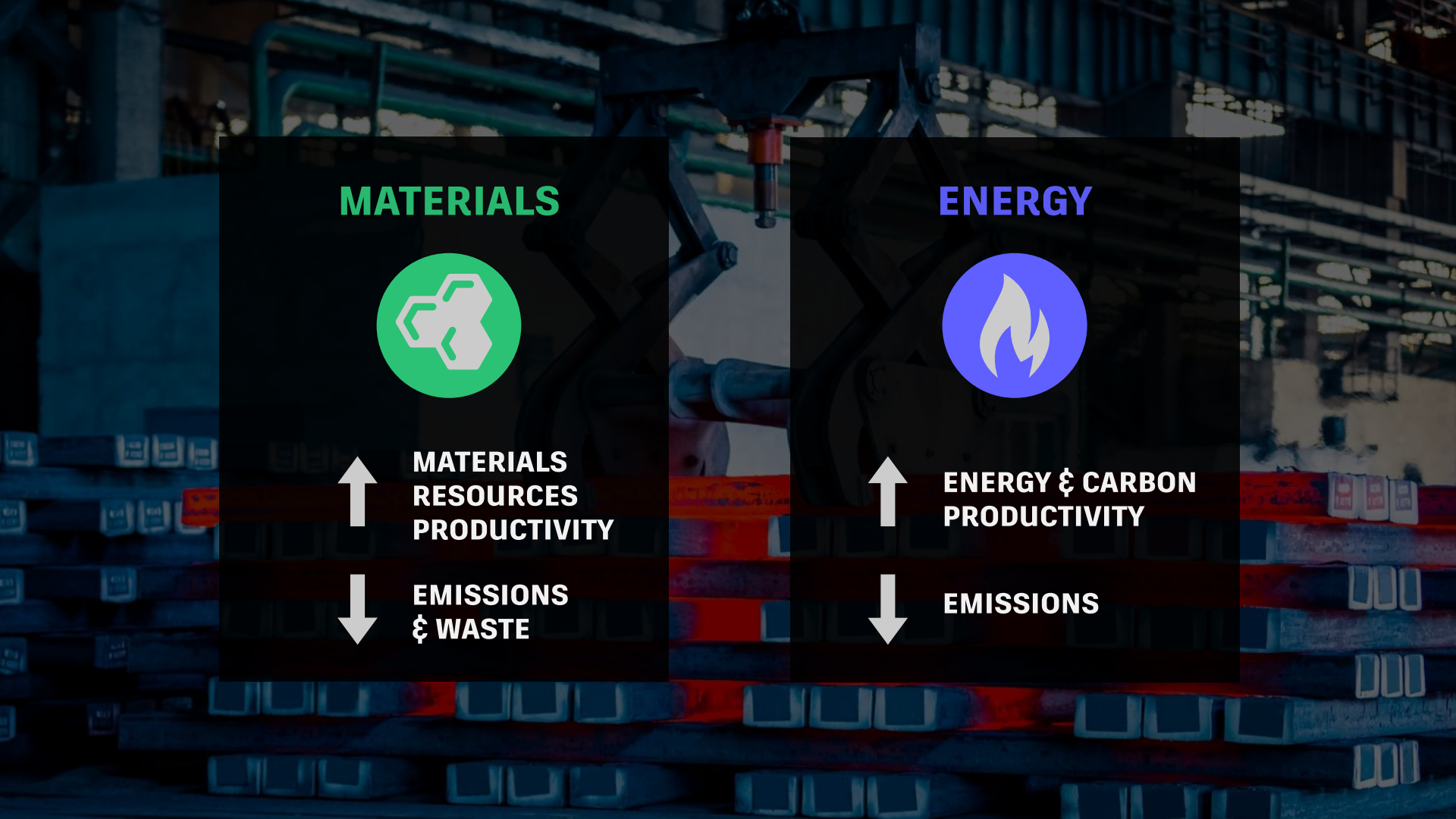
9.4.1 CO2 emission per unit of value added

Indicators

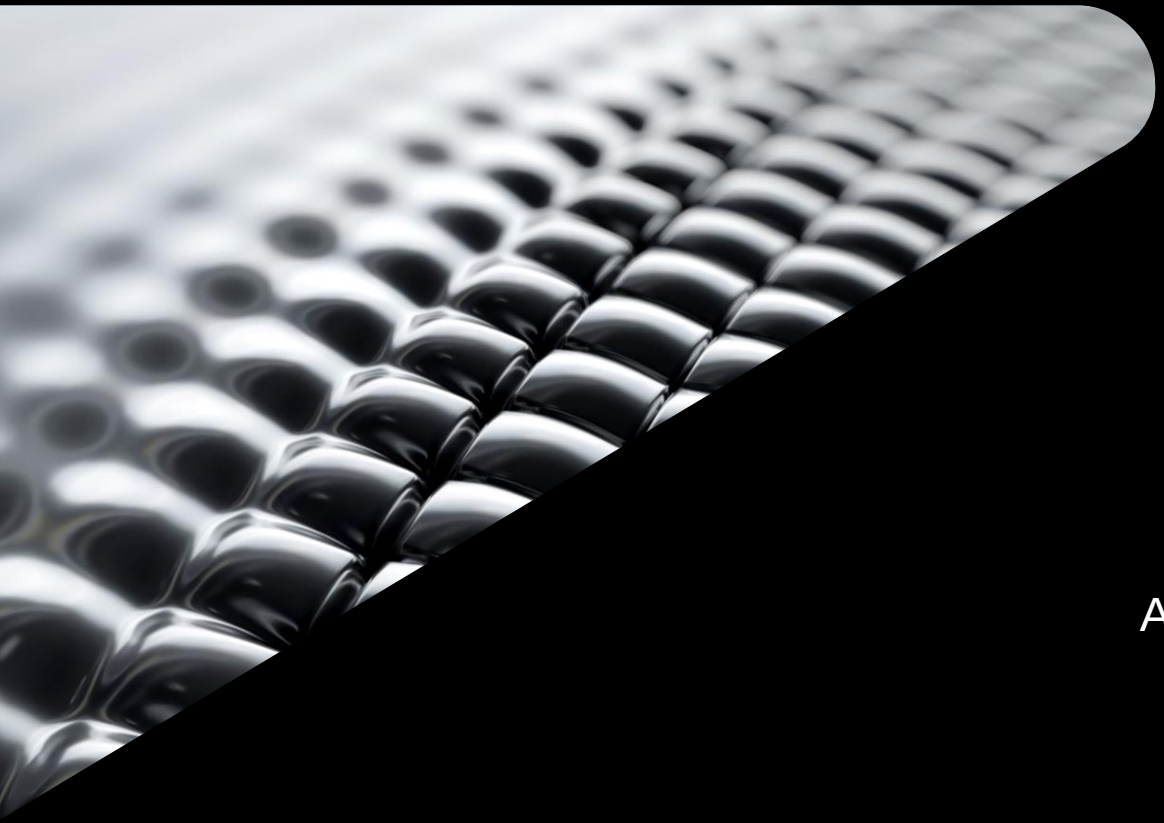
12.2.1 Material footprint, material footprint per capita, and material footprint per GDP

12.4.2 Hazardous waste generated per capita

12.5.1 National recycling rate, tons of material recycled


MATERIALS
MATERIALS RESOURCES PRODUCTIVITY
EMISSIONS & WASTE
ENERGY
ENERGY & CARBON PRODUCTIVITY
EMISSIONS

Use materials in the most productive way, use less, and reduce carbon footprint through the material lifecycle



Assessing Tradeoffs

Avoiding AM sustainability pitfalls

Additive Pro’s

- Ultra lightweight optimized designs
- Reduce material consumption
- Flexible localized production
- Mass customization
- Part consolidation

Additive Con’s

- High energy use
- High cost
- Material limitations
- Health and safety hazards
- Low Quality

Is 3d printing sustainable

- is 3d printing sustainable
- is 3d printing **clothes** sustainable
- is 3d printing **more** sustainable
- is 3d printing **environmentally friendly**
- **are** 3d **printers** sustainable
- is 3d printing **safe for the environment**
- is 3d printing **more environmentally friendly**

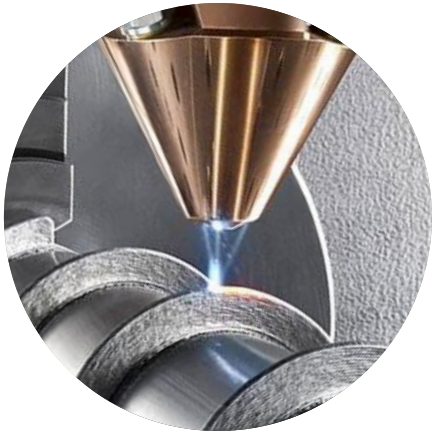
Is 3d printing sustainable

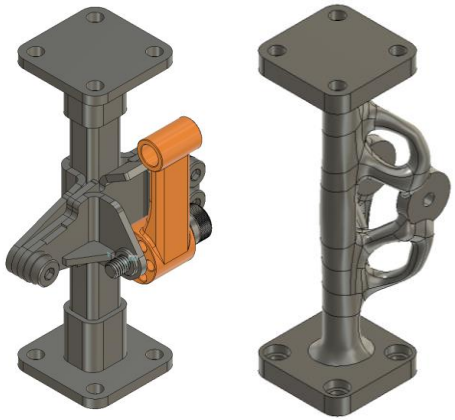
is 3d printing sustainable

"3D printing is often a more efficient process requiring less energy to create products"

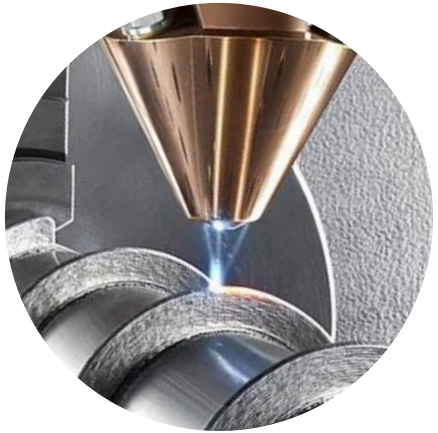
"The additive nature of 3D printing means that building parts are made layer by layer. It generates less wasted material than other subtractive forms of fabrication, such as milling or laser cutting. Another outcome making 3D printing sustainable."

"With the help of a 3D printer it is possible to make the entire product including packaging locally."

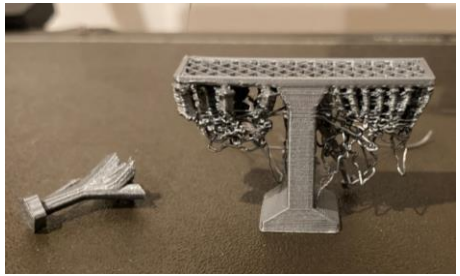


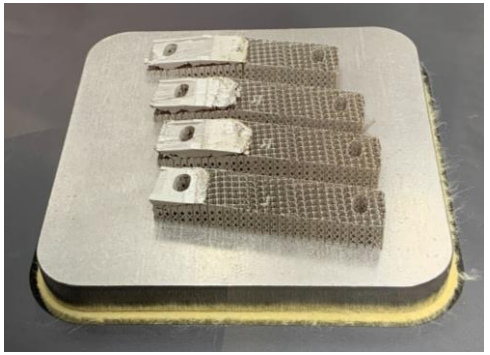


Waste Reduction



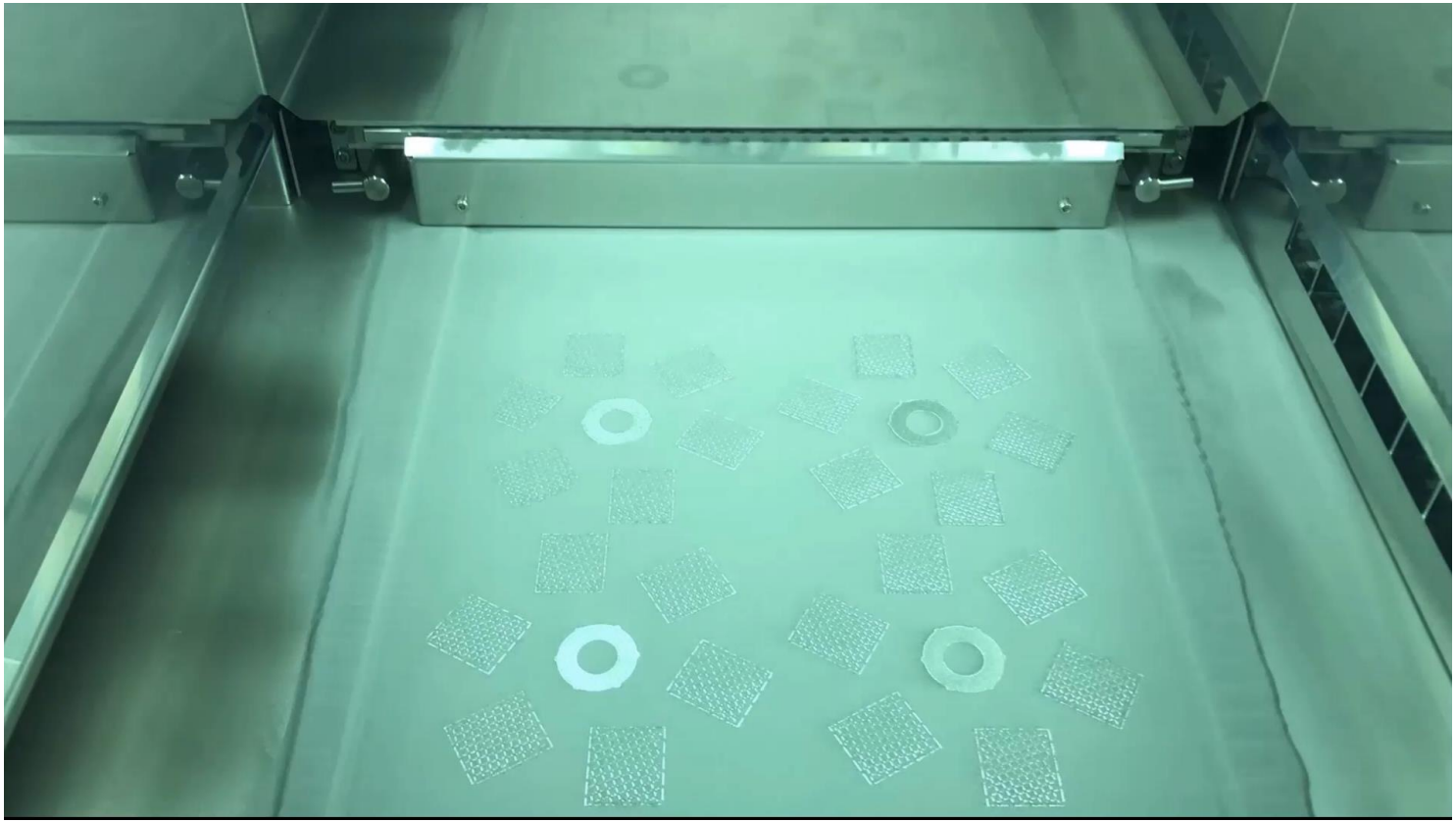
Waste Reduction?





Energy Reduction

Energy Reduction?



Energy Reduction?

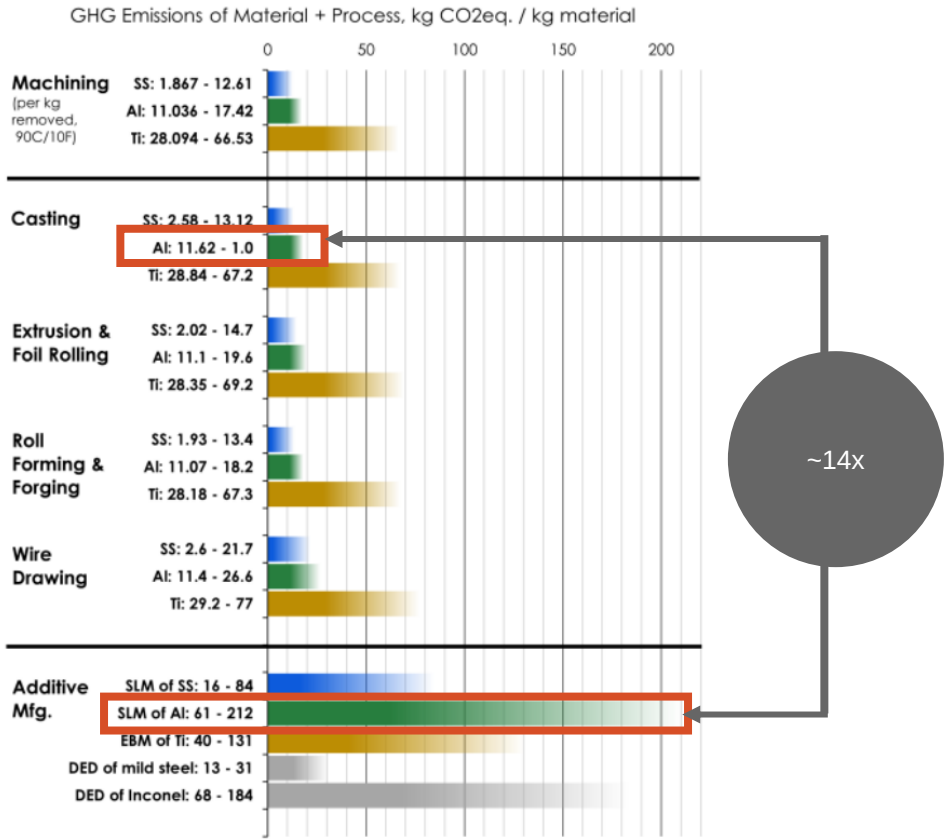
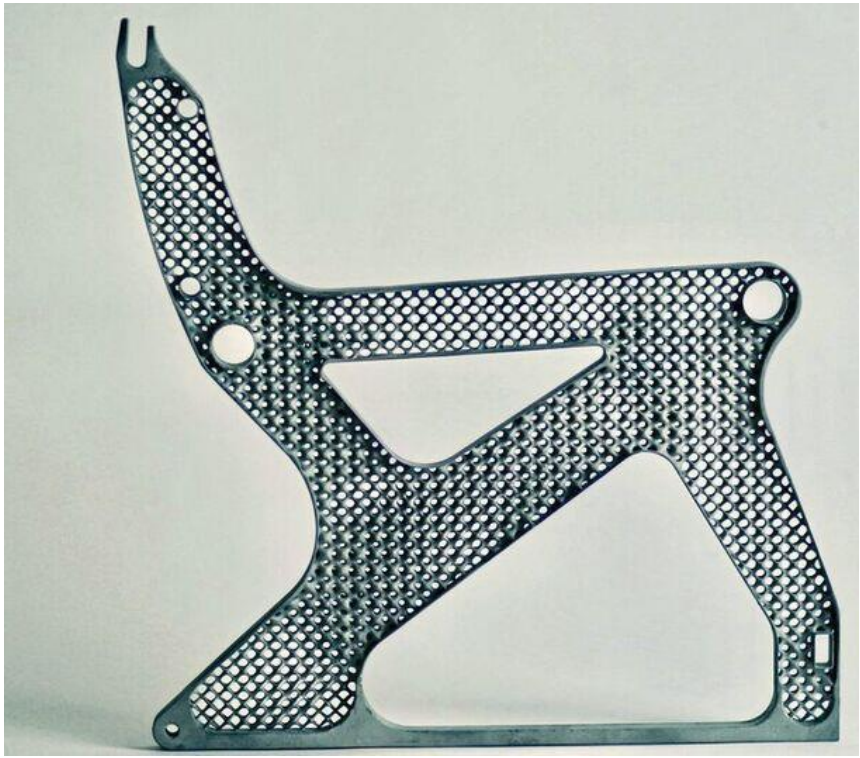


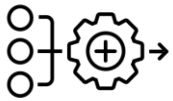
Figure courtesy of J, Faludi

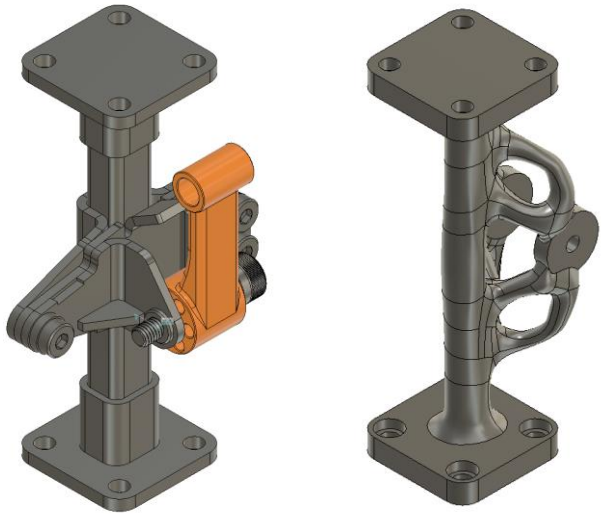
Energy Reduction?

- 30% Lighter than comparable cast seat in aluminum
- Saves 15 tonnes of CO_2 emissions per year
- Adds 105 tonnes of embodied CO_2 per aircraft if printed via SLM



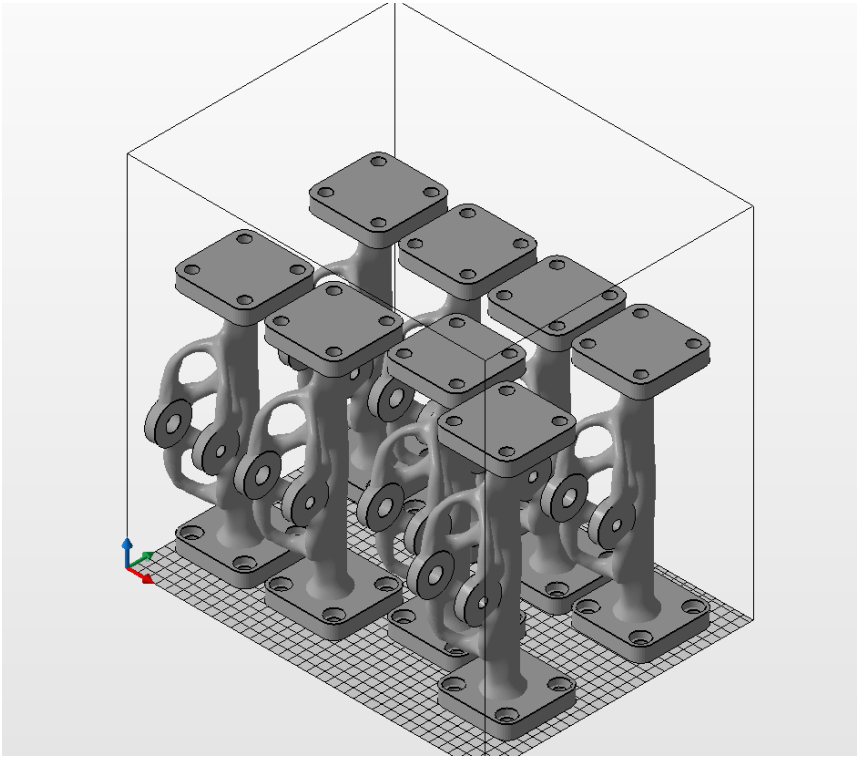
Part Consolidation



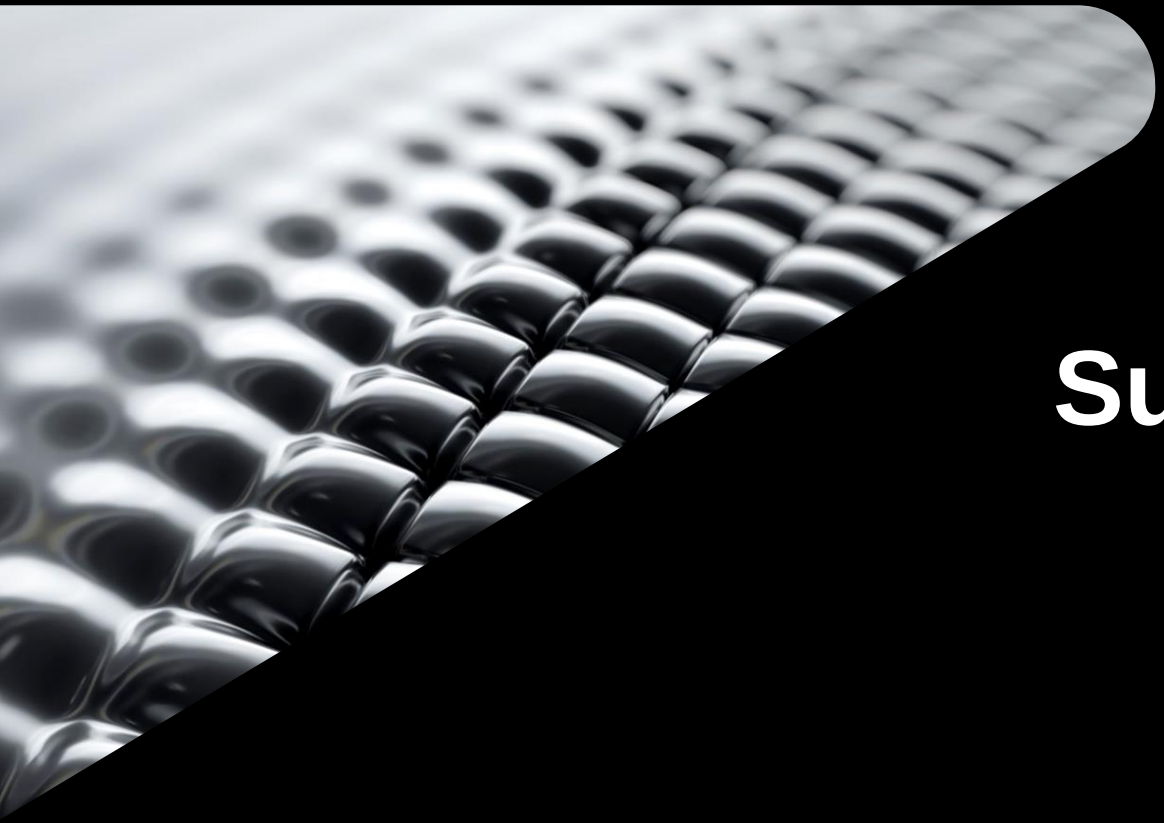


Consolidate Everything?

- 8 Parts per build
- 10% Packing density



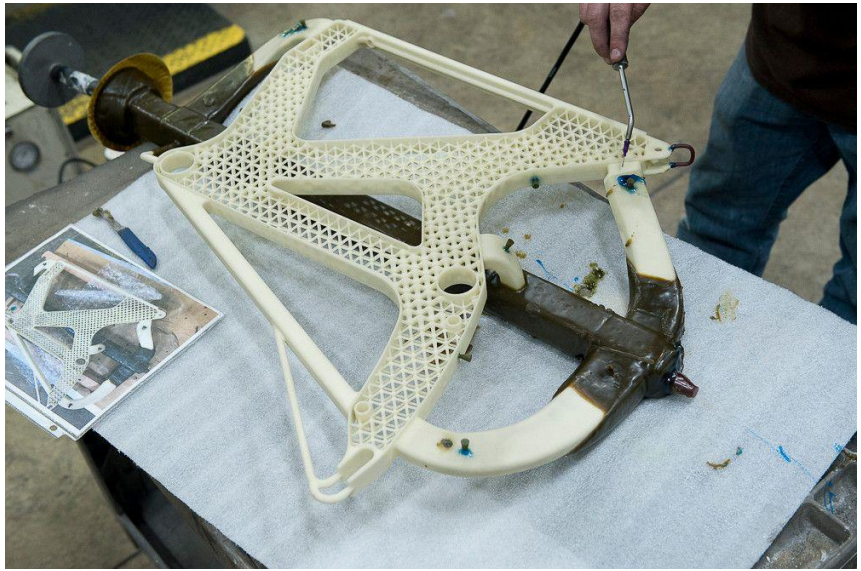
Takeaway #1:
Do not assume that AM = Sustainable



Identifying Sustainable AM Applications

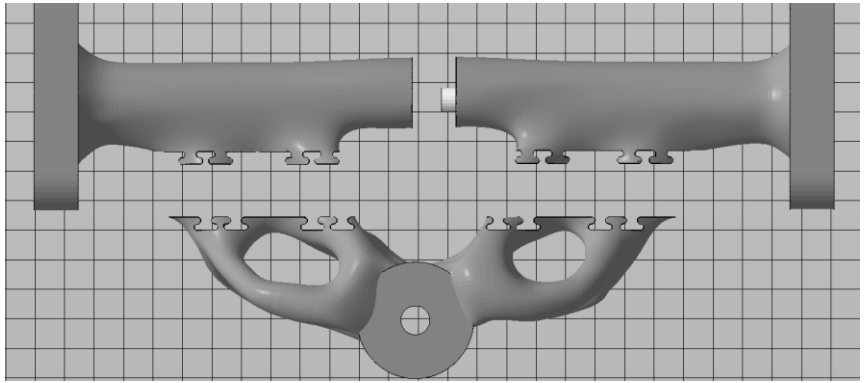
Harnessing AM Superpowers

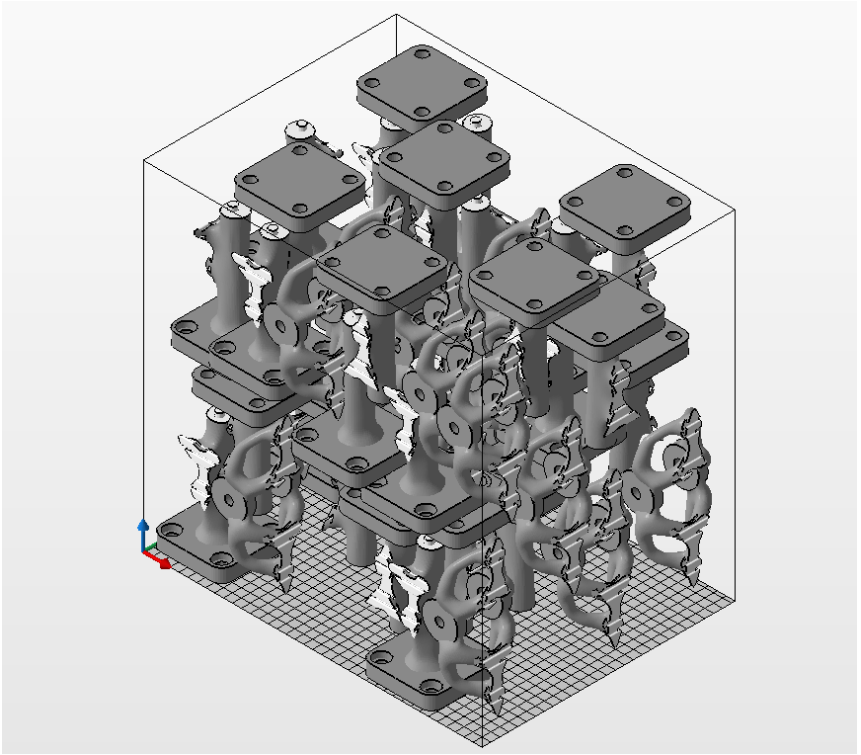
Print & Cast Workflow



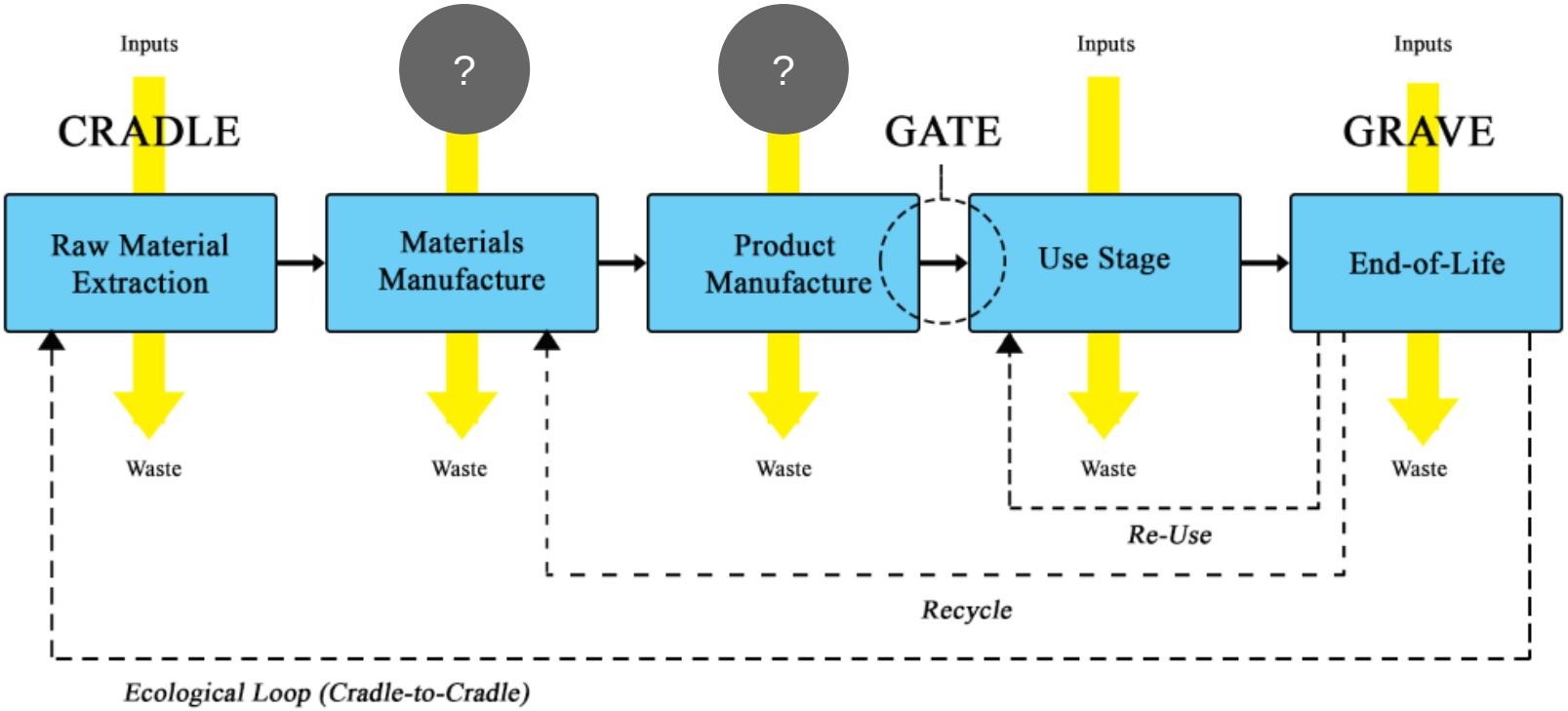
Effective Consolidation Workflows

- 8 -> 16 Parts per build
- 10% ->15% Packing density





Life Cycle Assessment



Takeaway #2:
Advocate for better LCA data for AM processes

Identifying AM Applications

Use materials in the most productive way, use less, and reduce carbon footprint through the material lifecycle

Use materials in the most productive way, use less, and reduce carbon footprint through the material lifecycle

Solution Categories

Use materials in the most productive way

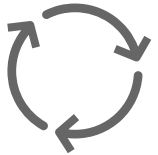
=

Improve Product Performance

Use less

=

Reduce waste during the manufacturing & product lifecycle



Reduce carbon footprint through material lifecycle

=

Shift to bio-based and recyclable materials

Practical Solutions

Improve Product Performance of Clean Technologies

Use materials in the most productive way

=

Improve Product Performance

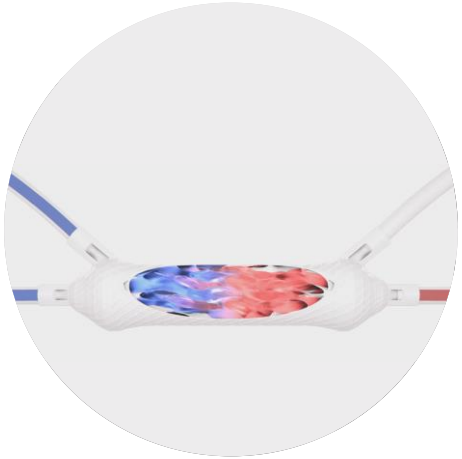


Image courtesy of H2GO Power

AM Superpower:
Design Complexity

Business Benefit:
More output per $ spent

Environmental Benefit:
Reduce CO2 emission per unit of value added

Examples:
Optimized heat exchangers

Practical Solutions

Simulate to reduce build failures

Use less

=

Reduce waste during the manufacturing & product lifecycle

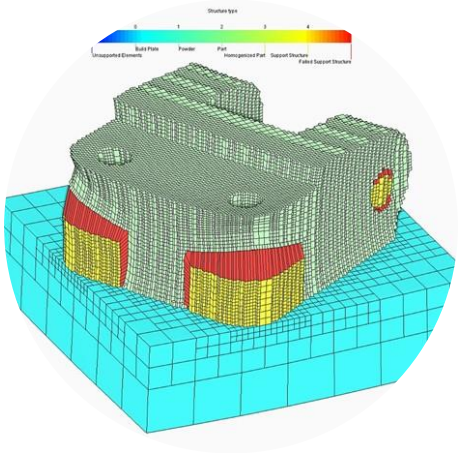


Figure courtesy of Dr. Ed Demeter (Penn State University)

AM Superpower:
Digitized manufacturing process

Business Benefit:
Save cost of wasted powder & increase machine utilization

Environmental Benefit:
Reduce hazardous waste emissions

Examples:
Metal AM process simulation to detect support structure failure

Practical Solutions

Remanufacturing to extend part life

Use less

=

Reduce waste during the manufacturing & product lifecycle

Image courtesy of RAMLAB

AM Superpower:
Selectively add material only where needed

Business Benefit:
Save cost by extending service life of parts

Environmental Benefit:
Increased amortization of embodied carbon

Examples:
Remanufacturing of turbine blades, propellers, molds

Practical Solutions

Digitize warehouses to produce parts on demand

Use less

=

Reduce waste during the manufacturing & product lifecycle

AM Superpower:
Flexible on demand production

Business Benefit:
Eliminate product waste and lost sales

Environmental Benefit:
Produce only what we need

Examples:
On demand digital warehouse

Practical Solutions

Shift production to bio-based & recyclable materials

Reduce carbon footprint through material lifecycle

=

Shift to bio-based and recyclable materials

Image courtesy of Kartell and Phillipe Starck

AM Superpower:
Rapid new material development

Business Benefit:
Increase demand in an environmentally focused economy

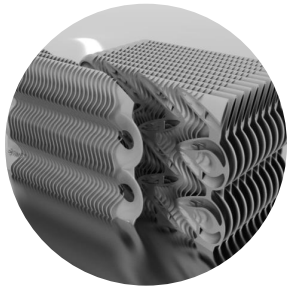
Environmental Benefit:
Extend material life cycle

Examples:
Rilsan Invent Natural PA 11

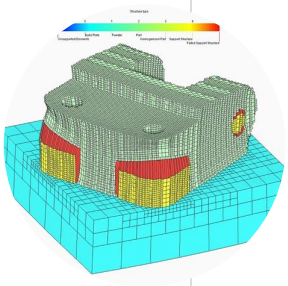
Practical Solutions

Use materials in the most productive way

Improve performance of clean technologies



Simulate to reduce build failures



Use less

Remanufacturing to extend part life

Reduce carbon footprint through material lifecycle

Digitize warehouses to produce parts on demand

Shift production to bio-based & recyclable materials

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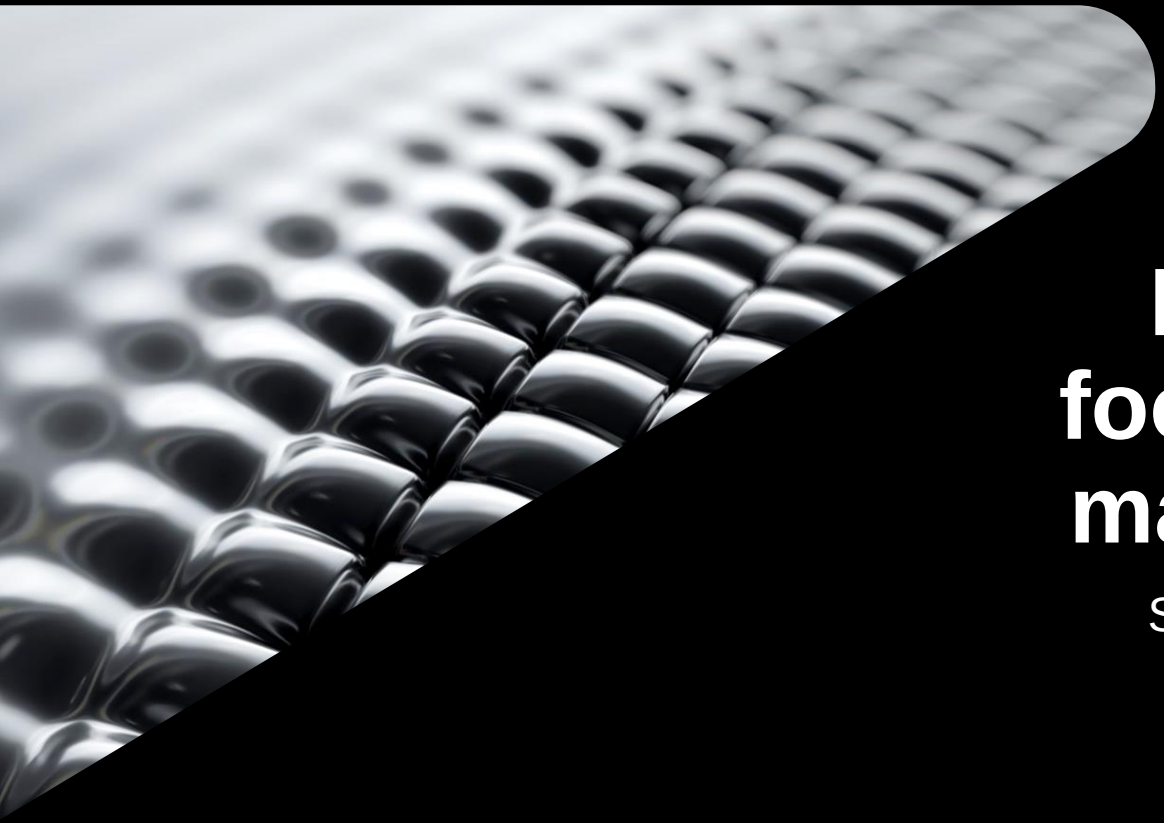
Images courtesy of Dr. Ed Demeter (Penn State University), RAMLAB, Kartell and Phillipe Starck.

Takeaway #3:
Build a business case that aligns economic and environmental benefits to the unique strengths of AM



Reduce carbon footprint through material lifecycle

Shift to bio-based and recyclable materials

Design and Print Workflow in Fusion 360

Generative Design

Fusion Additive

Set goals and constraints

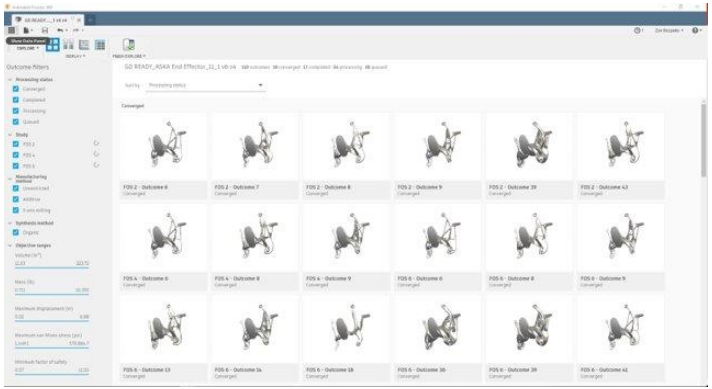
Run on the cloud

Explore results

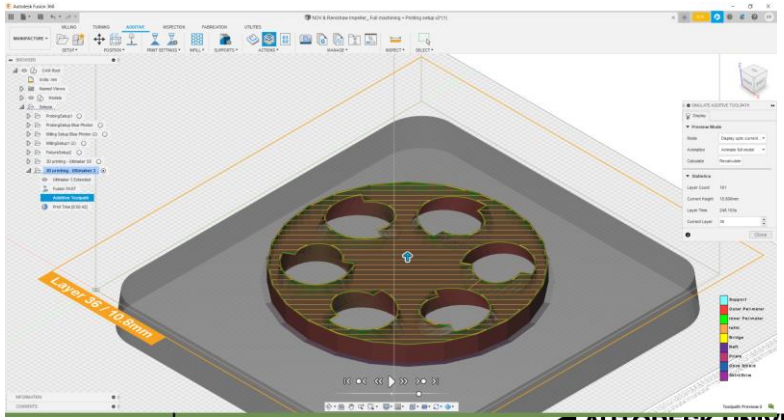
Optimize Print Process

Simulate & Validate

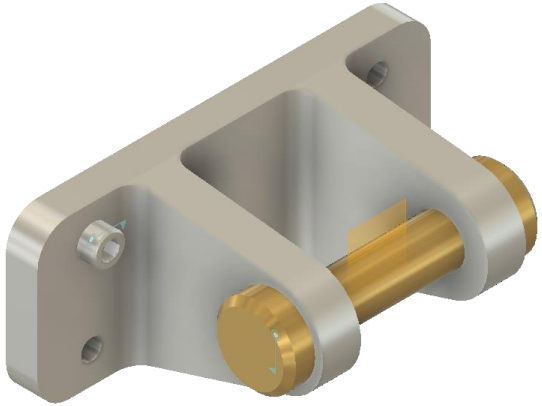
Explore options in Generative Design

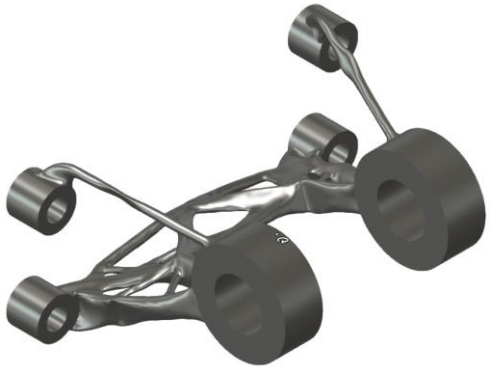


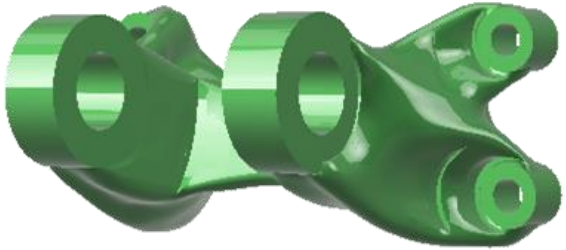
Optimize infills and support materials



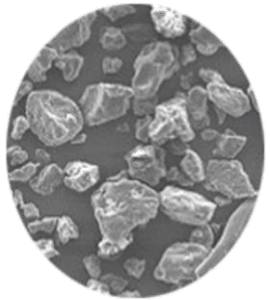
Can we use a different material?







Introduce Materials

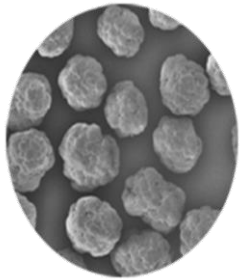


Nylon polyamide 11

- Nylon, generic name for family of polymers
- Bio-based
- Oil from the seeds of the castor bean
- Great for living hinges and car interiors

Rislan polyamide 11

- Trademarked by ARKEMA, it is Nylon



Orgasol polyamide 12

- Unique particle shape
- Narrow size distribution
- Smooth finish, like injection molding
- Excellent color durability
- Excellent contour resolution
- Used for high quality functional prototypes

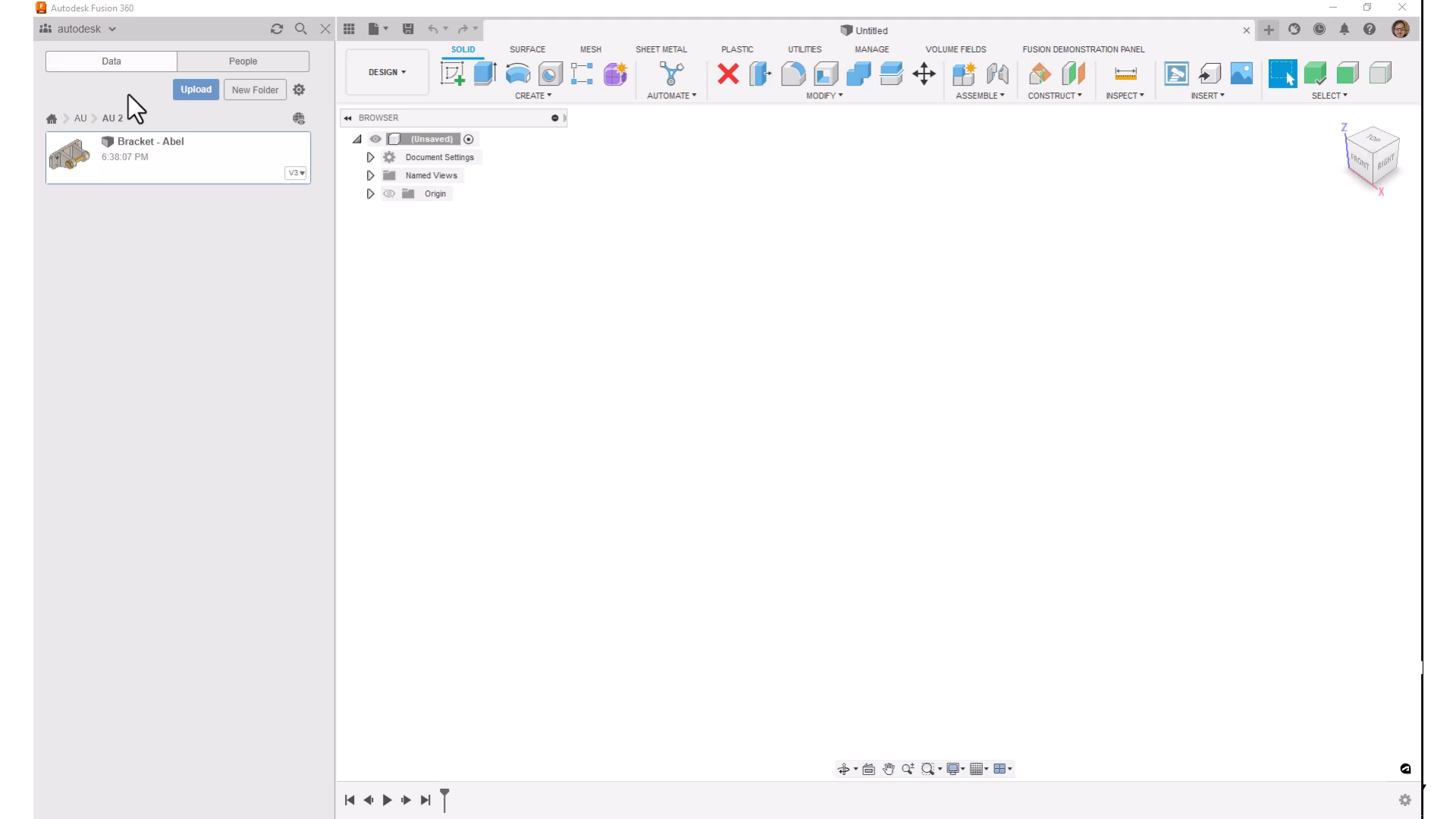
Material Properties

	Nylon - PA11	Orgasol – PA12	Rilsan – PA11
Density kg/mm3	1.17E-6	9.6E-7	1.02E-6
Young's GPa	2.6	1.68	1.5
Ultimate MPa	46	48	54

Lighter

Elastic

Stronger


Autodesk Fusion 360
autodesk
Data
People
Upload
New Folder
AU
AU 2
Bracket - Abel
6:38:07 PM
V3
Untitled
DESIGN
SOLID
SURFACE
MESH
SHEET METAL
PLASTIC
UTILITIES
MANAGE
VOLUME FIELDS
FUSION DEMONSTRATION PANEL
CREATE
AUTOMATE
MODIFY
ASSEMBLE
CONSTRUCT
INSPECT
INSERT
SELECT
BROWSER
(Unsaved)
Document Settings
Named Views
Origin
FRONT
RIGHT
Z
X

Autodesk Fusion 360

Bracket - Abel v4

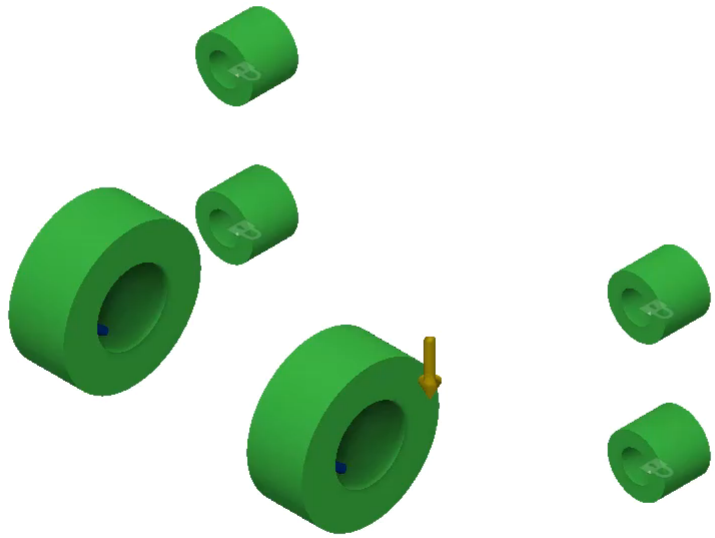
GENERATIVE DESIGN

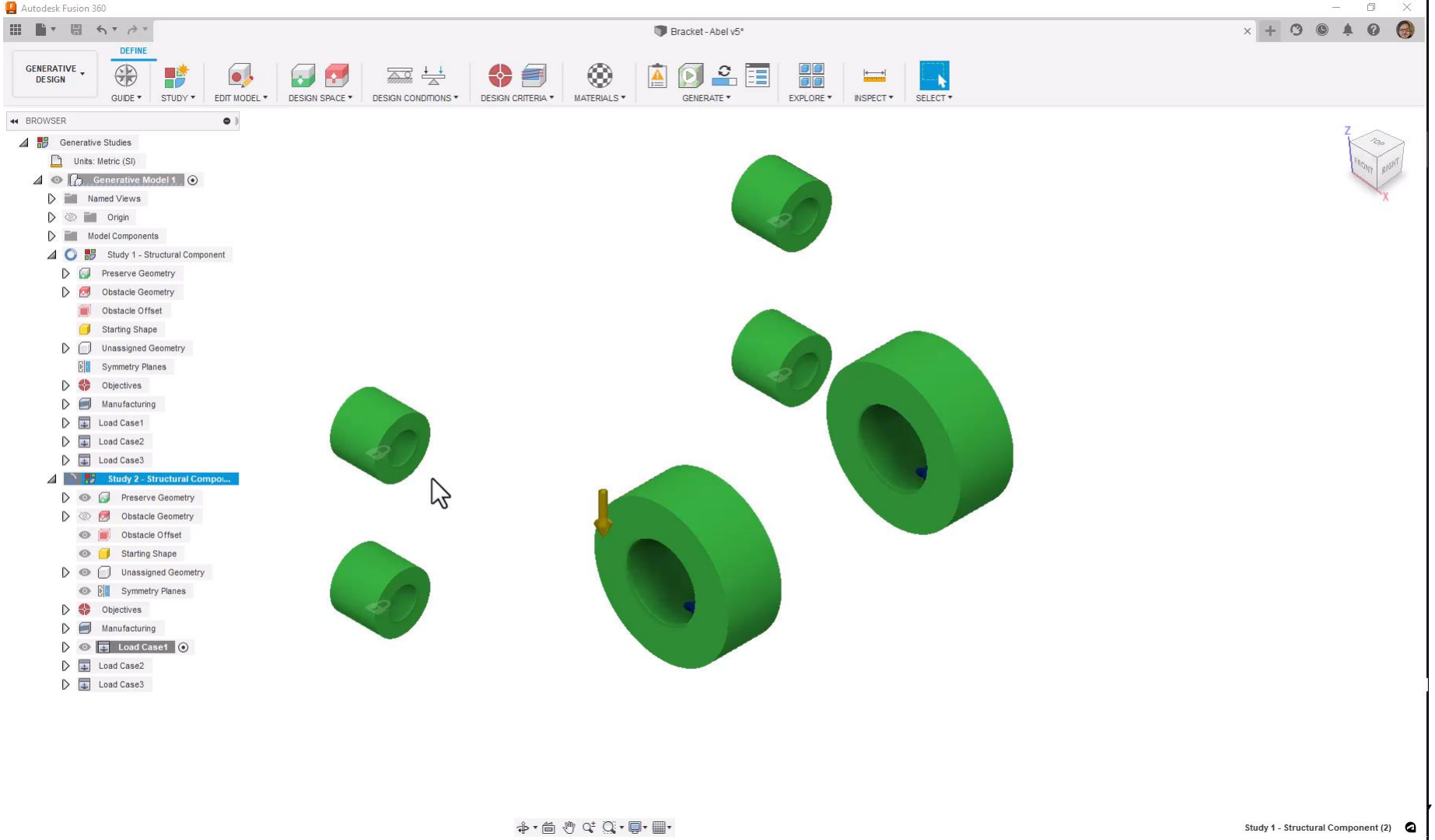
DEFINE

GUIDE | STUDY | EDIT MODEL | DESIGN SPACE | DESIGN CONDITIONS | DESIGN CRITERIA | MATERIALS | GENERATE | EXPLORE | INSPECT | SELECT

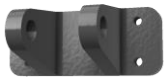
BROWSER

- Generative Studies
  - Units: Metric (SI)
  - Generative Model 1
    - Named Views
    - Origin
    - Model Components
    - Study 1 - Structural Compos...
      - Preserve Geometry
      - Obstacle Geometry
      - Obstacle Offset
      - Starting Shape
      - Unassigned Geometry
      - Symmetry Planes
      - Objectives
      - Manufacturing
      - Load Case1
        - Loads
        - Constraints
      - Load Case2
        - Loads
          - Gravity
          - Force2
        - Constraints
      - Load Case3
        - Loads
          - Gravity
          - Force3
        - Constraints



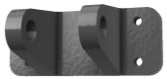

Autodesk Fusion 360
Bracket - Abel v5*
GENERATIVE DESIGN
DEFINE
GUIDE
STUDY
EDIT MODEL
DESIGN SPACE
DESIGN CONDITIONS
DESIGN CRITERIA
MATERIALS
GENERATE
EXPLORE
INSPECT
SELECT
BROWSER
Generative Studies
Units: Metric (SI)
Generative Model 1
Named Views
Origin
Model Components
Study 1 - Structural Component
Preserve Geometry
Obstacle Geometry
Obstacle Offset
Starting Shape
Unassigned Geometry
Symmetry Planes
Objectives
Manufacturing
Load Case1
Load Case2
Load Case3
Study 2 - Structural Compo...
Preserve Geometry
Obstacle Geometry
Obstacle Offset
Starting Shape
Unassigned Geometry
Symmetry Planes
Objectives
Manufacturing
Load Case1
Load Case2
Load Case3
FRONT
RIGHT
Z
X
Study 1 - Structural Component (2)

Informed Design Decisions Performance vs Cost

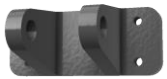


Design	Material	FOS	Volume cm3	Material Saved	Δ1 (mm)	Δ2 (mm)	Mass (g)
Original	Nylon PA11	2	108	-	0.7	1.8	127

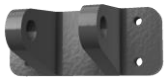
Informed Design Decisions Performance vs Cost

	Design	Material	FOS	Volume cm3	Material Saved	Δ1 (mm)	Δ2 (mm)	Mass (g)
	Original	Nylon PA11	2	108	-	0.7	1.8	127
	D1	Nylon PA11	2	93.3	14%	0.3	0.7	107

Informed Design Decisions Performance vs Cost

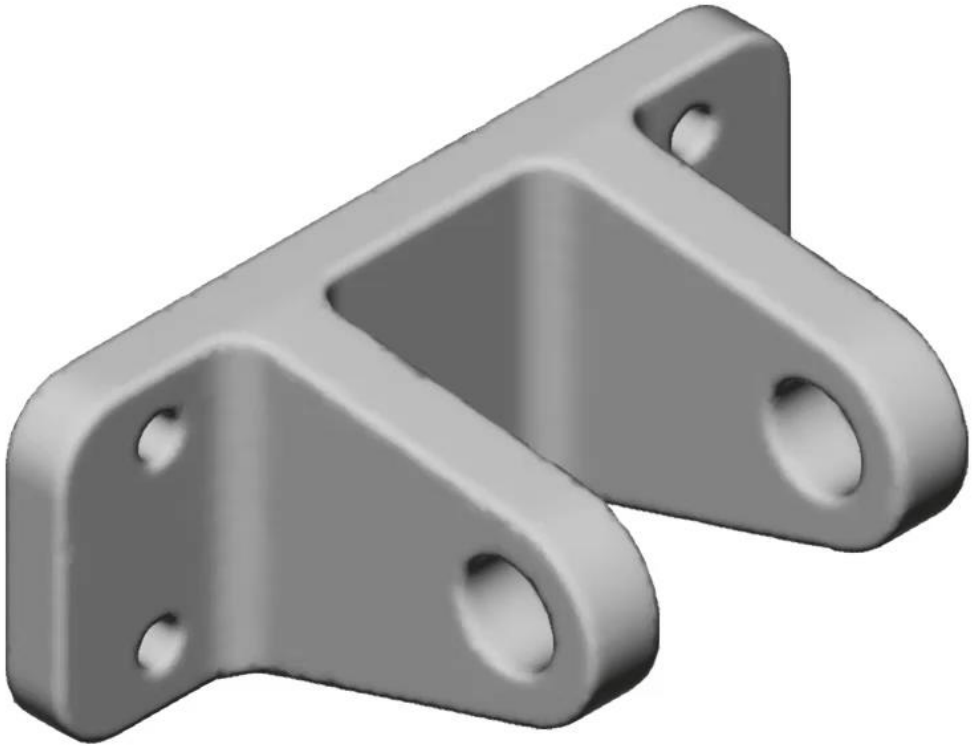
	Design	Material	FOS	Volume cm3	Material Saved	Δ1 (mm)	Δ2 (mm)	Mass (g)
	Original	Nylon PA11	2	108	-	0.7	1.8	127
	D1	Nylon PA11	2	93.3	14%	0.3	0.7	107
	D2	Orgasol PA 12	2	50.2	54%	0.9	2.2	56
	D3	Rilsan PA 11	2	54.8	49%	1.1	2.4	56

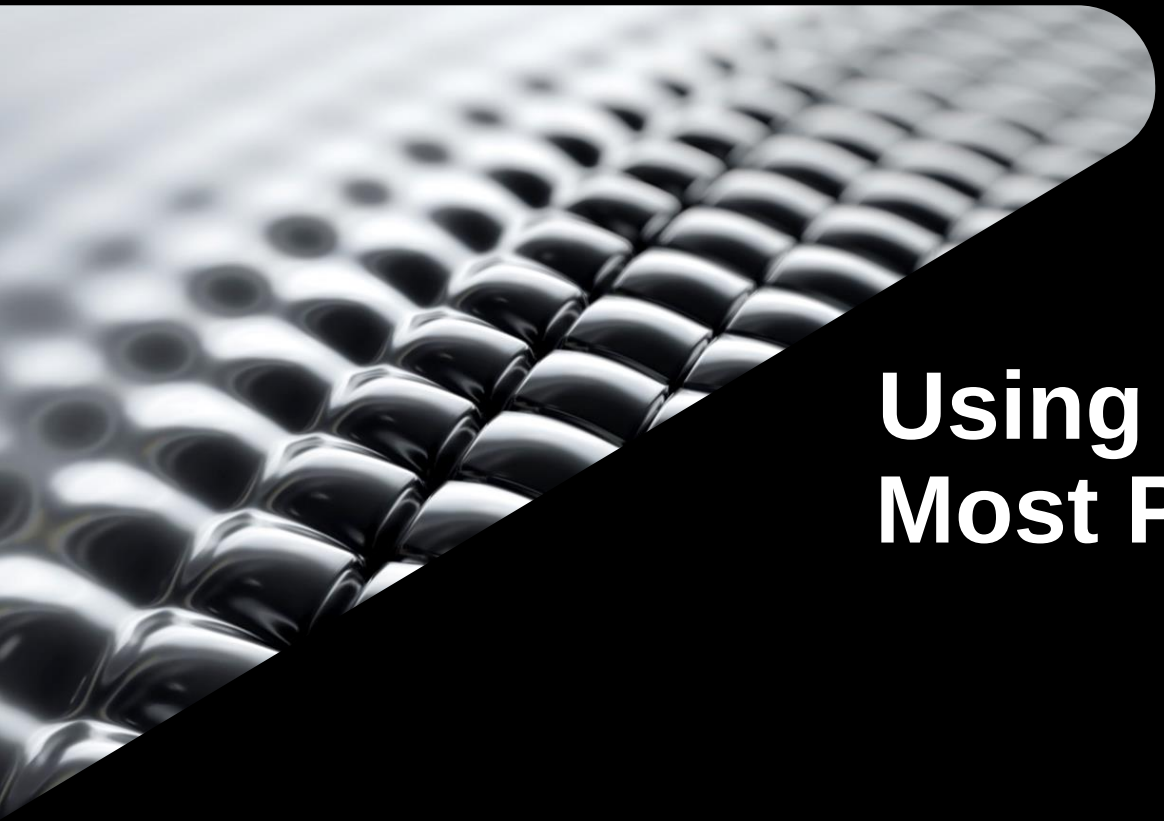
Informed Design Decisions Performance vs Cost

	Design	Material	FOS	Volume cm3	Material Saved	Δ1 (mm)	Δ2 (mm)	Mass (g)
	Original	Nylon PA11	2	108	-	0.7	1.8	127
	D1	Nylon PA11	2	93.3	14%	0.3	0.7	107
	D2	Orgasol PA 12	2	50.2	54%	0.9	2.2	56
	D3	Rilsan PA 11	2	54.8	49%	1.1	2.4	56
	D4	Orgasol PA12	3.3	87.5	19%	0.6	1.8	84
	D5	Rilsan PA 11	2.6	77.5	28%	0.8	1.8	79

Displacement Limited to Match Original Performance

How long did this take to do this?

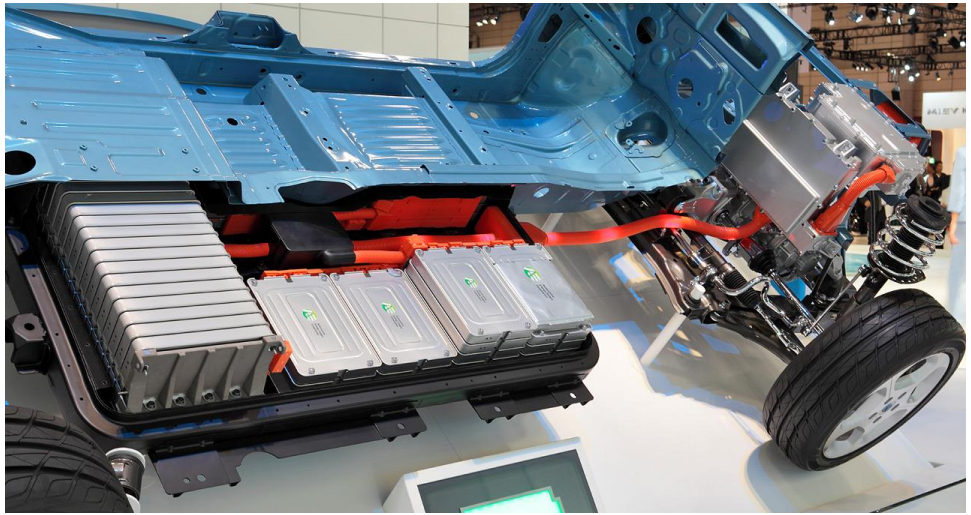




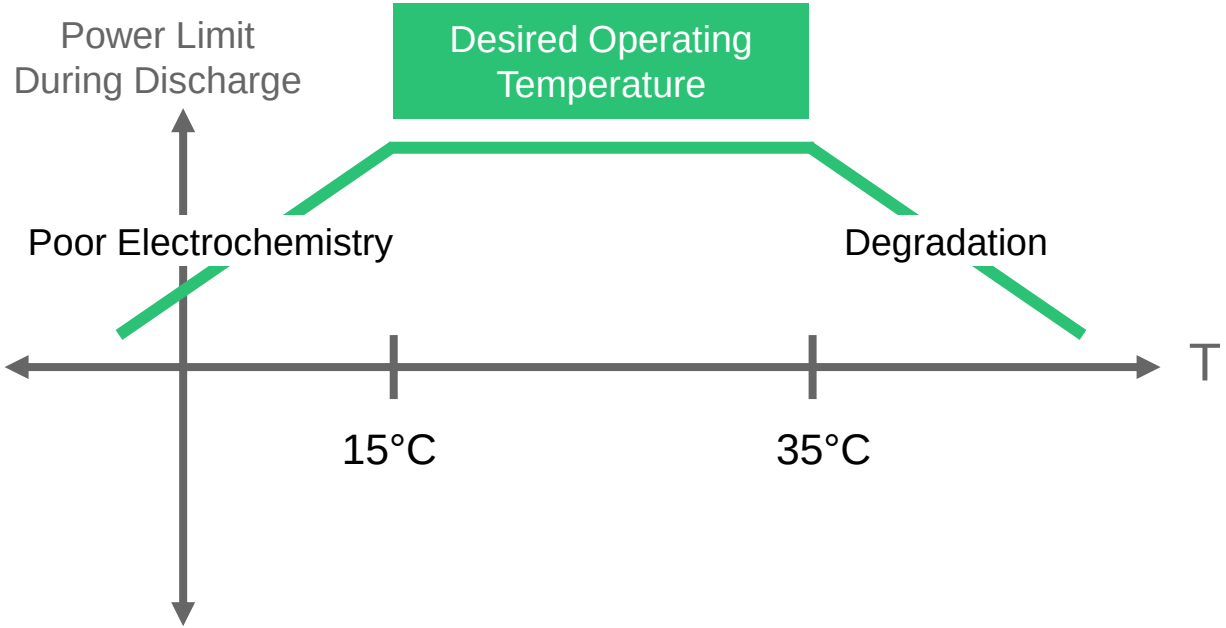
Using Material In The Most Productive Way

Improve performance of clean technologies

Cooling of Electric Vehicle Batteries

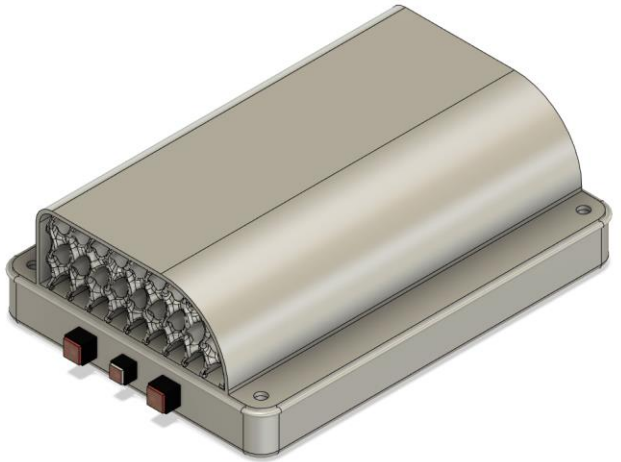


Cooling of Electric Vehicle Batteries



Cooling of Electric Vehicle Batteries

Can we improve cooling performance with Additive Manufacturing?



Autodesk Fusion 360

Battery Module - AU 2022 v1*

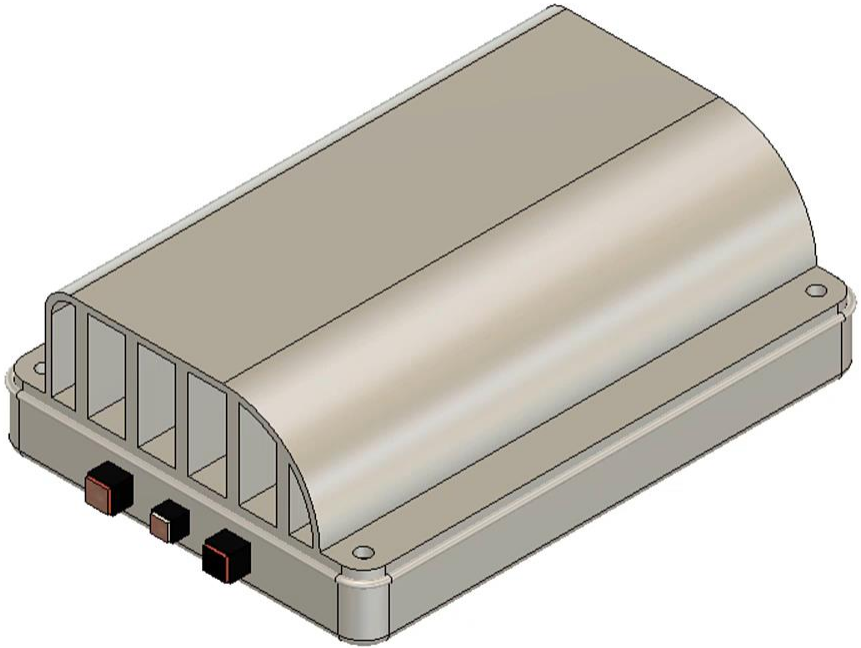
SOLID SURFACE MESH SHEET METAL PLASTIC UTILITIES MANAGE VOLUME FIELDS

DESIGN

CREATE AUTOMATE MODIFY ASSEMBLE CONSTRUCT INSPECT INSERT SELECT

BROWSER

- Battery Module - AU 2022 v1
  - Document Settings
  - Named Views
  - Origin
  - Analysis
  - Sketches
  - Battery Body:1
  - Heat Sink:1
  - Air Source:1
  - Duct:1



Autodesk Fusion 360

Battery Module - AU 2022 v1*

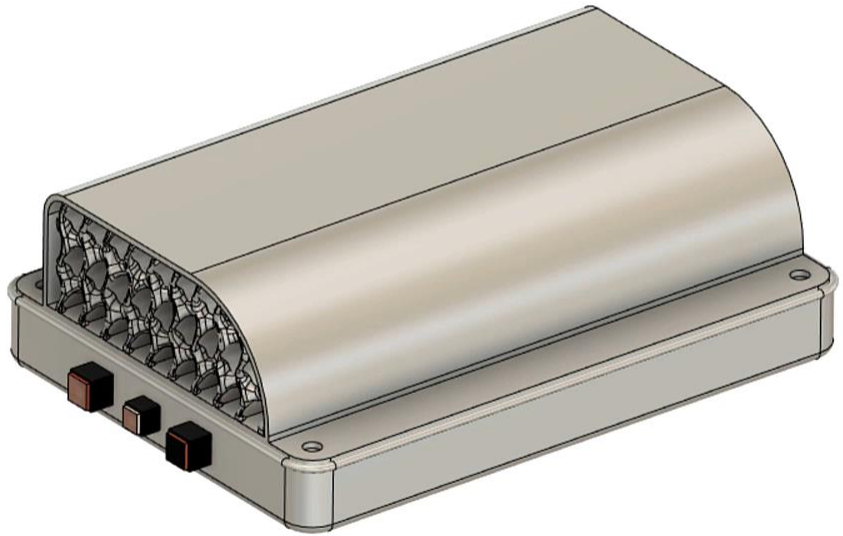
DESIGN

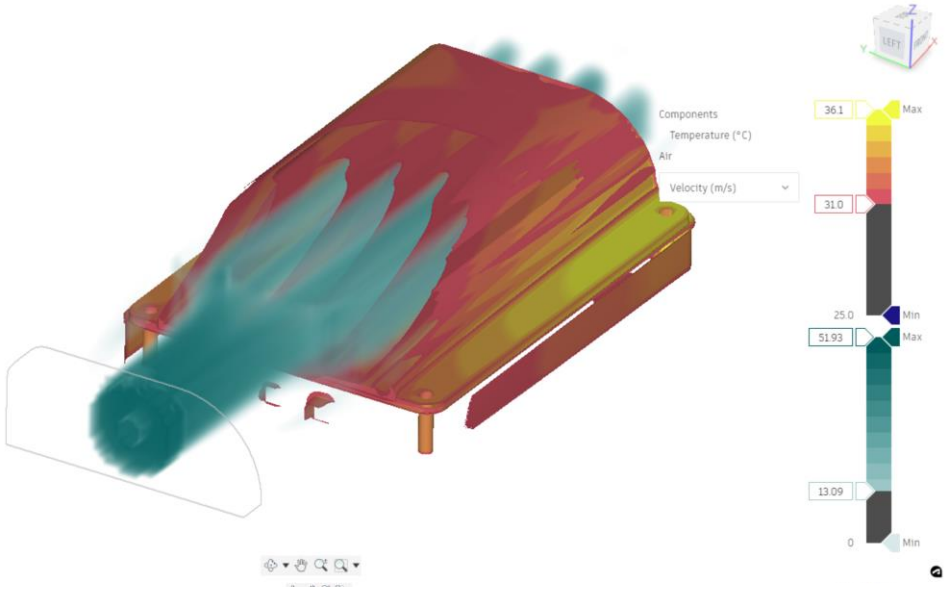
SOLID | SURFACE | MESH | SHEET METAL | PLASTIC | UTILITIES | MANAGE | VOLUME FIELDS

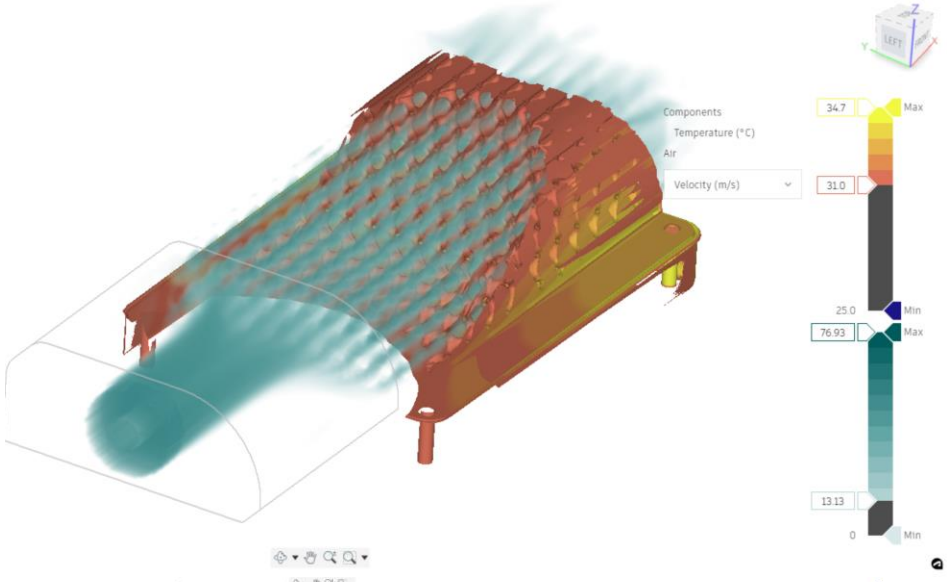
CREATE | AUTOMATE | MODIFY | ASSEMBLE | CONSTRUCT | INSPECT | INSERT | SELECT

BROWSER

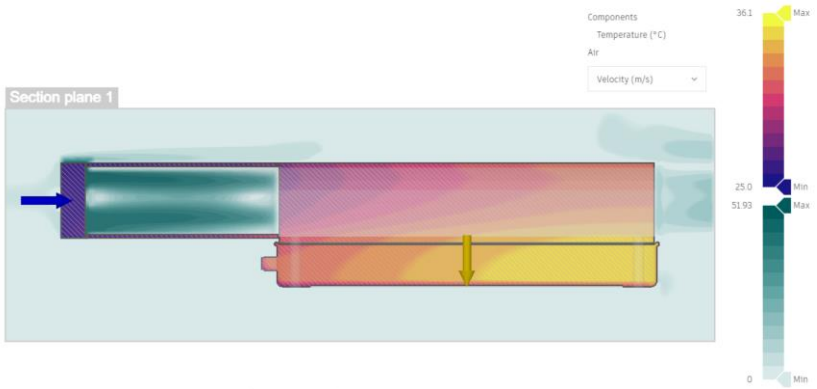
- Battery Module - AU 2022 v1
  - Document Settings
  - Named Views
  - Origin
  - Analysis
  - Sketches
  - Battery Body:1
  - Heat Sink:1
  - Air Source:1
  - Duct:1
  - Gyroid Heat Sink:1



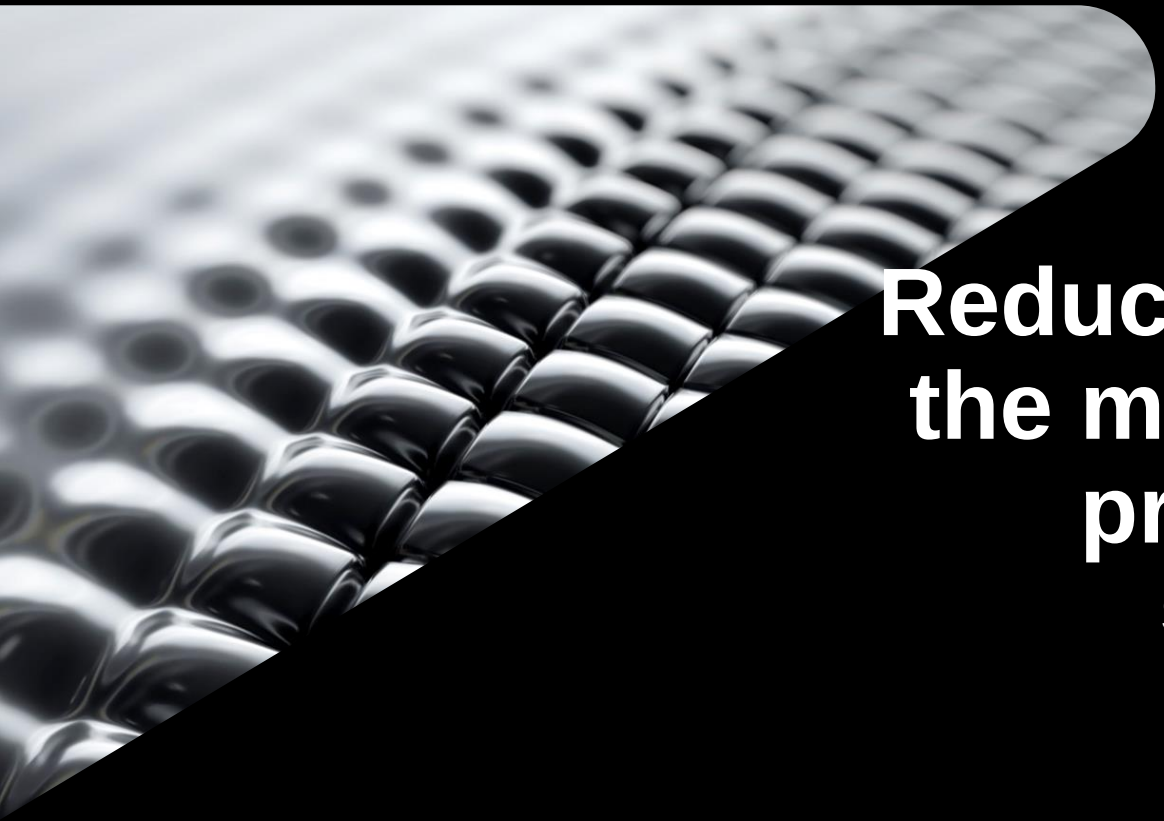

Components
Temperature (°C)
Air
Velocity (m/s)
36.1
Max
31.0
25.0
Min
51.93
Max
13.09
0
Min


Components
Temperature (°C)
Air
Velocity (m/s)
34.7
Max
31.0
25.0
Min
76.93
Max
13.13
0
Min

Improving Product Performance



	Fin Heat Sink	Gyroid Heat Sink	% Difference
Max Temp (C)	35.9	34.6	-3.6%
Surface Area (mm2)	1.02E+05	1.43E+05	+40.2%
Mass (g)	420	385	-8.3%

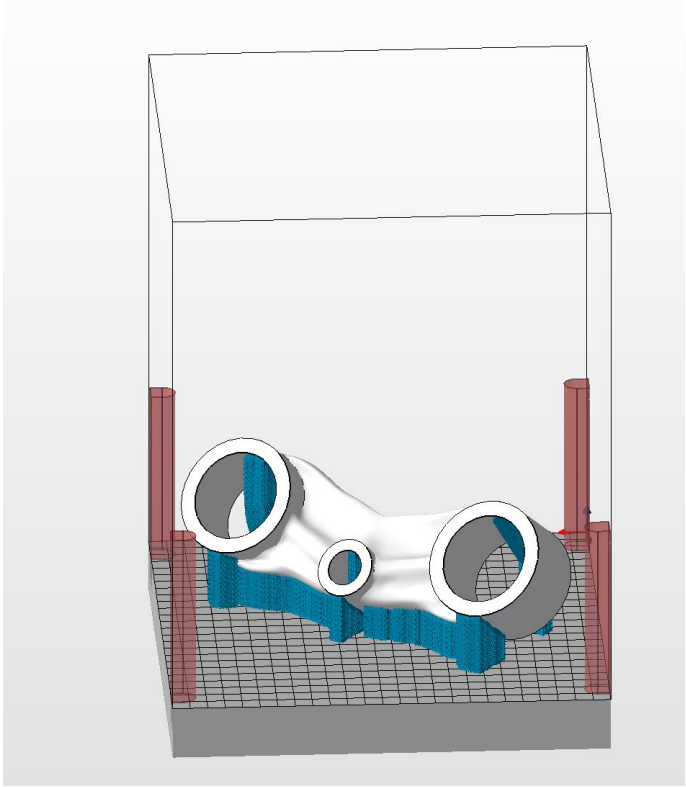


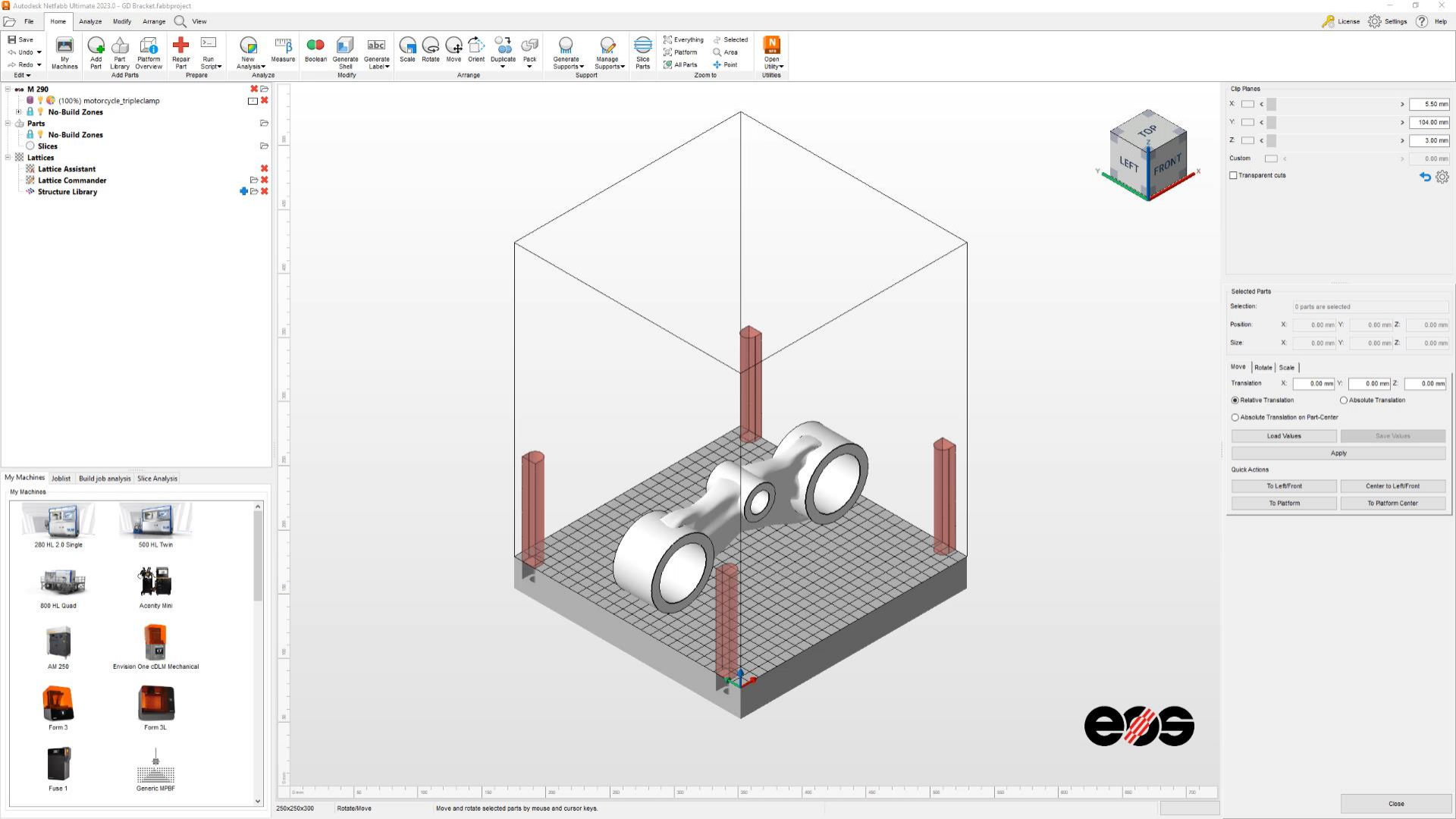
Reduce waste during the manufacturing & product lifecycle

Simulate to reduce build failures

Simulating to Reduce Build Failures

Can we predict and prevent a build failure before it happens?



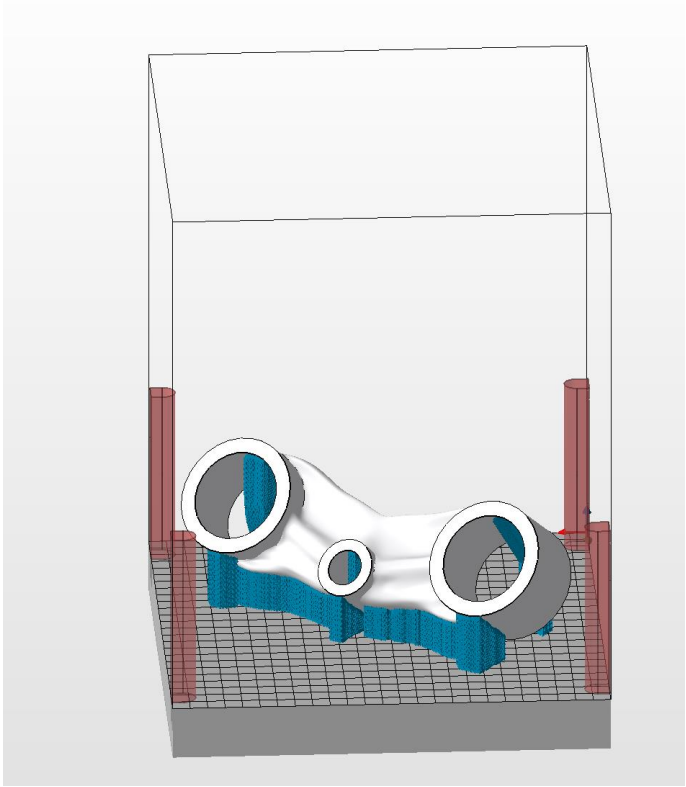

Autodesk Netfabb Ultimate 2023.0 - GD Bracket.fabbproject
File
Home
Analyze
Modify
Arrange
View
License
Settings
Help
Save
Undo
Redo
Edit
My Machines
Add Part
Part Library
Platform Overview
Add Parts
Repair Part
Run Script
Prepare
New Analysis
Measure
Analyze
Boolean
Generate Shell
Generate Label
Modify
Scale
Rotate
Move
Orient
Duplicate
Pack
Arrange
Generate Supports
Manage Supports
Support
Slice Parts
Everything
Platform
All Parts
Selected
Area
Point
Zoom to
Open Utility
Utilities
M 290
(100%) motorcycle_tripleclamp
No-Build Zones
Parts
No-Build Zones
Slices
Lattices
Lattice Assistant
Lattice Commander
Structure Library
My Machines
Joblist
Build job analysis
Slice Analysis
My Machines
280 HL 2.0 Single
500 HL Twin
800 HL Quad
Aconity Mini
AM 250
Envision One cDLM Mechanical
Form 3
Form 3L
Fuse 1
Generic MPBF
TOP
LEFT
FRONT
Clip Planes
X:
Y:
Z:
Custom
Transparent cuts
5.50 mm
104.00 mm
3.00 mm
Selected Parts
Selection:
0 parts are selected
Position:
Size:
Move
Rotate
Scale
Translation
Relative Translation
Absolute Translation
Absolute Translation on Part-Center
Load Values
Save Values
Apply
Quick Actions
To Left/Front
Center to Left/Front
To Platform
To Platform Center
Close
250x250x300
Rotate/Move
Move and rotate selected parts by mouse and cursor keys.

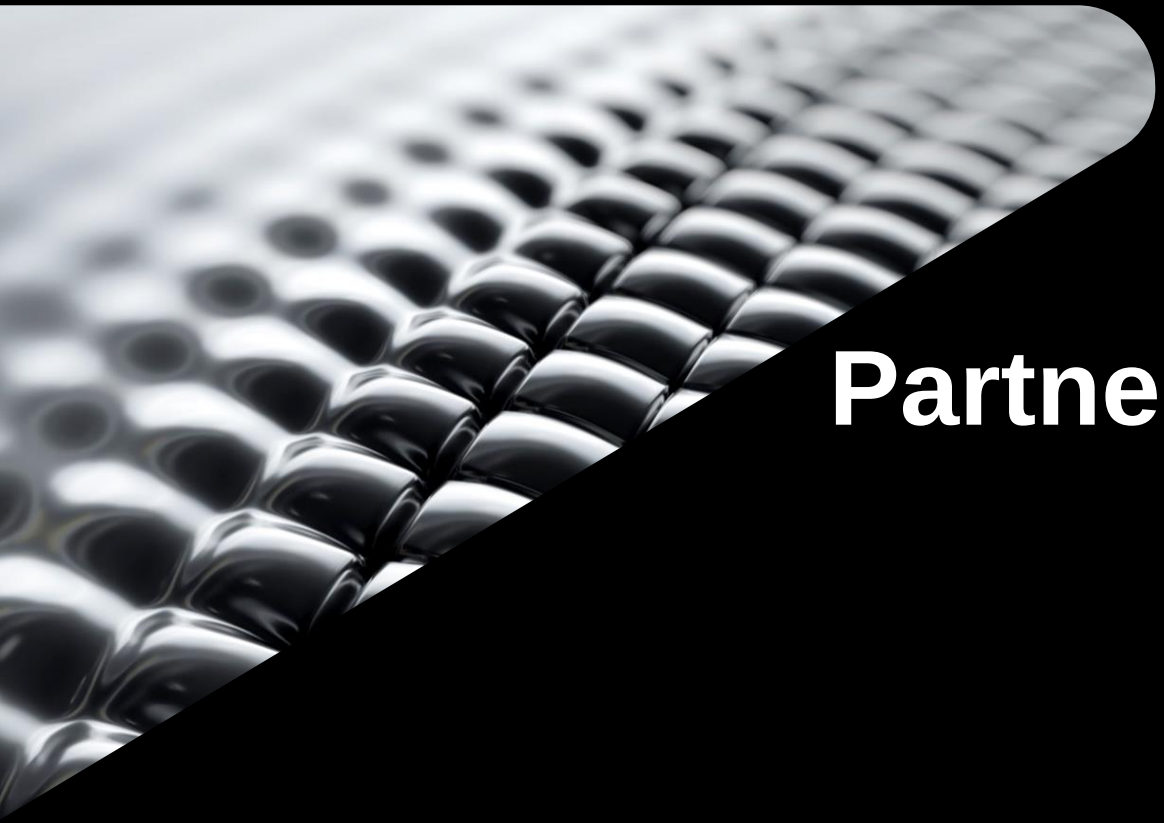
Simulating to Reduce Build Failures

2x15-minute build simulation prevented:

1.5 kg of wasted powder or

155 kg CO2 equivalents





Partnerships for the Win

Build Your External Network

"Strengthen the means of implementation and revitalize the global partnership for sustainable development"

Finance
Technology
Capacity Building
Trade

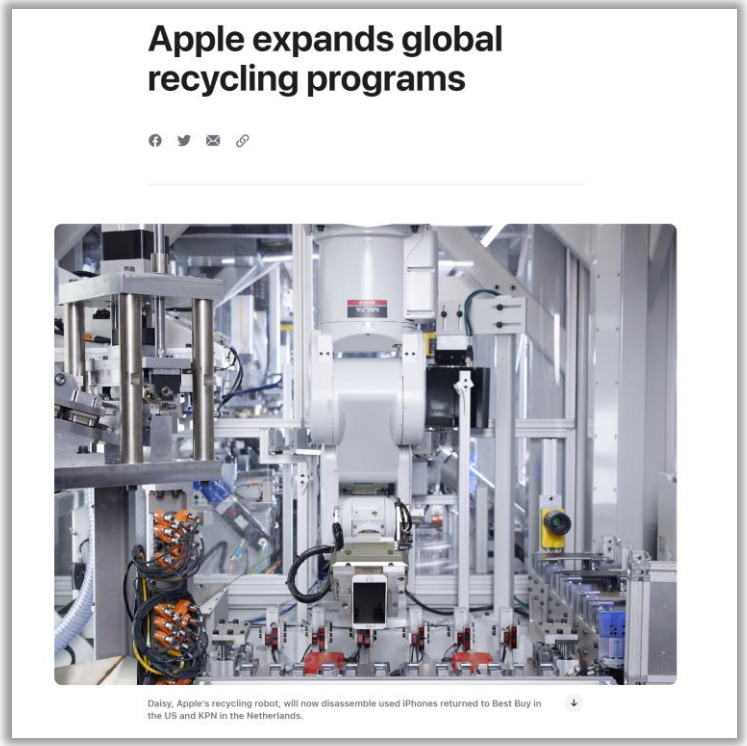
Target 17.6: Knowledge sharing and cooperation for access to science, technology and innovation
Target 17.7: Promote sustainable technologies to developing countries
Target 17.8: Strengthen the science, technology and innovation capacity for least-developed countries
Target 17.17 Encourage public-private and civil society partnerships

Apple's Partnership, Carnegie Mellon University

Robotics & Innovation

Apple partners with Carnegie Mellon University for robotic device recycling

July 15, 2021



Government Lead Partnerships

Partnership between OEMs and some of their SME suppliers with the goal to speed up adoption of additive manufacturing

OEM Members

GE
Lockheed
Raytheon
Siemens
Energy
Honeywell
Northrup Grumman

MANUFACTURING

Biden Announces AM Forward Program To Foster Adoption Of Additive Manufacturing

Willy Shih Senior Contributor ⓘ
I teach at Harvard Business School, and I write about manufacturing

May 6, 2022, 05:00am EDT

Laser sintering is one of the technologies used for the additive manufacturing of metals GETTY

REMADE INSTITUTE
A Division of the Sustainable Manufacturing Innovation Alliance Corp.

Design for Recovery, Reuse, Remanufacturing & Recycling (Re-X)

** NEW ** **Development of a Novel Design for Remanufacturing Software Plugin for CAD** – *Rochester Institute of Technology (RIT), Caterpillar, Inc. BorgWarner (Delphi), Trane Technologies, ZF Group (WABCO), Remanufacturing Industries Council (RIC), Autodesk*

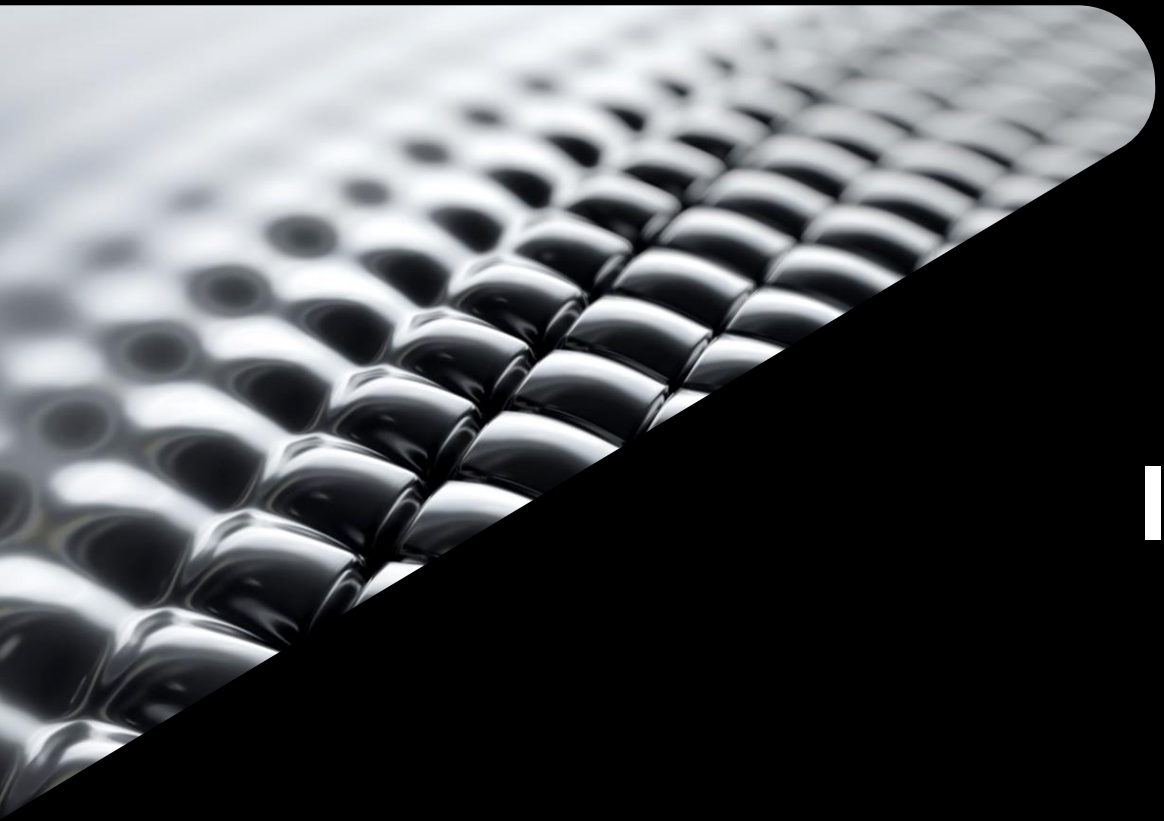
ACCELERATING THE TRANSITION TO A CIRCULAR ECONOMY

REMADE brings together industry innovators, academic researchers, and national labs to enhance the nation's industrial competitiveness and lead the transition to a Circular Economy in the U.S.

MICHELIN, Milliken, MODERN Disposal Services, MJCELL EXTRUSION LLC., MYCOCYCLE, niagara, Novelis, Oculatus Consulting, LP PADNOS, paragon technical services, inc., PHINIX, plastilene, PROTO MANUFACTURING, PSE A Siemens Business, ReJoule, RENEWANCE, RRS, Schnitzer, Sealed Air, SECAT, Shaw, SOLVUS GLOBAL, SOM, SHELTER SERVICE, SugarCreek Brandworthy Food Solutions, SUNNKING, SYNERGY ADDITIVE MANUFACTURING, LLC., Thiele, TRANE TECHNOLOGIES, Unilever, WM WASTE MANAGEMENT, WestRock, WINGATE PACKAGING

adidas, Alcoa, allbirds, ALO ADVISORS, AMP ROBOTICS, anteagroup, AUDUBON METALS, BARNES, BASF, Braskem, BRUNSWICK, Building Transparency, CATERPILLAR, CFS, Chemstations, CHZ TECHNOLOGIES, CompuTherm FOR MATERIALS DESIGN, CoreCentric Solutions, Danfoss, DAVIES OFFICE, DOW, DTG Recycle, DYNAMIC LIFECYCLE INNOVATIONS, ECK INDUSTRIES, ERI, ERCo ENERGY RESEARCH COMPANY, FIBER INDUSTRIES, First Solar, Ford, GORDON ALUMINUM, Graphic Packaging INTERNATIONAL, iMFLUX, Impossible Objects, JOHN DEERE, KPM Kingston Process Metallurgy Inc., KOHLER, level seven, LID VIZION

Remanufacturing Conference



In Conclusion

What’s Next?

Key Takeaways

1. **Do not assume that AM by default = sustainable**
2. **Advocate for better LCA data for AM processes**
3. **Build a business case that aligns economic and environmental benefits to the unique strengths of AM**

Learning Objectives

1. Assess AM design trade-offs while avoiding common pitfalls
2. Identify applications where additive manufacturing provides business and sustainability benefits and where it doesn’t
3. Apply DfAM techniques such as generative design, latticing, and part consolidation
4. Implement design workflows that drive more sustainable and higher performing part designs