RICARDO

3D Printed Tools: Opportunities and Limitations of an Emerging Capability

Alan Munday, Manager–North America, Ricardo Strategic Consulting

Delivering Excellence Through Innovation & Technology

www.ricardo.com

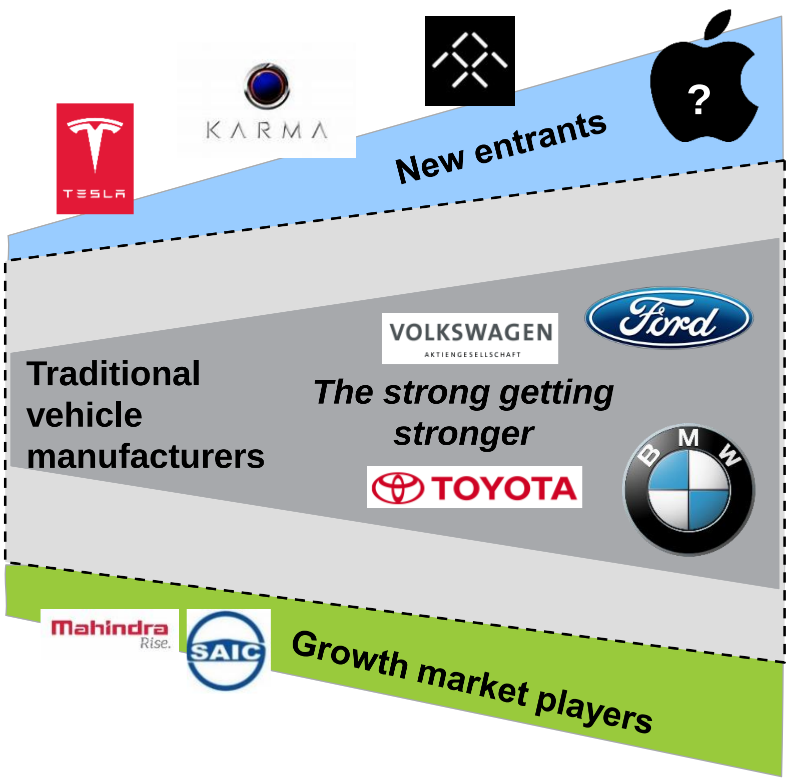
Agenda

- Project: Reducing Automotive CAPEX Entry Barriers through Design, Manufacturing and Materials
- Corolla vs. BMW i3 (lightweighting and low volume cost reduction)
- 3D printing: What are we talking about?
- 3D printing techniques, application limitations and imminent opportunities
  - Directed energy (e-beam, laser, arc) – metals
  - Powder bed – metals, polymers, ceramics
- Case study die analysis (WAAM)
- Outlook or further research (materials, process parameters, software)

The Automotive industry structure is changing – new suppliers too

Industry structure of vehicle manufacturers and automotive suppliers

Vehicle Manufacturers



Suppliers

Source: Ricardo analysis

Thermoeconomic's is being used to optimize manufacturing costs

$$\text{Total cost } f\begin{pmatrix} Product \\ Cost \end{pmatrix} = \$_{Materials} + \$_{Process} + \$_{Waste}$$

Thermoeconomic
synthesis/design

$$$

- Raw materials
- Tooling
- Energy

$$$

$$$

- Waste
- Emissions

Economics continues to push for light weighting.. but why?

EPA estimated fuel economy mpg:

- 2014: 18 city/22 hwy/18 combined
- 2016: 19 city/26 hwy/22 combined

18% improvement

SpaceX Flacon Heavy
~$11,000 per kg

http://www.ford.com/trucks/f150/

Impact of light-weight design and low production volumes on manufacturing cost – BMW i3 and Toyota Corolla

- CAFE fuel economy standards and are driving need to reduce vehicle weight
- Light-weight materials are changing OEM’s approaches to tooling

Objectives:

- Evaluate cost effectiveness of in-production light-weight design
- Identify best practices in light-weighting and opportunities for capital cost reduction

Baseline

Toyota Corolla

Selected components:

- Floor Assembly
- Front Door Assembly

Light-weight Design

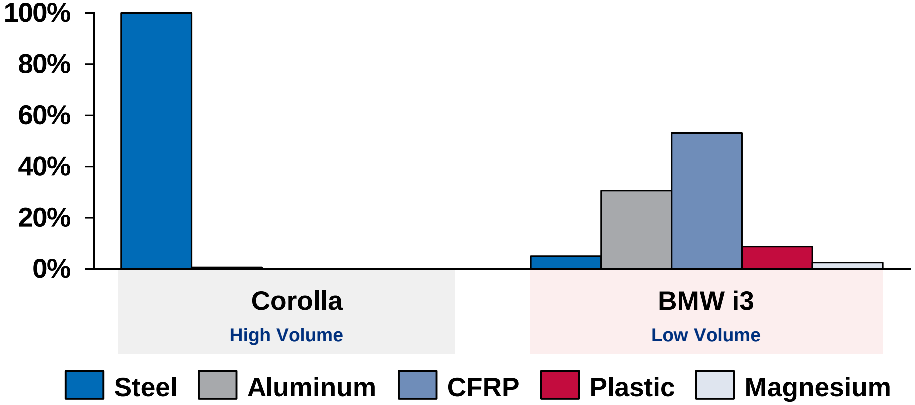
BMW i3

Barriers to Entry in Automotive Production and Opportunities with Emerging Additive Manufacturing Techniques
Authors: Piyush Bubna (Ricardo), Michael P. Humbert (UTRC), Marc Wiseman(Ricardo), Enrico Manes(UTRC)

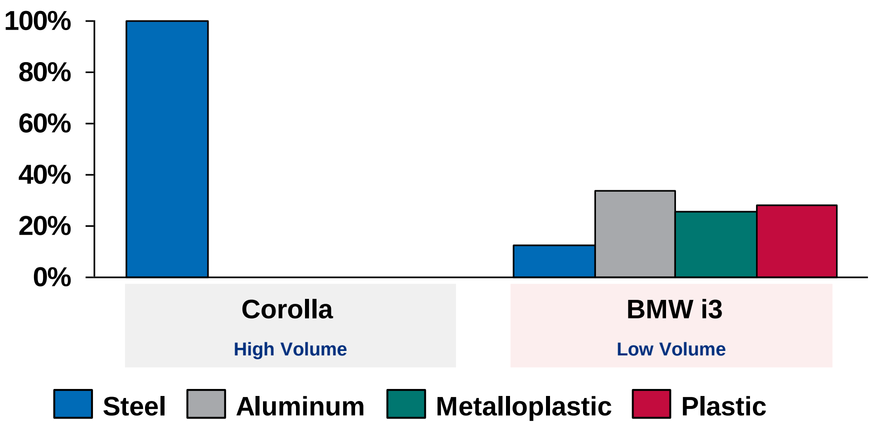
Estimated tooling investment for automotive sub-assemblies

Toyota Corolla and BMW i3 material usage and annual sales volume

% Material Distribution in Body In White



% Material Distribution in Closure System (Door, Hood, Trunk)



Selected Vehicles

Toyota Corolla

- High volume
  - 300,000 pa
- Conventional steel body

BMW i3

- Low volume
  - 16,000 pa
- Combination of steel, Al, plastic & composite

Cost estimation

CAPEX

Tooling

Tooling cost includes:
- Dies
- Fixtures
- Robotic features

OPEX

Materials

OPEX

Virtual Factory

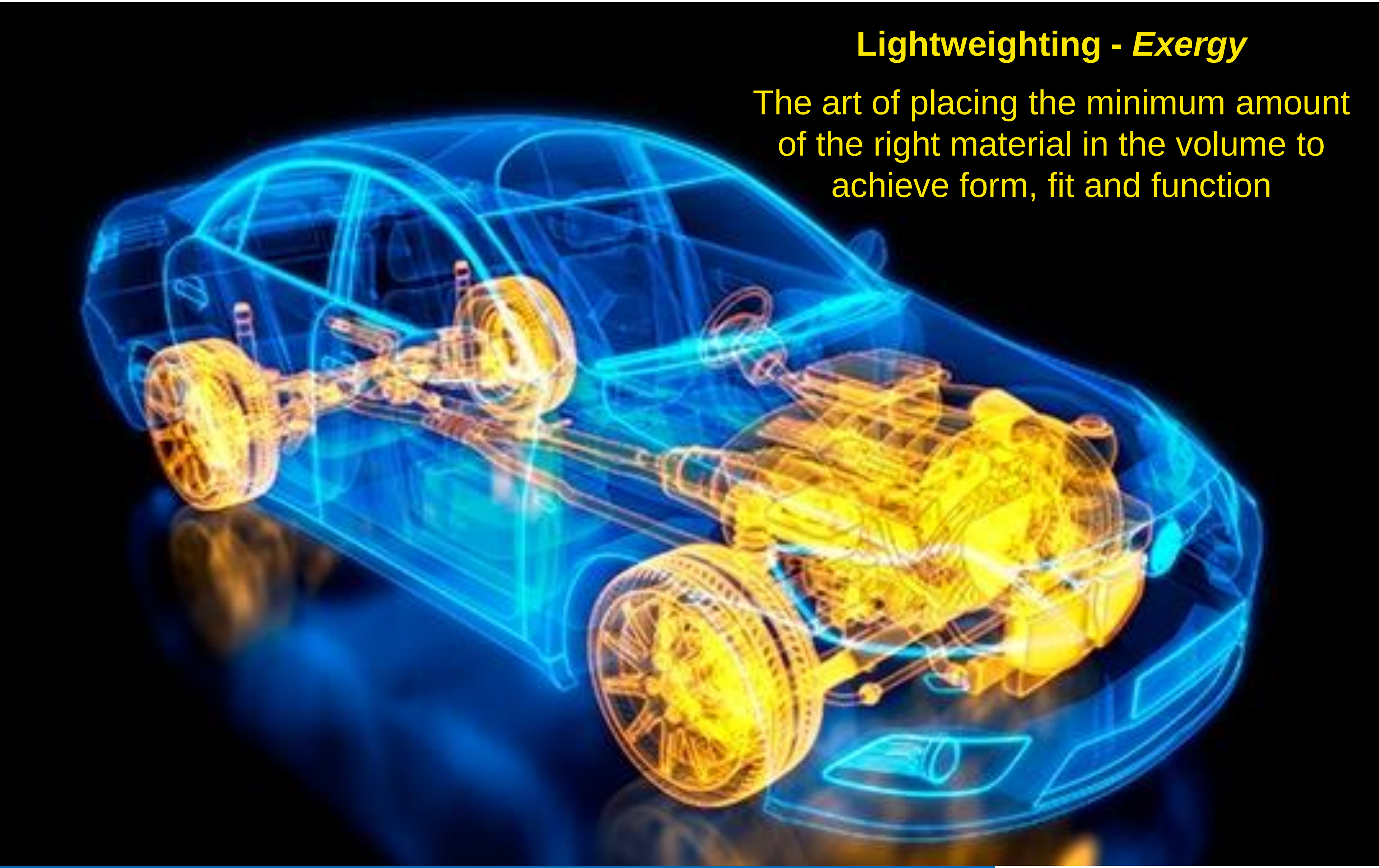
Equipment and staff to produce parts to order

Process Cost

- Equipment amortized costs (for outsourced manufacturing)
- Factory annual operating hours
- Labor (Direct & Indirect)
- Maintenance
- Utilities
- Floor space
- Insurance and taxes
- Supporting plant equipment

The virtual factory can be setup differently for various production volumes

What can 3D printing do for you?

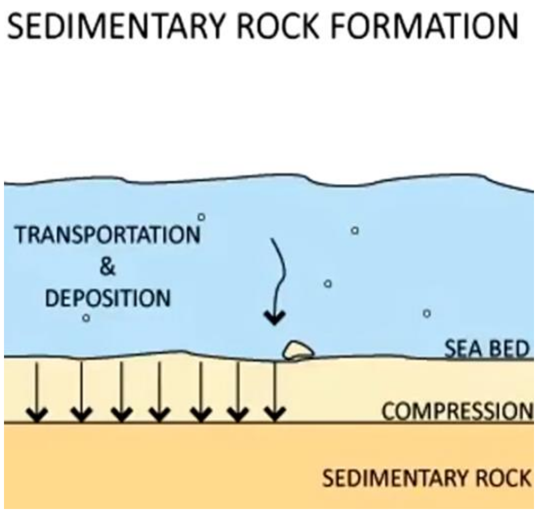


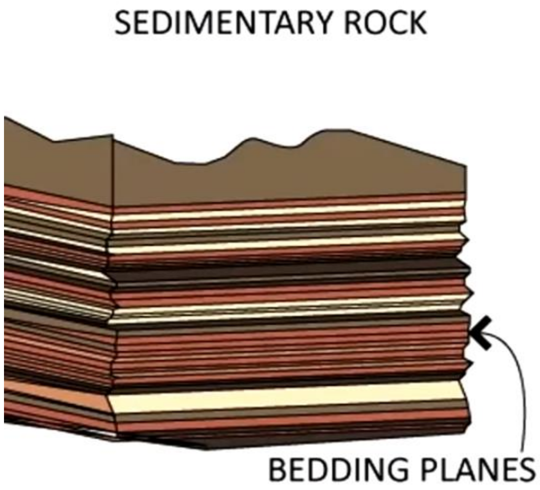
Lightweighting - *Exergy*

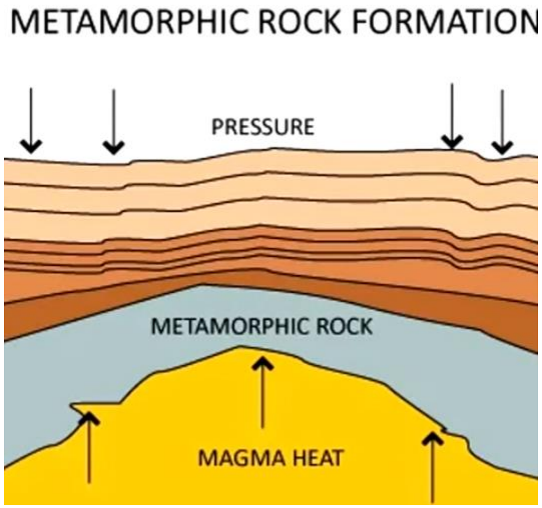
The art of placing the minimum amount of the right material in the volume to achieve form, fit and function

3D printing is not new endeavor – principle found in nature

The basic principles of additive manufacturing has been at play for millennium







Even creatures get in on the act

- Crustaceans
  - Oysters
  - Clams
  - Snails

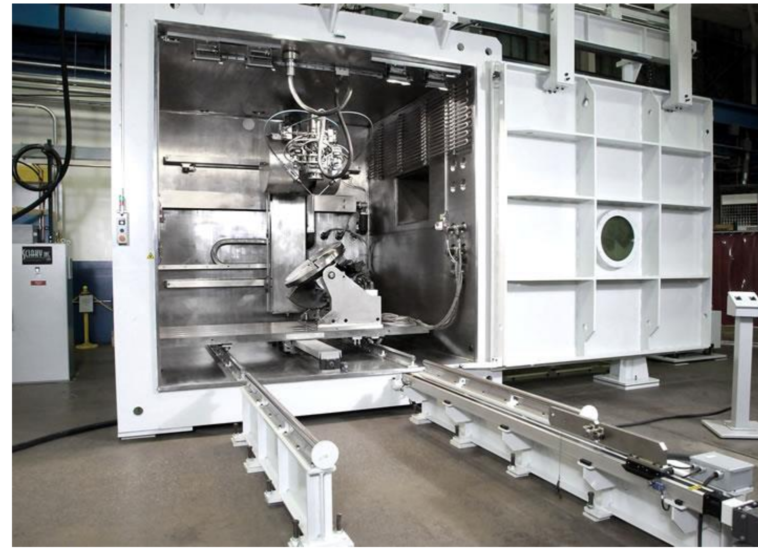
Precision placement of materials is seen in beehives

– Bees – Direct energy approach

Directed Energy Deposition - wire feed electron beam

- Sciaky electron beam wire feed
  - High deposition rate

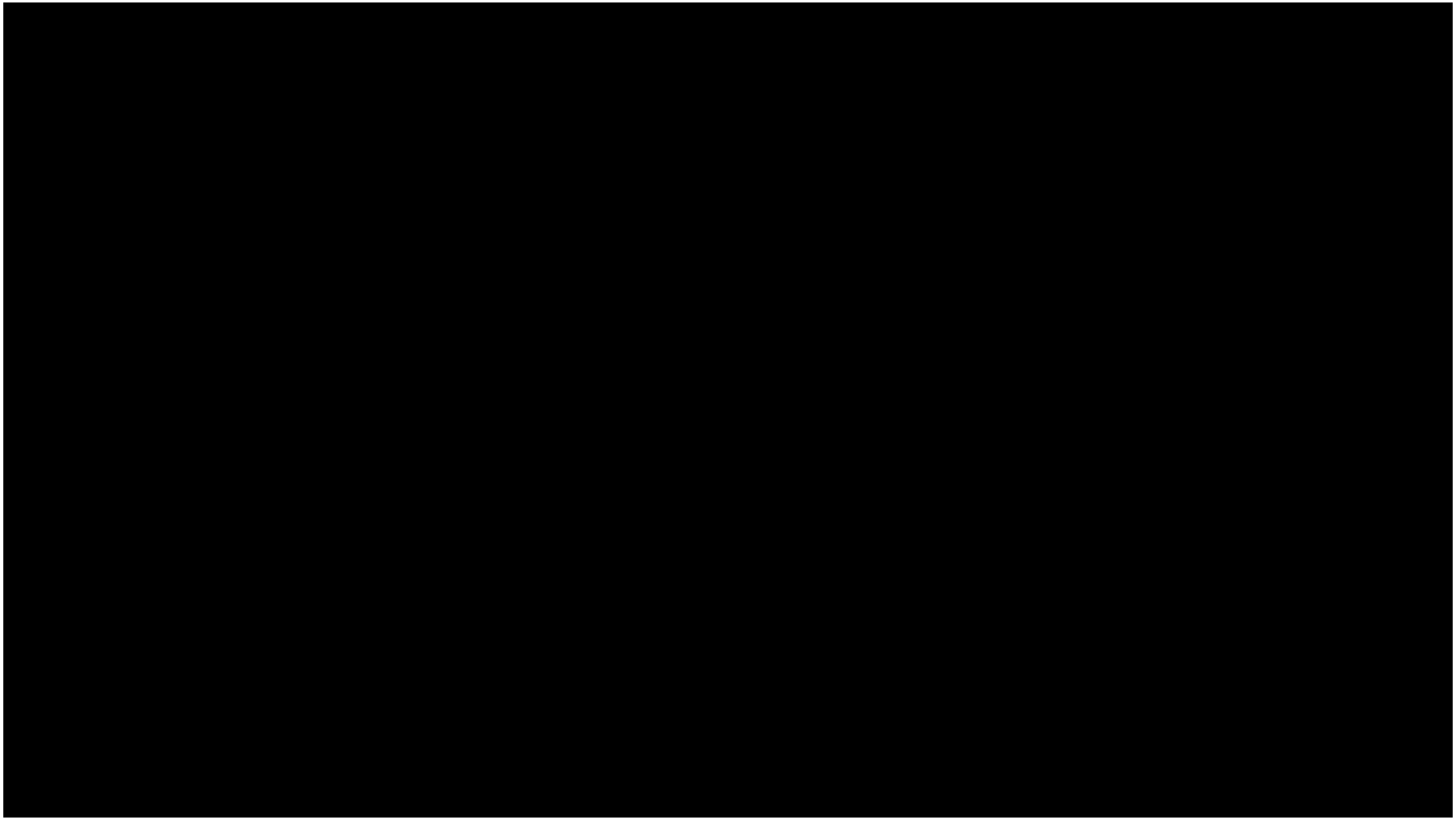
    > 10 pounds per hour
  - Well suited to large structures
  - Titanium, tool steel and stainless steel
  - Requires a high quality vacuum as the operating atmosphere



This Component is 22 Inches in Diameter and 12 inches Tall.

Pictures of the Successive Building of an EB Wire-Feed INCO 718 Deposited Engine Case.

Directed Energy Deposition - wire feed electron beam



Sciaky

Directed Energy Deposition – wire arc welding

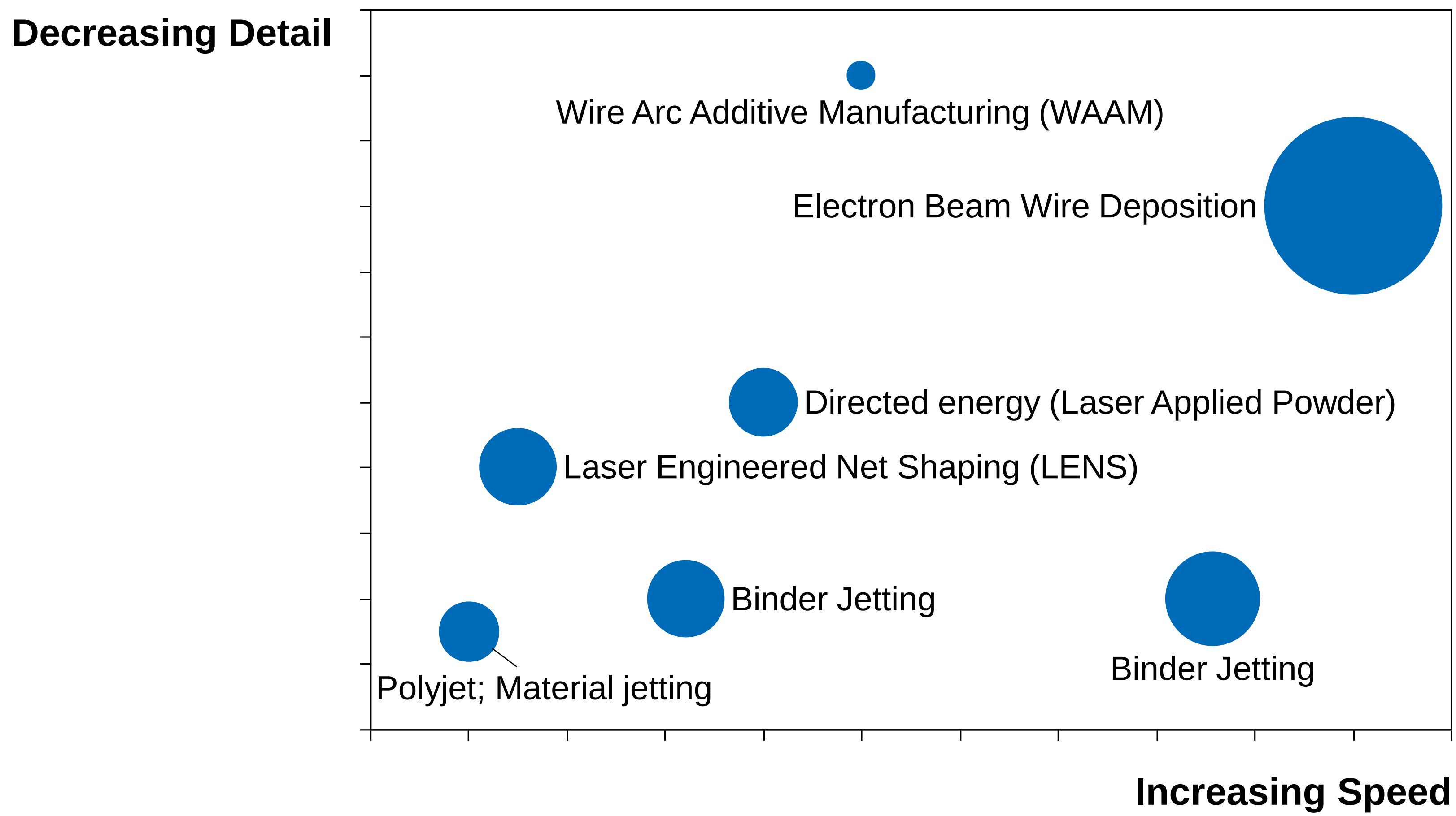
- Wire-arc based processes: MIG welder style system
  - Lower cost than laser and electron beam systems, but typically produces lower quality deposits
  - Integrated industrial welding robots and setups are very cost effective

Thermal stress management

0.6 metre x 0.6 metre titanium frame for BAE Systems
http://waammat.com/about/demo-parts

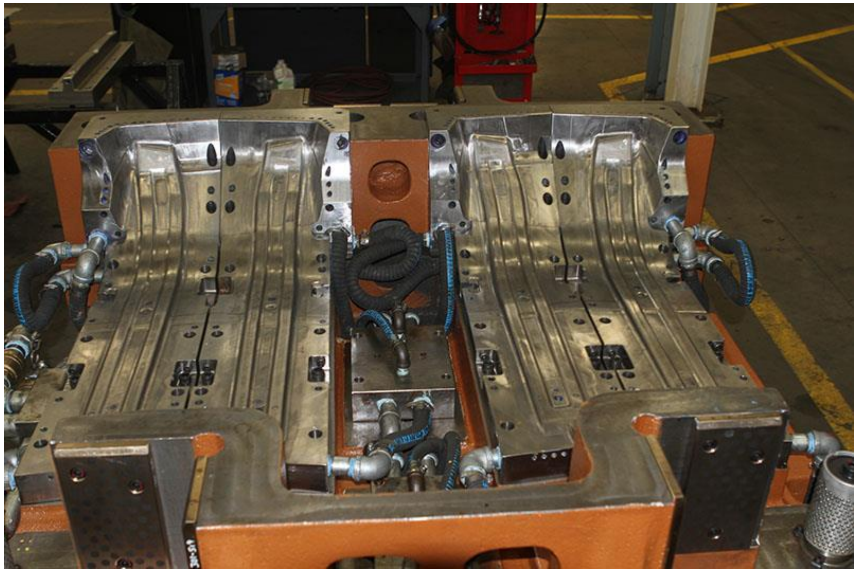
Materials Science and Technology
http://www.tandfonline.com/doi/pdf/10.1179/1743284715Y.0000000073

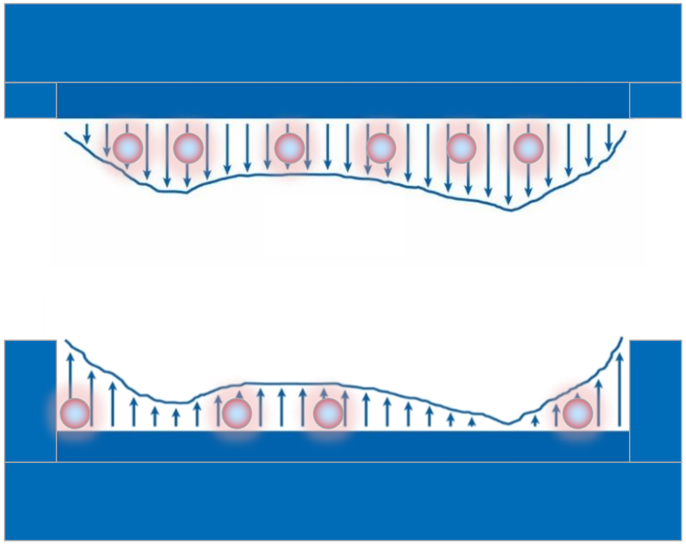
Additive manufacturing technologies speed vs detail vs capital cost



The tool making challenge for hot forming Boron steel

- Lower production volumes
- More capabilities
- Shorter lead times
- Lower cost
- 3D geometry





Door Skin Tooling – Conventional Stamping Dies

- Stamping of the front door outer skin is completed in 4 stations:

1. Blanking – one die set ($40k)
2. Forming – one die set ($125k)
3. Trim + pierce – one die set ($75k)
4. Check fixturing/gauges ($7.5k)

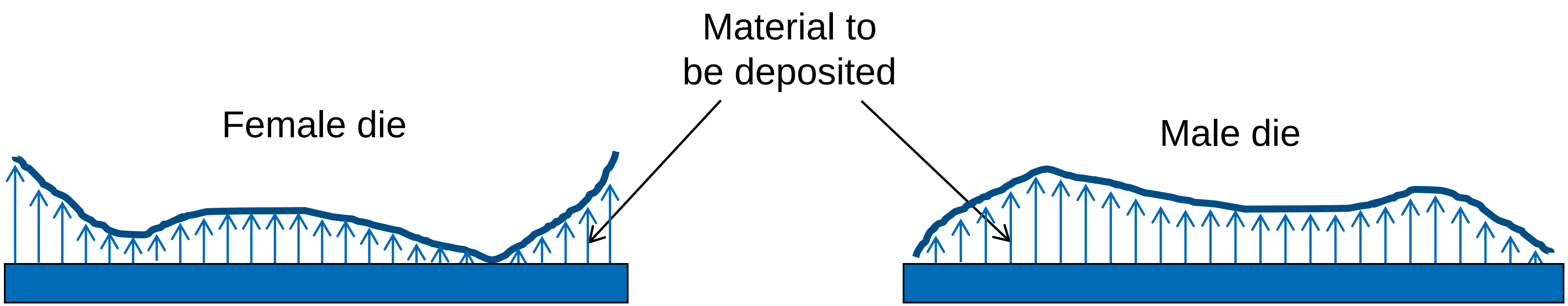
TOTAL COST TO MANUFACTURE ~ $0.25 million

- Durability – 1.5 million hit durability (tool steel)
  - Capable of 300,000 per annum volume for 5 years without being replaced

Teardown Images: Courtesy of A2MAC1 LLC

Front Door Tooling – Additive ‘A’ surface form die

- Part dimensions are 1.13 m x 0.74 m x 0.1 m depth of draw
  - Plate dimensions (each) are 1.43 m x 1.04 m x 0.15 m (15% increase)
- Volume of material added to each die:
  - Assume equal distribution between male and female die
    - **54,000 cm^3 added to plate for each die (587.4 kg)**

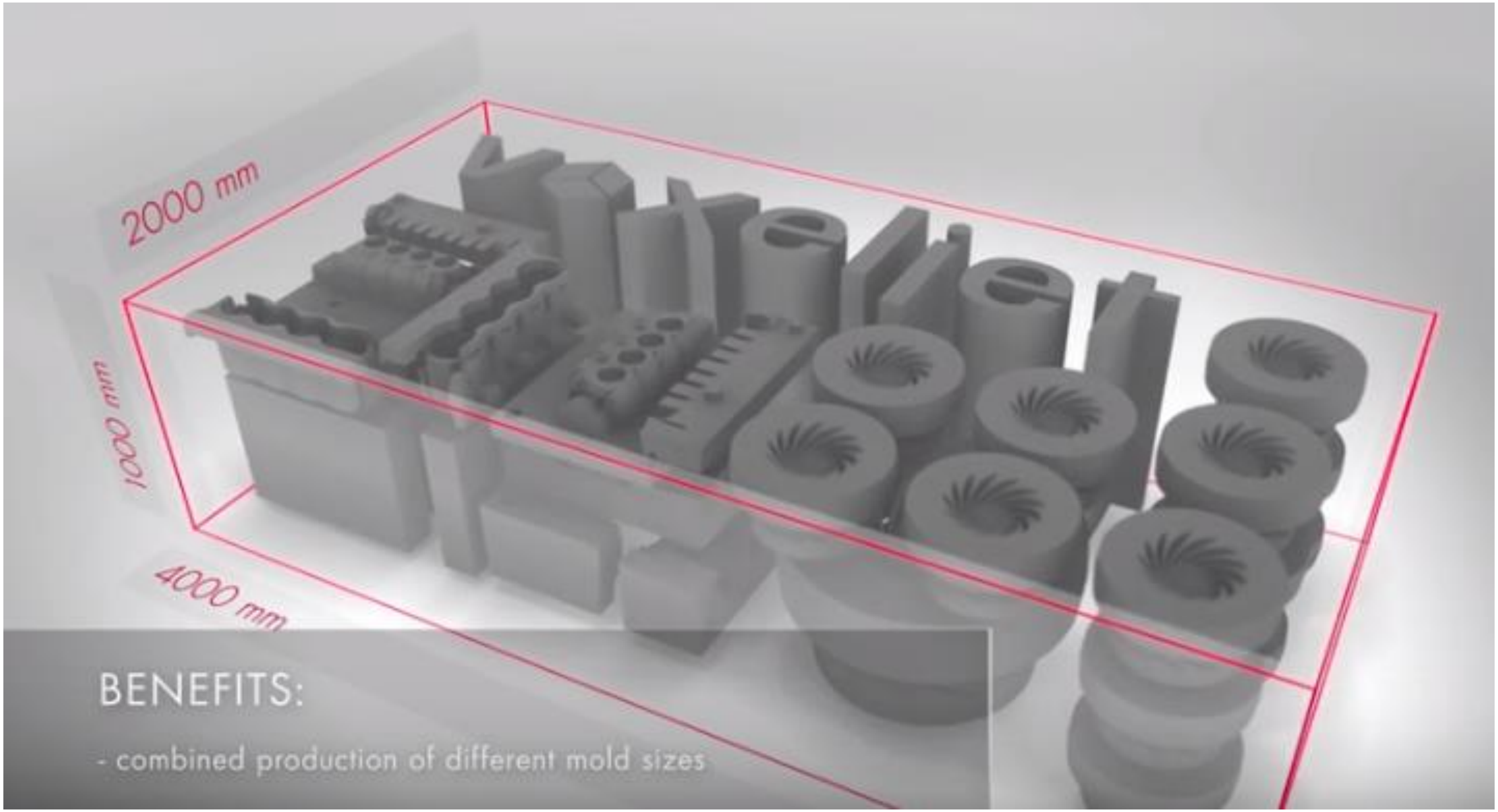


- Cost: WAAM machine ($20.16/hour) Material ($33.00/hour)
- **Total cost for the Forming die set $100,000**
- Conventional Stamping **die set costs $125,000 to manufacture**

20% cost savings

Material Jetting Technologies

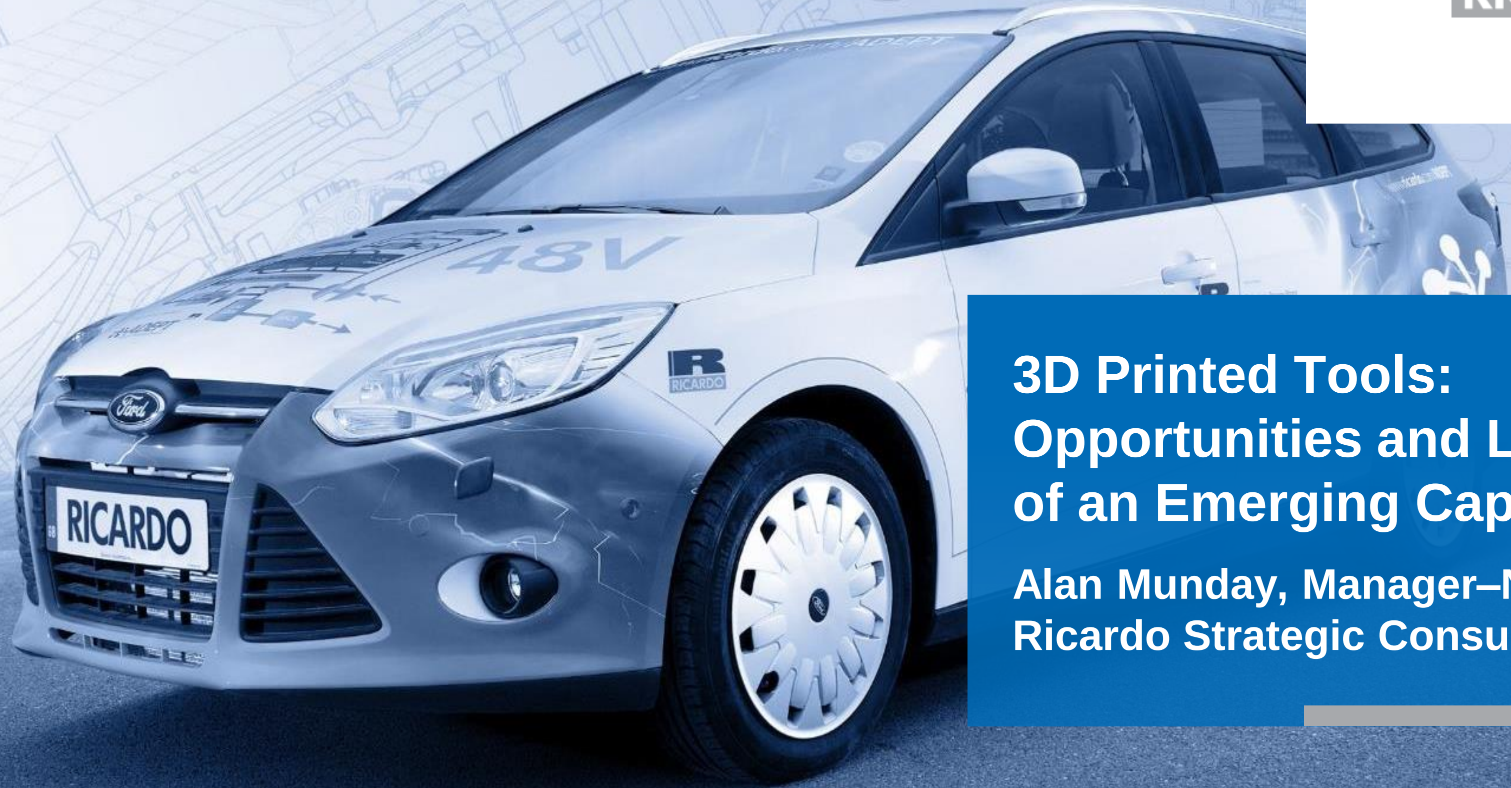
Binder jetting creates casting cores and molds




voxeljet


UNPACKING:
Removing the unprinted
particulate material and the side walls

Thank You



RICARDO

3D Printed Tools: Opportunities and Limitations of an Emerging Capability

Alan Munday, Manager–North America, Ricardo Strategic Consulting

Front Door Tooling - Additive

- Cost to use WAAM machine is $20.16/hour
- Material cost (tool steel wire) is assumed to be $33.00/hour

Starting plate cost (w/ D2 steel)		
Plate height (cm)	143	
Plate width (cm)	104	
Plate thickness (cm)	15	
Volume (cm^3)	223,080	
Mass (kg)	1762.3	
Material cost ($/kg)	1.65	
Plate cost		$2,908

Additive manufacturing cycle time (deposition time required on WAAM equipment)		
Mass to be deposited (kg)	587.4	
Deposition rate (from above)	2.0	(D2 steel)
Buy-to-fly ratio (estimate for amount of finish machining necessary)	1.15	
Total deposition time (hr)		337.8 hr
Time to load/unload system (hr)		1.5 hr
Additive machine cost		$6,840
Additive material cost		$11,146

Post processing considerations		
Mass of material to be removed via milling (kg)	88.1	
Rough cut milling rate (kg/h)	47.4	
Finish cut milling rate (kg/h)	0.1896	
% of material roughed	85%	
Milling set up and clean up time (h)	0.25	
Milling total time (h)	71.54	
Milling cost ($/h)	$100.00	
Total finish machining time (hr)		71.5 hr
Total finish machining cost ($)		$7,154

Front Door Tooling - Additive

Cost of heat treatment	
Final die weight (kg)	2349.7
Heat treat cost ($/kg)	$2.20
Total cost	**$5,169**
Cycle time (h)	**13.00**

Cost of polishing	
Surface area to geometric area ratio	1.5
Approximate die surface area (cm^2)	22308
Polishing time (h)	371.8
Polishing cost ($/hr)	$45.00
Total cost	**$16,731**

Total cost	Cycle time	Cost
Material cost	---	$14,054
Additive cost/cycle time	339.3	$6,840
Finish machining cost/cycle time	71.5	$7,154
Heat treatment cost/cycle time	13.0	$5,169
Polishing cost/cycle time	371.8	$16,731
Total cost/cycle time for making die	**795.6**	$49,948

- Total cost for a male OR female die is $49,948
- Forming die set costs $99,896
- A traditionally manufactured die set costs $125,000 to manufacture
  - 20% cost savings