LIGHTWEIGHT INNOVATIONS FOR TOMORROW

Operated by *ALMMII*

National Network for Manufacturing Innovation:
Lightweight Metals Institute

Metamorphic Manufacturing (a.k.a. Robotic Blacksmithing):

The Third Wave of Digital Manufacturing

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University of Michigan

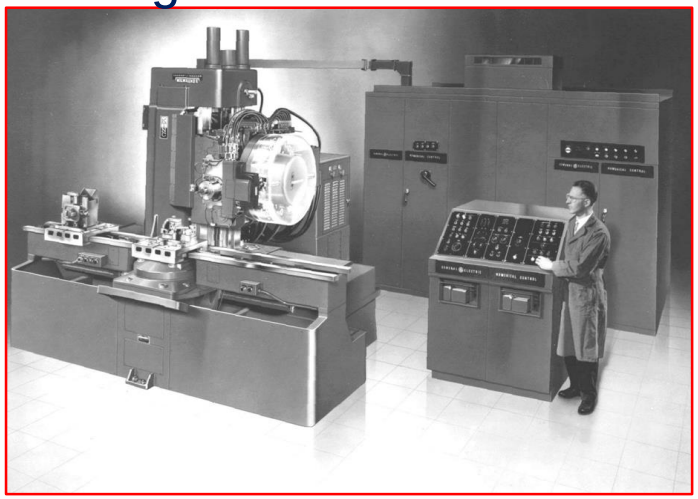
Office of Naval Research
Science & Technology

Digital Manufacturing: Hope & Hype

***First Wave* – CNC**

Removal

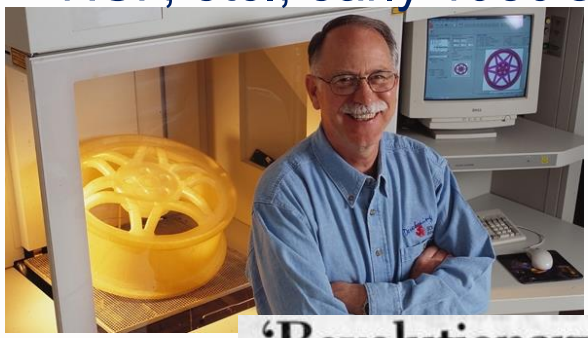
USAF Funding at (MIT) starting in 1949.

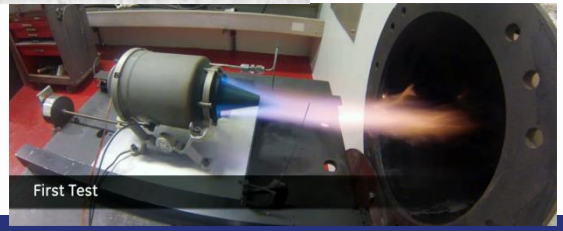


***Second Wave* – AM**

Additive

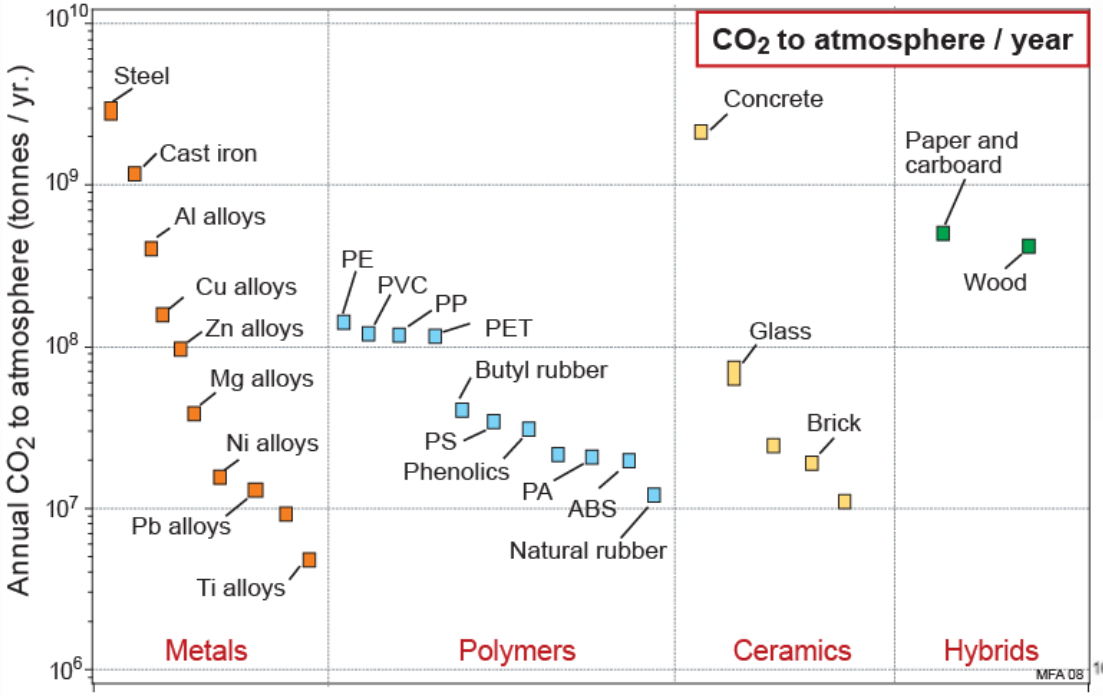
NSF, etc., early 1980's





Metals: Primary Engineered Material

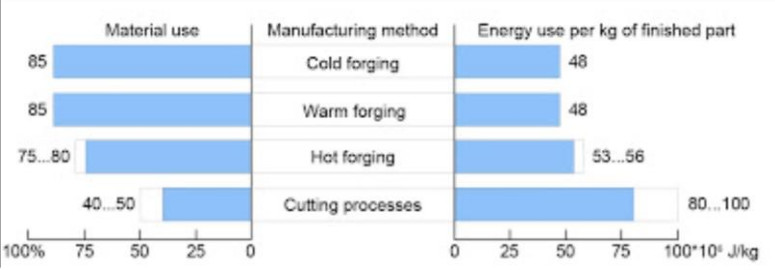
- Production → large fraction of energy use
- Application → huge in energy efficiency
  - Light vehicles, efficient engines, advanced construction



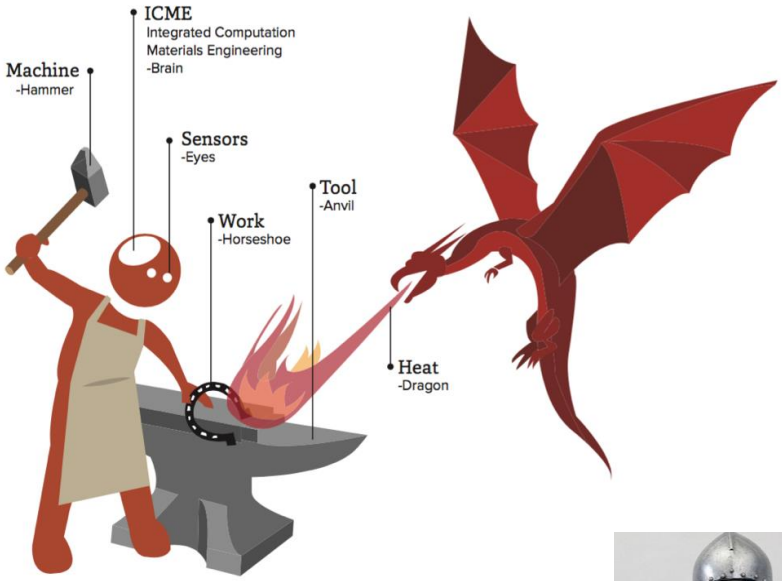
M. F. Ashby, 2010
www.grantadesign.com/education/resources

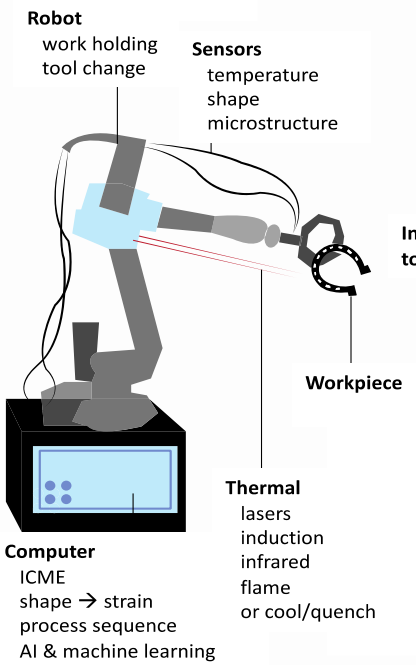
Resource Productivity

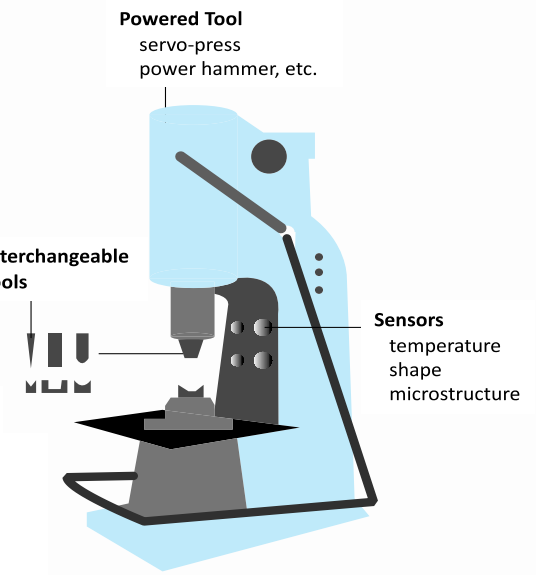
Dornfeld (2013, blog)
Tekkaya & Lange



Third Wave: Metamorphic







Proof: Plasticine and Metal

[redacted]

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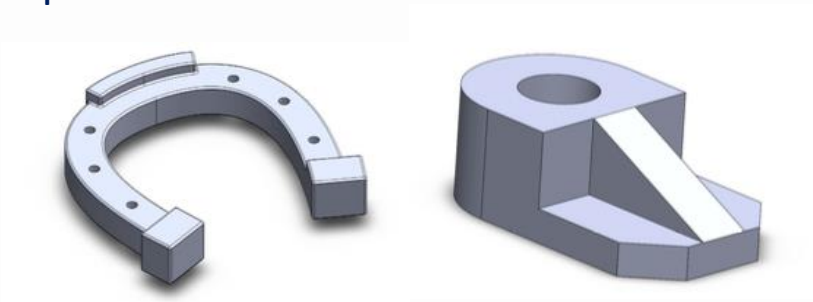
LIFT Prize – $25k offered for a single programmable system that can shape 2 of 3 target parts.



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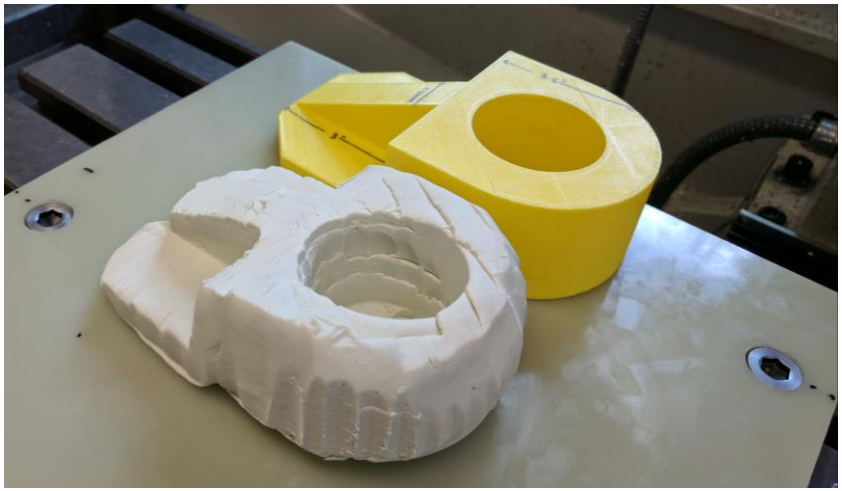
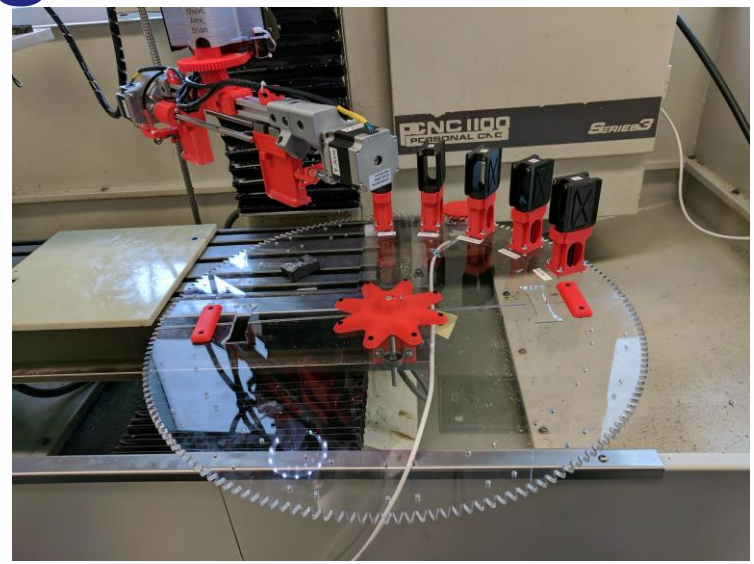
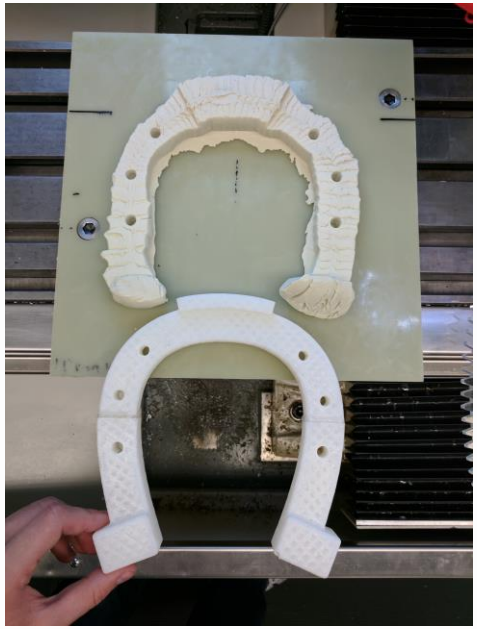
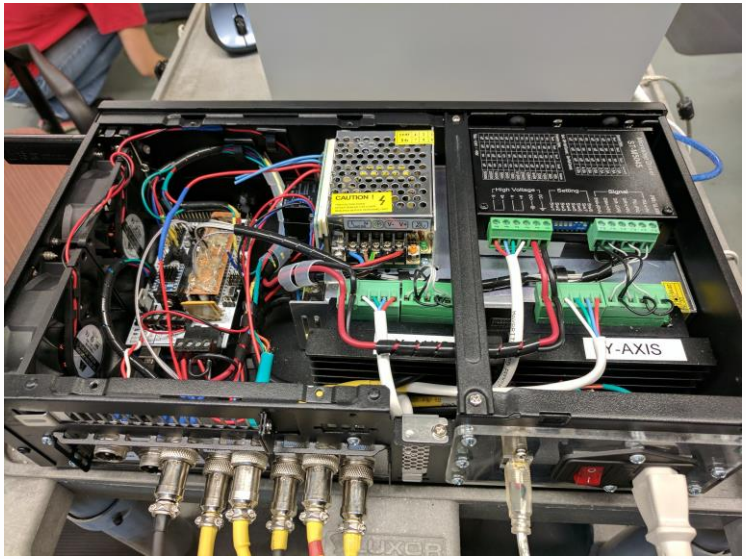
Team Honey Badger, of Ohio State University.
Alex Koenig, Bhuvi Nirudhoddi and Brian Thurston
See: RoboticBlacksmithing.com for details.

Team Honey Badger: Detail









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Technical: How

Fundamentals

Plasticine is a hot metal surrogate.

Volume conserved

$$\varepsilon_1 + \varepsilon_2 + \varepsilon_3 = 0$$

Can make complex shapes by:

→ Squeezing

&

→ Bending

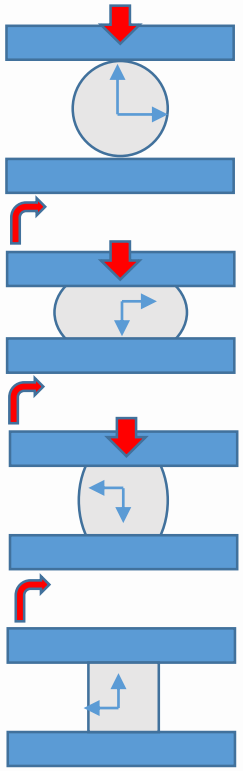
Primary deformation trumps secondary deformation.

How would you make a cube from a piece of clay?

Controlled open die

Primary deformation trumps secondary deformation.

Rotate, shape, repeat. . .



squeeze

rotate

squeeze

rotate

squeeze

rotate

Final!

Increments

Very simple hydraulic cylinders can offer 40,000 ponds force; ~1” square interchangeable tools and multiple programmed strokes.

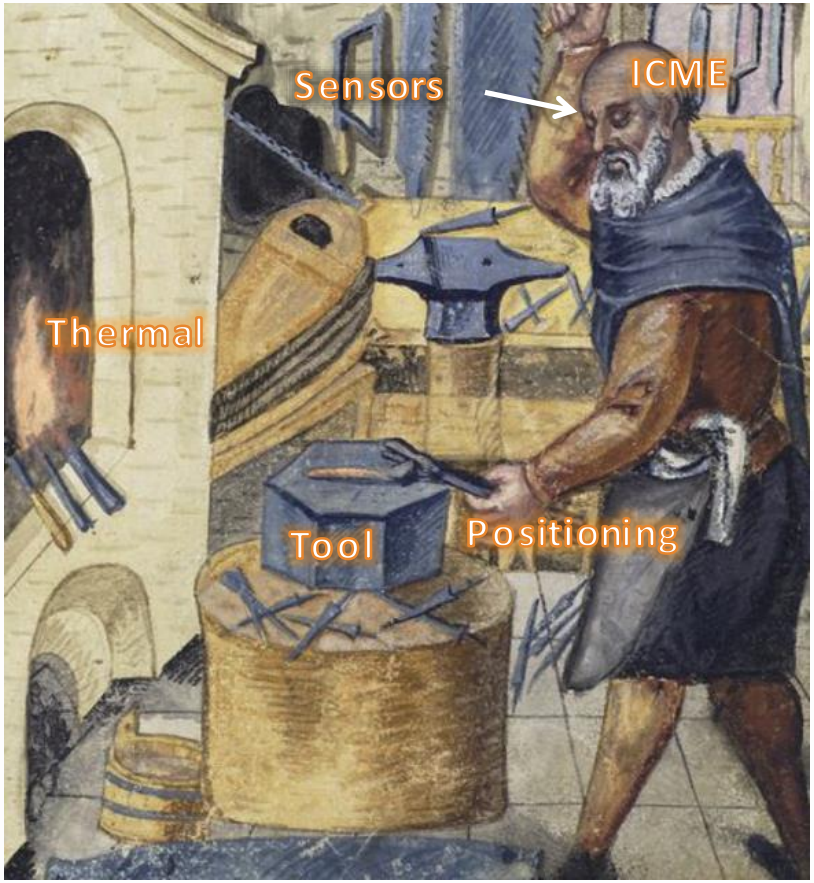
20-Ton C-Clamp, 40 kg
20-Ton cylinder, 15 kg

Technical: How

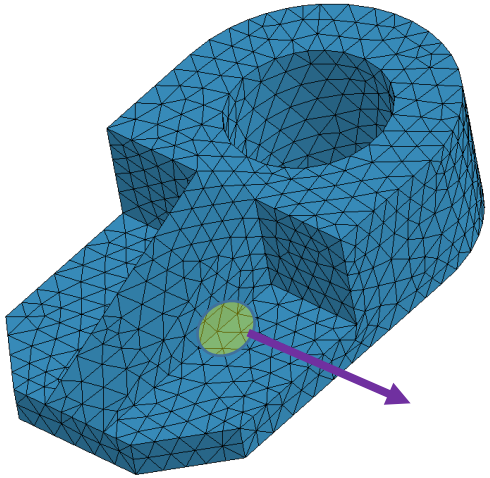
<u>Many focused examples:</u>

Incremental sheet
Incremental bar
Stretchers
Shrink
Flexible profile bending
Flexible ring rolling
Open die forging
Powered hammers
Etc…

Technical: What

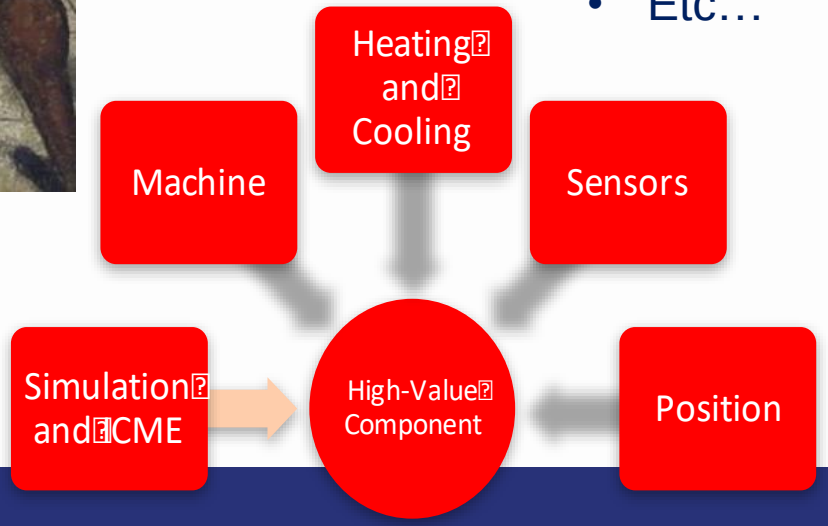


German anonymous, circa 1606



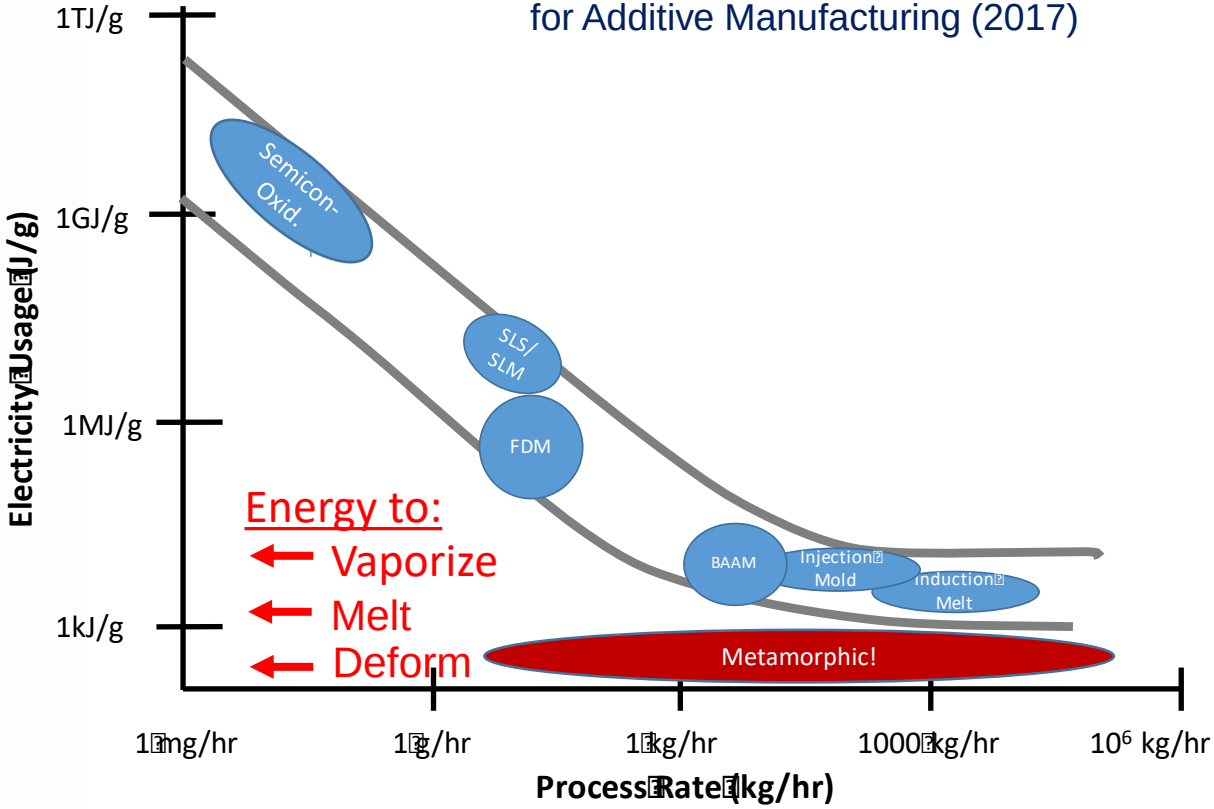
Track with time:
- Temperature
- Strain tensor
- Stress tensor

Predict:
- Microstructure
- Damage
- Anisotropy
- Etc…



Technical: Why -- Carbon Footprint

Gutowski et.al.: Energy Efficiency for Additive Manufacturing (2017)



Shape by deformation more efficient than:

- Machining
- Casting
- Powder Metallurgy
- Additive

Also

- Range of materials
- Established Tech.
- No HIPping

Technical: Better, Cheaper, Assured

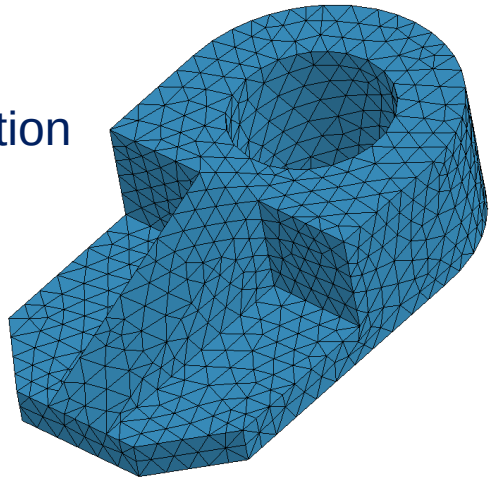
Wrought metals generally have the best properties

Weld metal lay-ups could provide initially graded compositions

Metal forming is relatively inexpensive. Dies account for most of the cost and lead time.

Power of the forming system largely sets forming time

Sensing and big data assure each part is within specification



Policy: Synthesis, not just Analysis

Lots to be done to launch an new industry. Public investment needed.

Scientific basis is **not** the key; its synthesizing building, developing standards and communities.

Need to engage our workforce and community colleges.

Demonstrate room for creativity and innovation in manufacturing.

Need to stay in front of Fraunhofer-like collaborations.

Fund translational research centers
(See MForesight talk, Thursday).

Fund openly available specialized facilities for training, innovation trials and research.

Don’t get locked out of IP.

Press Function : Multi-purpose double action forming

Capabilities:

- Local temperature control
- Double action forming 300x230Ton
- FB35”xSS35”x 24” Daylight

Summary: We Need Metamorphic Mfg!

Subtract → Add → Morph. (shape and properties)

Based on fast advancing disciplines
- Robotics
- Integrated Computational Materials Engineering
- Artificial Intelligence
- Sensors
- Control

Can scale naturally to large sizes

Provides exceptional materials properties; extendable to graded chemistry

Naturally provides a path for qualification and certification

Is an opportunity for the USA. Helps balance of trade. Cement this here by:
- Fast innovation
- Skilled workforce (motivated by creative opportunity)
- Unique and accessible equipment

Further Information

LIFT Agile and Low Cost Processing Pillar Docs: https://lift.technology/pillar/novel-agile-processing/

Key elements of this technology:

Open die forging: https://en.wikipedia.org/wiki/Forging

Closed loop control: http://www.hydraulicspneumatics.com/other-technologies/get-more-closed-loop-control

Incremental Forming: "Incremental Bulk Metal Forming", P. Groche, et al. https://doi.org/10.1016/j.cirp.2007.10.006

3-D optical dimensional measurement: https://en.wikipedia.org/wiki/3D_scanner

Thermo-mechanical processing: (huge topic), maybe start at: https://www.doitpoms.ac.uk, here's a book: http://www.sciencedirect.com/science/bookseries/14701804/11

Daehn and Taub *Manufacturing Letters* Publication: https://doi.org/10.1016/j.mfglet.2018.02.014

Robots -- Way better than humans

Stronger.

Better sensors.

Faster decisions.

Can Learn!

Can record everything.

No attitude.

Example: **Japanese Robot Sumo**
Movie from: https://www.youtube.com/watch?v=QCqxOzKNFks
See rules at: http://robogames.net/rules/all-sumo.php

Other examples:
Making pizza
laying bricks
Robo-dogs
Robo-Soldiers