



CHANGING WHAT'S POSSIBLE

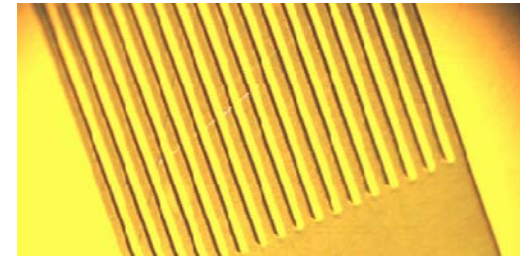
Growing the Next Generation of High-Temperature Heat Exchangers

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...**BUT CAN YOU MAKE IT?**

Compact heat exchangers
Geometry **size** limit



Heat Recovery Steam Generators
(HRSG)
for waste heat recovery
Thermal **cycling** limit

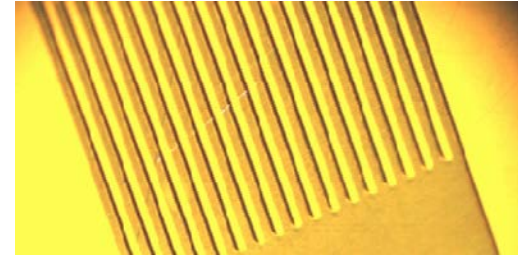


High T receivers for
Concentrated Solar Power
Temperature limit



...BUT CAN YOU MAKE IT?

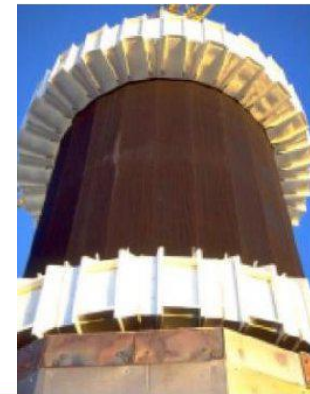
Small things connected
to make big things



...so there are a lot of joints



...and joints break at high T

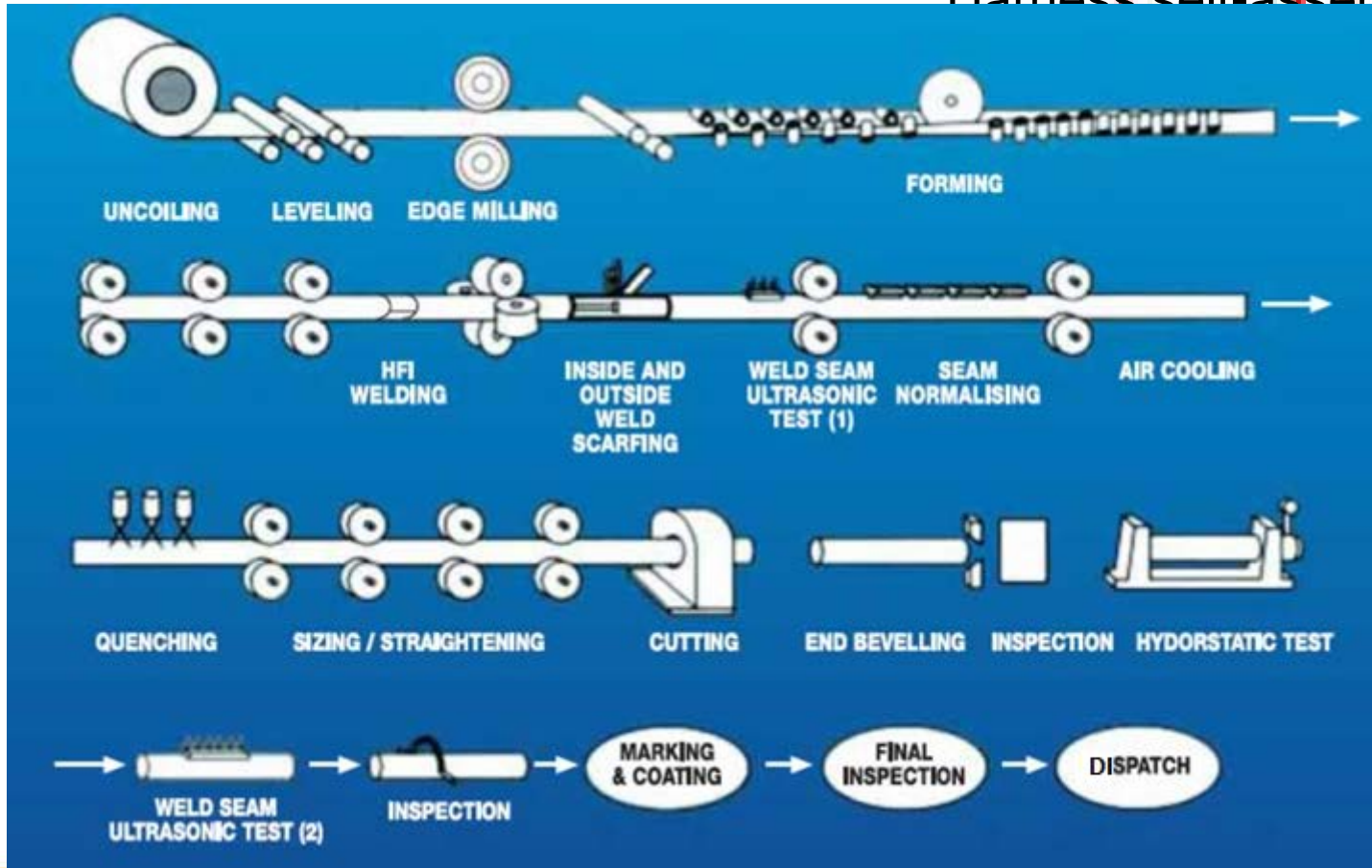


Path Forward

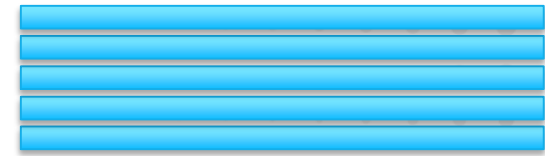
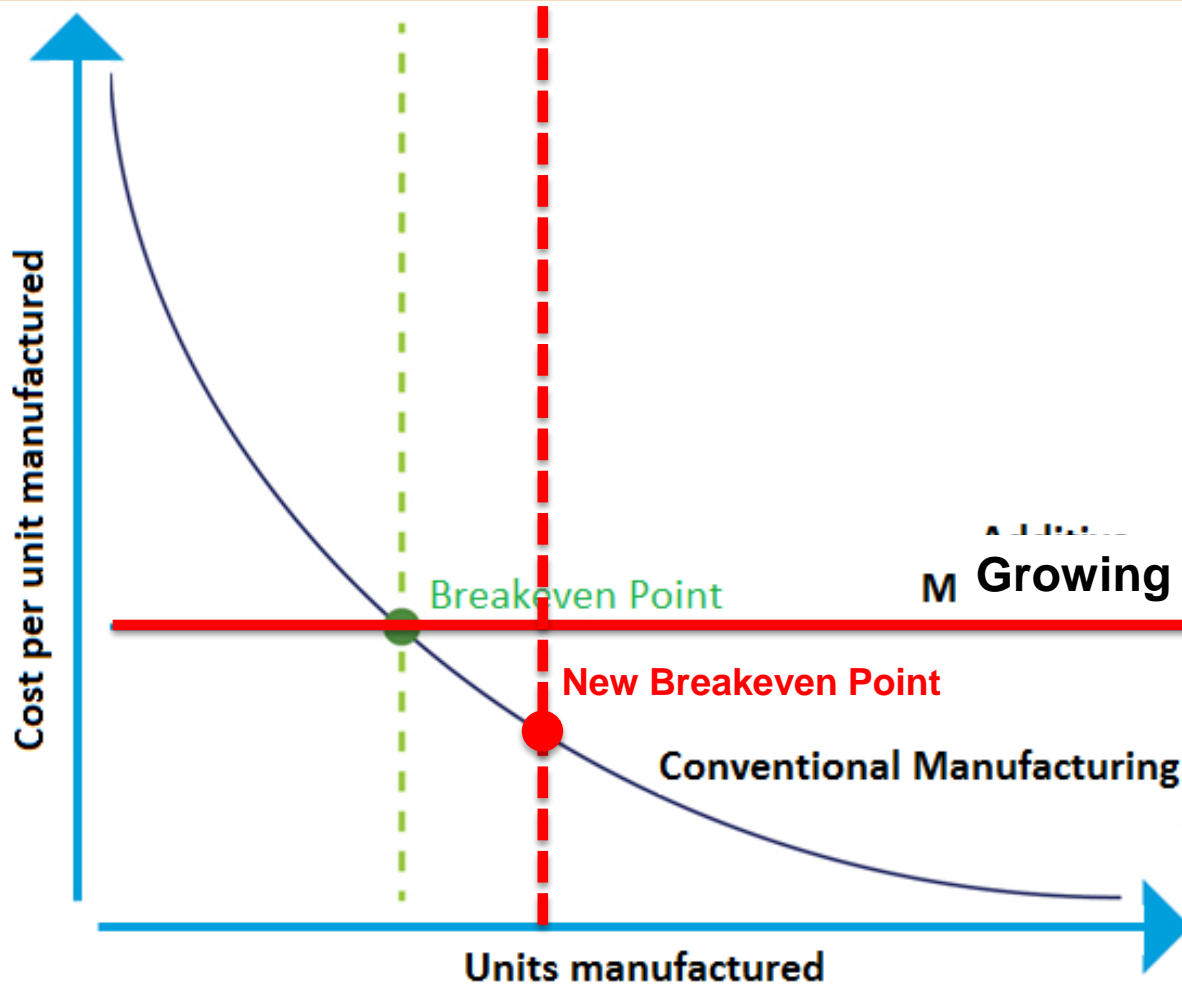
- ▶ US steel production:
~79 million tons in 2015

“GROW”

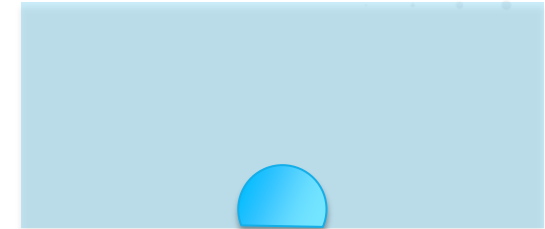
Harness self-assembling
technology



Beyond “3D Printing”



“3D printing”



Growth

- ▶ True 3D structures
→ **faster?**
- ▶ Chemical assembly
→ **high T materials?**

Source: Mark Cotteleer and Jim Joyce, *3D opportunity: Additive manufacturing paths to performance, innovation, and growth*, Deloitte University Press, <http://dupress.com/articles/dr14-3d-opportunity/>, accessed March 17, 2015.

Graphic: Deloitte University Press | DUPress.com

An Enabling Technology

“GROW”

Combined
Manufacturing
Processes



Reduced cost and time
Remove joints



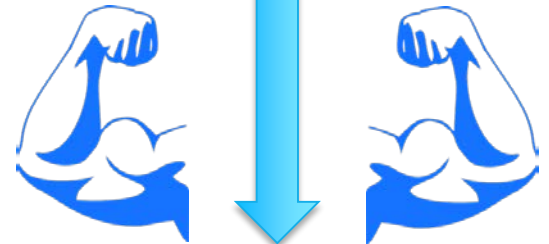
New Material
Options



Higher T materials



Microstructure
Customization



New/enabling properties



Sample Growing Paths

Sample 1: Biology as the machinist

▶ Copy **structure** or **process**

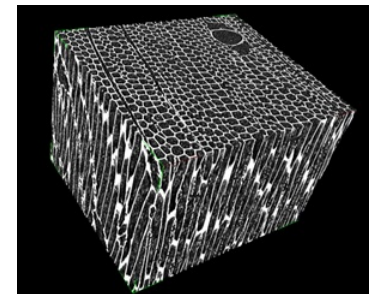
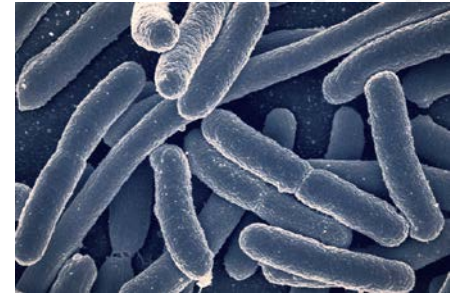
▶ ...then strengthen

– Plasticize

– Fossilize

– “Metalize”...?

– “Ceromitize”...?



▶ **Joint-free parts**

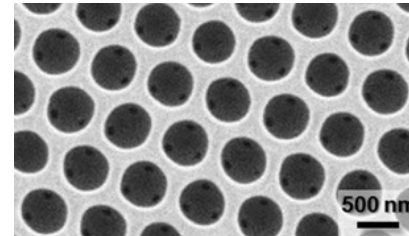
– Continuous microstructure

– Reduce thermal cycling fatigue?

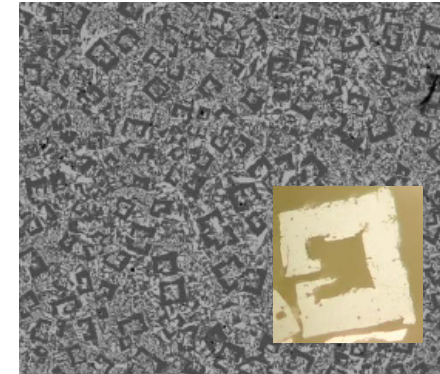
Sample Growing Paths

Sample 2: Chemistry as the carpenter

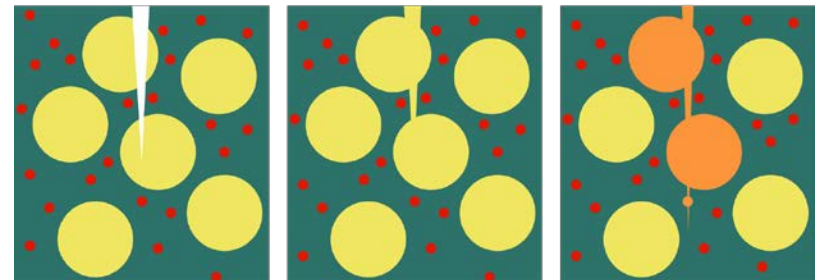
- ▶ **Self-assembly** of metamaterials
- ▶ Tailored anisotropic properties
 - Directional conductivity?
 - Strength @ high T ?
 - Composition gradients?
- ▶ **Self-healing** capabilities
 - Restore coatings?
 - Fill cracks?



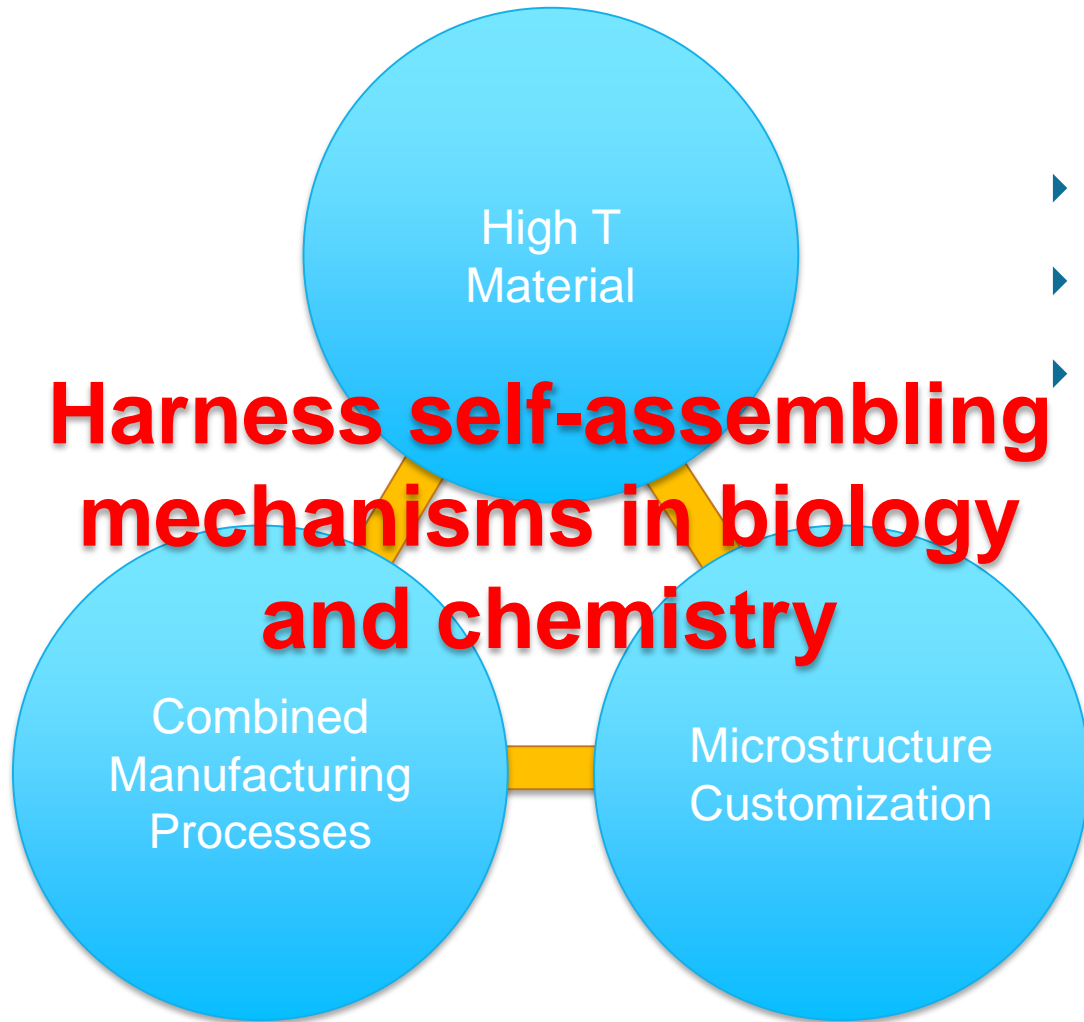
Inverse Opal Structure
do Rosário *et al.* (2015)



Split-Ring Resonator
Pawlak *et al.* (2010)



Growing Forward



- ▶ **Grow** your heat exchanger
- ▶ **Grow** your company
- ▶ **Grow** your energy impact