



# NextManufacturing

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Carnegie Mellon University

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# Additive Manufacturing Challenges for the Gas Turbine Industry

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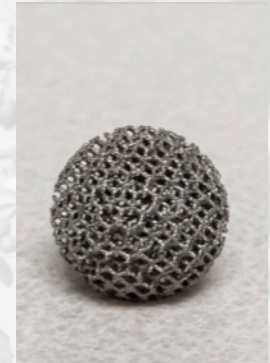


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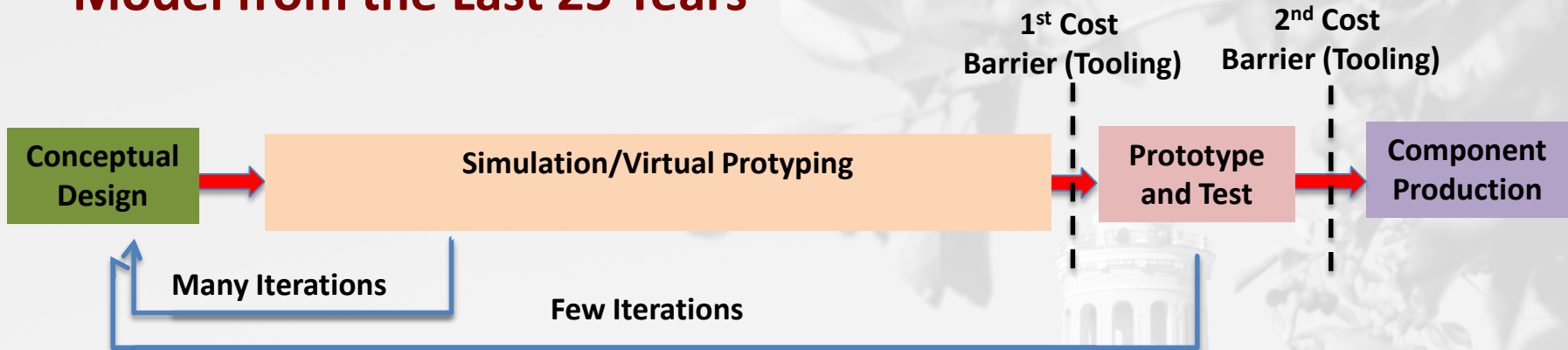
# Take-Aways

- **AM Can Impact Product Development without Being Used for Production**
  - Impact on Prototyping and Simulation
- **Full Mastery of AM Part Production Requires Broad Expertise**
  - Five (at least) Design Spaces to Navigate!
  - Process Design is Moving Quickly



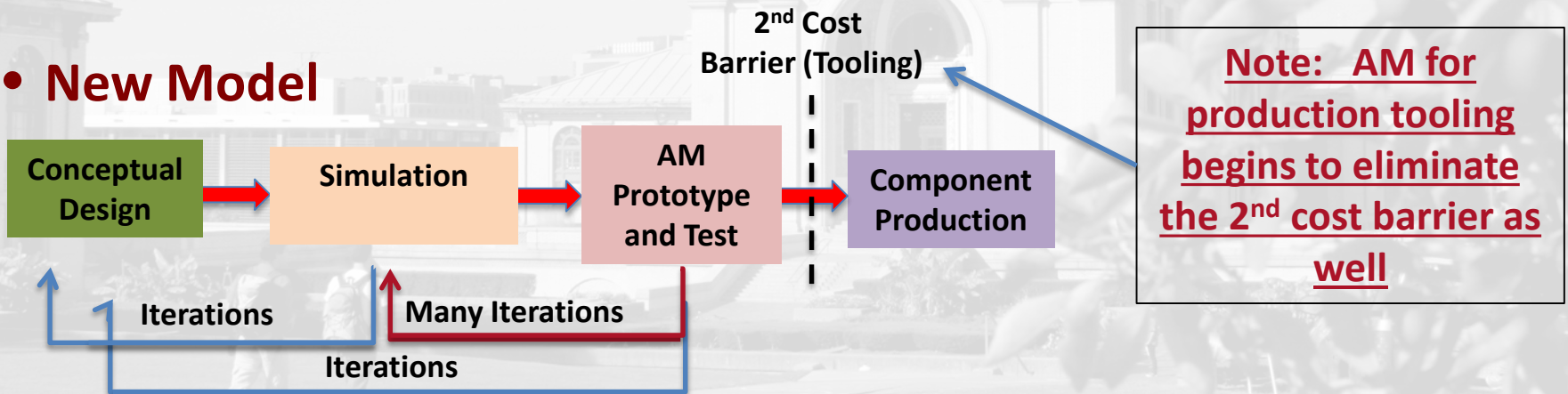
# AM Prototyping Impact on Product Development

## • Model from the Last 25 Years



- Lots of simulation, then prototyping (expensive, minimized), then production
- Cost barriers to prototyping and production due to tooling

## • New Model



**Note: AM for production tooling begins to eliminate the 2<sup>nd</sup> cost barrier as well**

- **Concurrent simulation and prototyping** (first cost barrier gone)
- Shortened product development times

# AM Impact on Product Manufacturing: Thread of Five AM Design Spaces

- It is not just designing components for AM – at least 5 design spaces
- Each design space category depends on the others



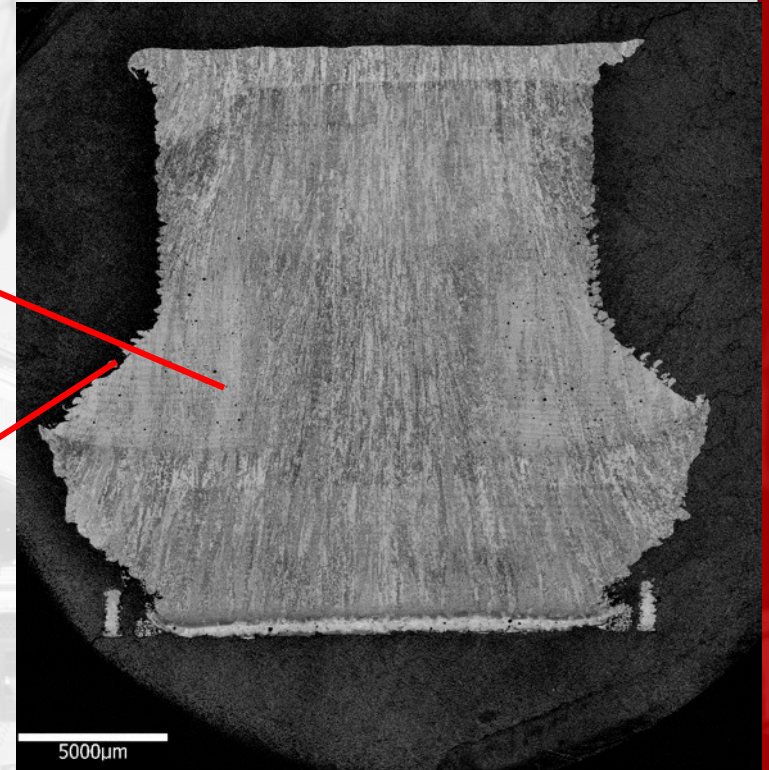
**Unifying**: Need to balance *Five Design Space Categories* Using 6) **Cost** 7) **Time to Market** and 8) **Performance Enhancement** as Objectives

- **All are supported (or will be) by simulation**

# Process Design for Microstructure

Finer Grains in Stress  
Concentration Regions

Printed  
without  
contours

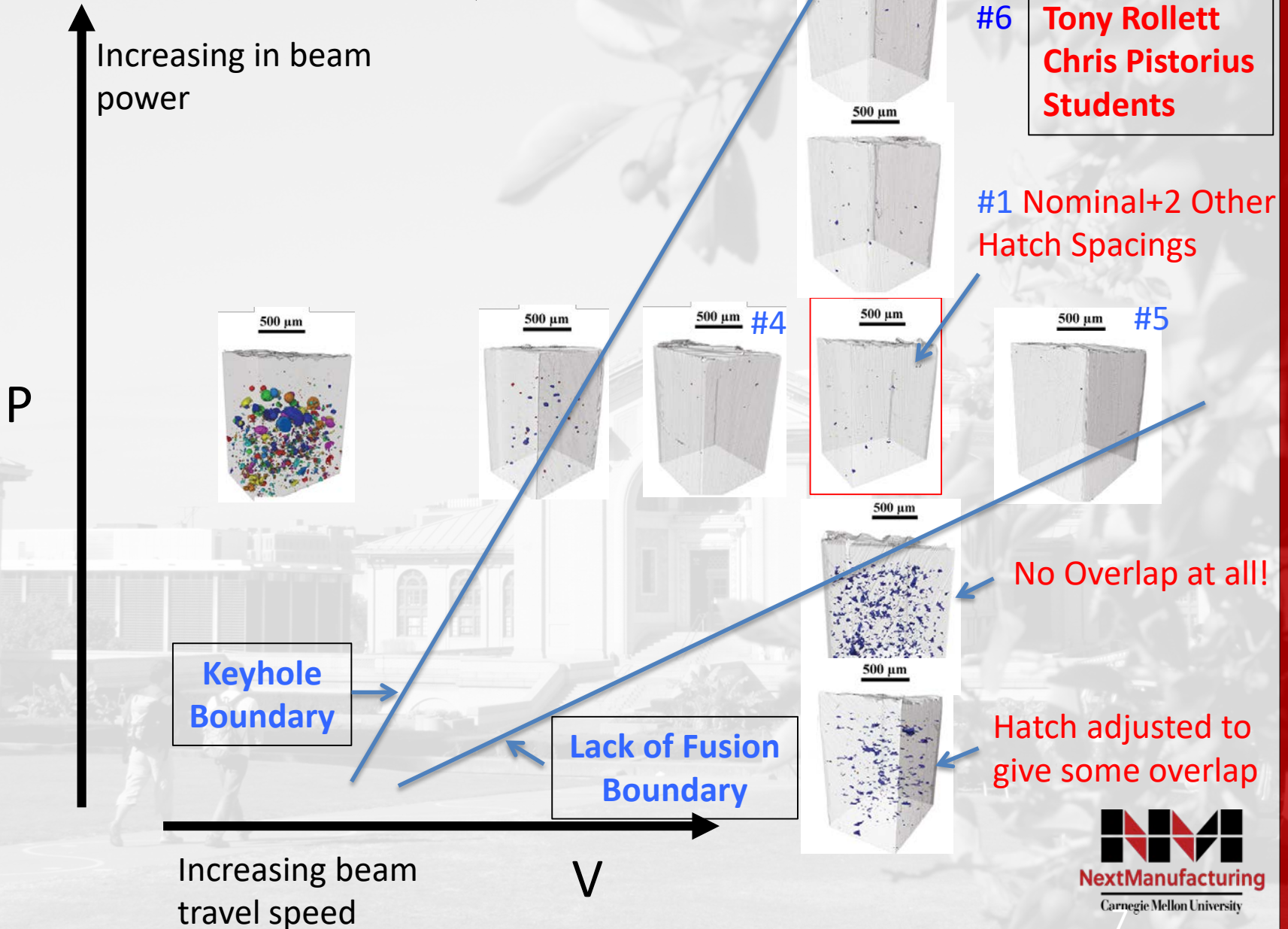


- Average Expected Grain Size in Bulk Region = 109  $\mu\text{m}$
- Average Expected Grain Size at Stress Concentrators = 212  $\mu\text{m}$

# Porosity in Processing Space

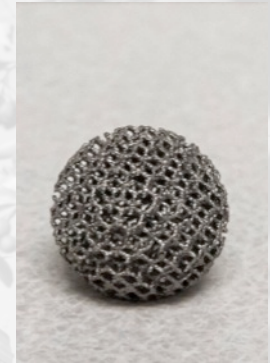
(Internal rasters, Ti64, EOS)

Research by:  
**Jack Beuth**  
**Tony Rollett**  
**Chris Pistorius**  
**Students**



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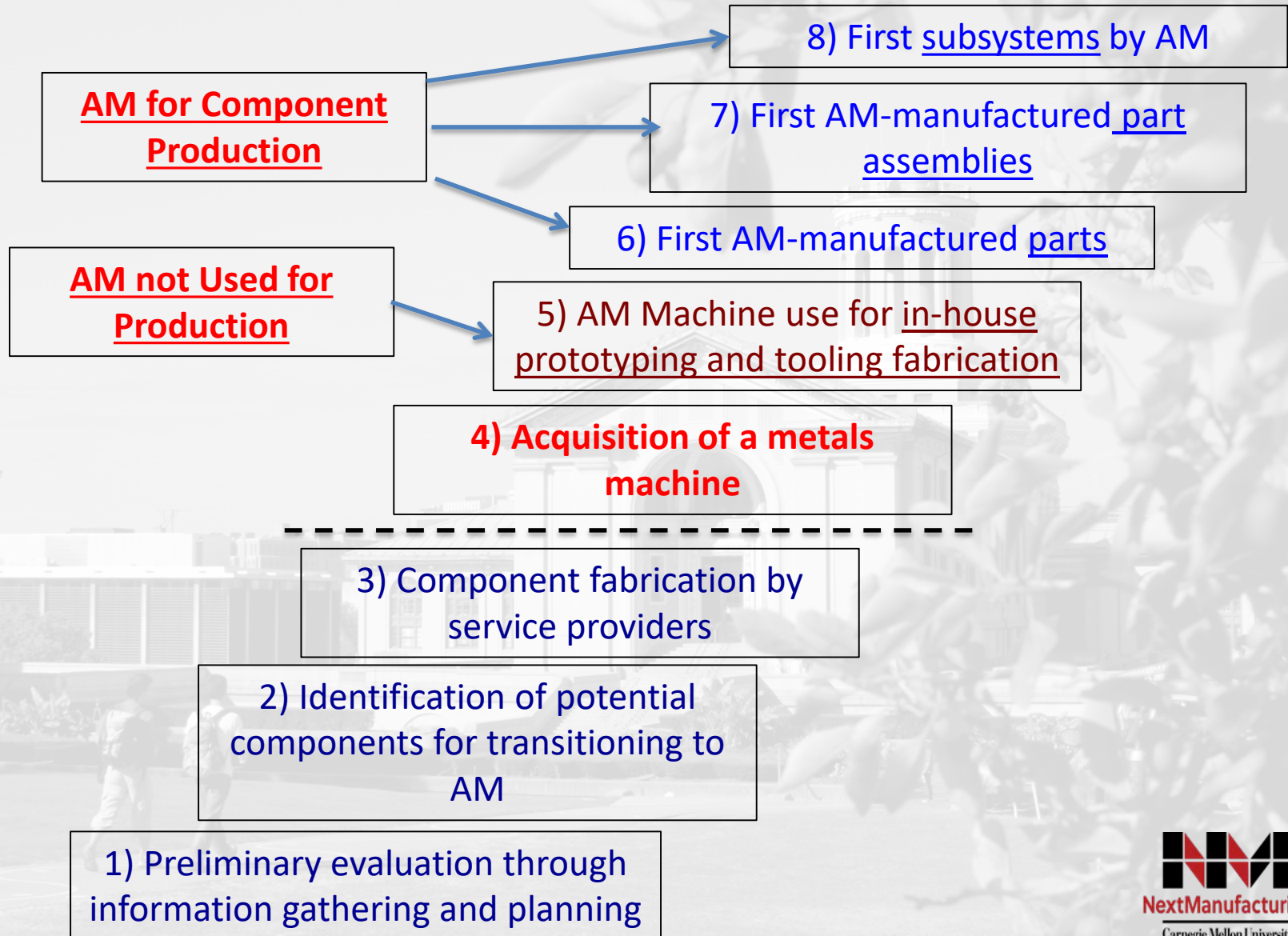
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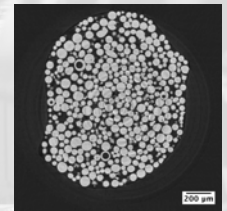
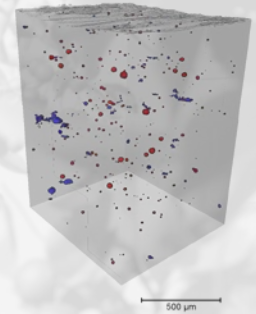
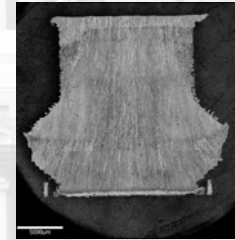
# Industry Steps in Adopting Metals AM

(with Insights from Kirk Rogers, GE)



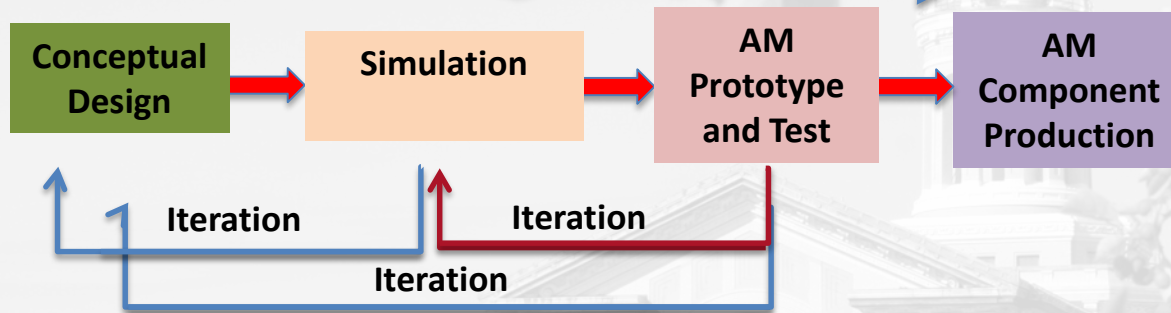
# Looking Ahead 5-10 Years (or sooner!)

- **AM processing will change significantly.** Within 5 years AM Machine Users Will be Able to
  - Design the process as they design a part (integrate with cost models and part design)
  - Exploit sophisticated process monitoring and controls
  - Vary microstructure and properties within parts
  - Choose from a wide variety of powders
  - Eliminate porosity
  - Exploit merging of computer science with additive
  - Use new alloys for AM
- **The CMU NextManufacturing Center is performing research enabling each of these advances**



# AM Production Impact on Product Manufacturing

- New Model



Note: 2<sup>nd</sup> cost barrier (tooling) is now gone

- Cost barrier to component production goes away
- Door is open to small production lots *and components intensely designed for AM*