Factoring the Impact of Additive Manufacturing
A model for university, industry, & government collaboration
One Industry Perspective

1. Development Pipeline

- <1 year
- 1 – 3 years
- <5 years

2. Product life cycle

- Product Launch
- >20 years

3. Purchasing scale

- $0
- $1MM
- $10MM
- $100MM
- $1B
Intellectual Property Perspective

“That ideas should freely spread from one to another over the globe, for the moral and mutual instruction of man, and improvement of his condition, seems to have been peculiarly and benevolently designed by nature, when she made them, like fire, expansible over all space, without lessening their density in any point, and like the air in which we breathe, move, and have our physical being, incapable of confinement or exclusive appropriation. Inventions then cannot, in nature, be a subject of property.”

Thomas Jefferson, 1813

Winners will be decided by Speed & Intellect (i.e. the best collaborators)
Manufacturing Technology
Operating Model

- Governments
- Universities
- Consortiums
- Supplier Network
- GE
- Global Research Center
- GE Manufacturing Technology Organizations
- Power & Water
- Engineering / Product Line Mgmt
- Global Supply Chain Division
- Manufacturing Engineering Council

GE Manufacturing Technology Organizations
Technology Transition
Technology Transfer Criteria

Manufacturing Readiness Levels

Processes
• Variables and parameters established
Development Resources
• Production representative development/optimization assets available
Infrastructure
• Equipment specifications, product flow, plant design, and supply chains in place
People
• Skill sets define, training available
Tools & Information
• Design practices, analysis methods, process specifications, quality requirements, cost models
Progression of AM Applications

Change DFM paradigm… “make what we can design”
Additive Manufacturing Factors
Additive Manufacturing Breakdown

Customers

- Repairs
- Product
- Support & Services

3rd Parties → OEMs ← Tier Suppliers

- Designs
- Materials
- Equipment
- Software
- Inspection
Level 0 - Customer Perspective

Why would a customer select an additive manufactured product

- Greater Perceived Value for the Same Price
- New Features or Capabilities
- New Market
- Lower Costs
Level 1 - Industry Capacity

Scale
Rate
Standardization

Processes
• Consistency from run to run and machine to machine or process to process

Development Resources
• Limited configurability

Infrastructure
• Changing rapidly

People
• Small pool

Tools & Information
• Proprietary
• Generic
Level 2 - Design

Functionality
Design & Producibility Rules

Processes
• Repeatability

Resources
• Adapting traditional subtractive infrastructure
• N/A

People
• Creativity to think in additive dimensions

Tools & Information
• CAD/CAM
Level 2 - Materials

Metals
Polymers
Ceramics

Processes
• Microstructures
• Alloying
• Residual stresses
• Bi-material processing

Resources
• Adapting pre-existing materials

Infrastructure
• Limited material supply base
• Captive material supply

People
• Materials science, chemist

Tools & Information
• Properties testing & variation
Level 2 - Equipment

Cabinets
Beds
Laser
Electron beam
Heating source
Nozzles
Mechanical
Electrical
Controls

Processes
• Repeatability

Resources
• Larger and/or specialized
• Controls
• Software

Infrastructure
• Reliability
• Maintainability

People
• Multi-discipline skill set
• Tear down & rebuild

Tools & Information
• Sensors/feedback
• Process simulation
Level 2 - Software

CAD
STL file formats
Layering
3D Nesting
Integration

Processes
• Errors
• Orientation

Resources
• Captive

Infrastructure
• Not well integrated

People
• Specialization in 1 s/w

Tools & Information
• Need improved file transfer
Level 2 - Inspection

Destructive
Radiography
Computed tomography
Infrared thermography
In-situ

Processes
• Probability of detection undefined

Resources
• Basic inspection technologies are in place
• Selecting appropriate techniques

Infrastructure
• Utilizing commercial technologies

People
• Process knowledge

Tools & Information
• Stronger understanding of processing principles required
**Summary**

Model for evaluation of technology transfer readiness

1. Greater collaboration and inclusion of multiple disciplines
2. Progression of additive manufacturing applications

<table>
<thead>
<tr>
<th>Additive Manufacturing Factors</th>
<th>Processes</th>
<th>Resources</th>
<th>Infrastructure</th>
<th>People</th>
<th>Tools &amp; Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OEMs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tier Suppliers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Parties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>