Assessing the Economic Impact of LLNL's Additive Manufacturing Technology

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Market Intelligence

Industrial Partnerships Office

LLNL-PRES-500312

Agenda

I. Introduce project and discuss its significance
II. Provide overview of additive manufacturing industry
III. Briefly explain LLNL's AM techniques
IV. Describe setup of project
V. Introduce bullet market
VI. Discuss key findings in bullet case study and outline direction for future work
VII. Introduce knee implant market
VIII. Discuss key results in knee implant case study and suggest future work
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Project Overview

Objectives:

1. **Research the lab's techniques and explore potential advantages of additive methodology over conventional processes**
2. **Investigate cost flows of lab's technology and compare to conventional machining processes**
3. **Assess economic impact of LLNL's additive manufacturing technology**

Why is this information valuable?

- **Minimal research done investigating economic or environmental impact of additive manufacturing (AM)**
- **Analysis could help improve competitiveness and efficiencies of AM processes by identifying cost-limiting factors in production**
- **Highly attractive and rapidly evolving market with strong momentum of growth**
- **Cutting edge technology with high coefficient of innovation**
- **Area of research where laboratory could excel**

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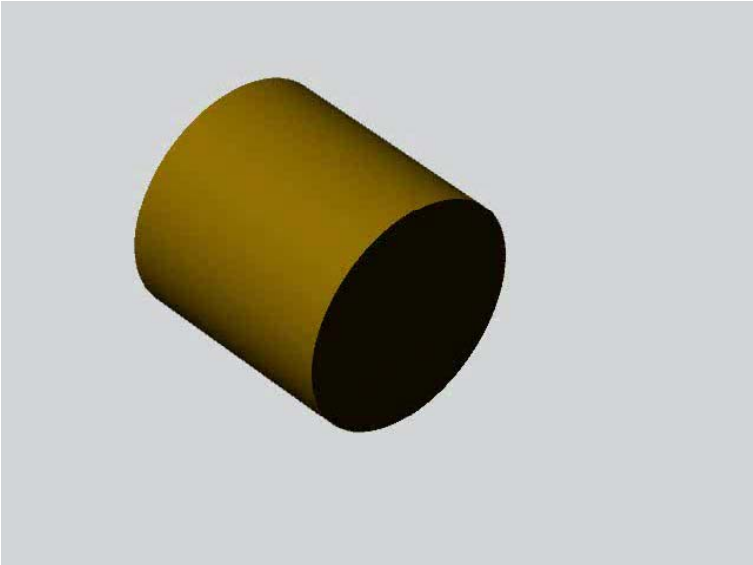
What exactly is additive manufacturing?

- **22 year history**
- **Defined as "the process of joining materials to make objects from 3D model data, usually layer by layer"**
- **Different from subtractive manufacturing, e.g. CNC machining, lathing, etching, etc**
- **Synonyms: additive fabrication, direct digital manufacturing, freeform fabrication, 3D printing**
- **used to build physical models, prototypes, and production parts using plastic, metal, ceramic, or composite materials**

Subtractive manufacturing vs. additive manufacturing



Subtractive

Additive

Advantages of additive manufacturing

1. **Streamlines and expedites product development process**

2. **May help reduce time to market, improve product quality, and cut cost**

3. **Typically advantageous in complex, customized products**

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Growing number of industrial sectors (e.g. consumer, industrial, medical, and military markets) and geographical regions are embracing AM technology

AM Industry is attractive & growing rapidly

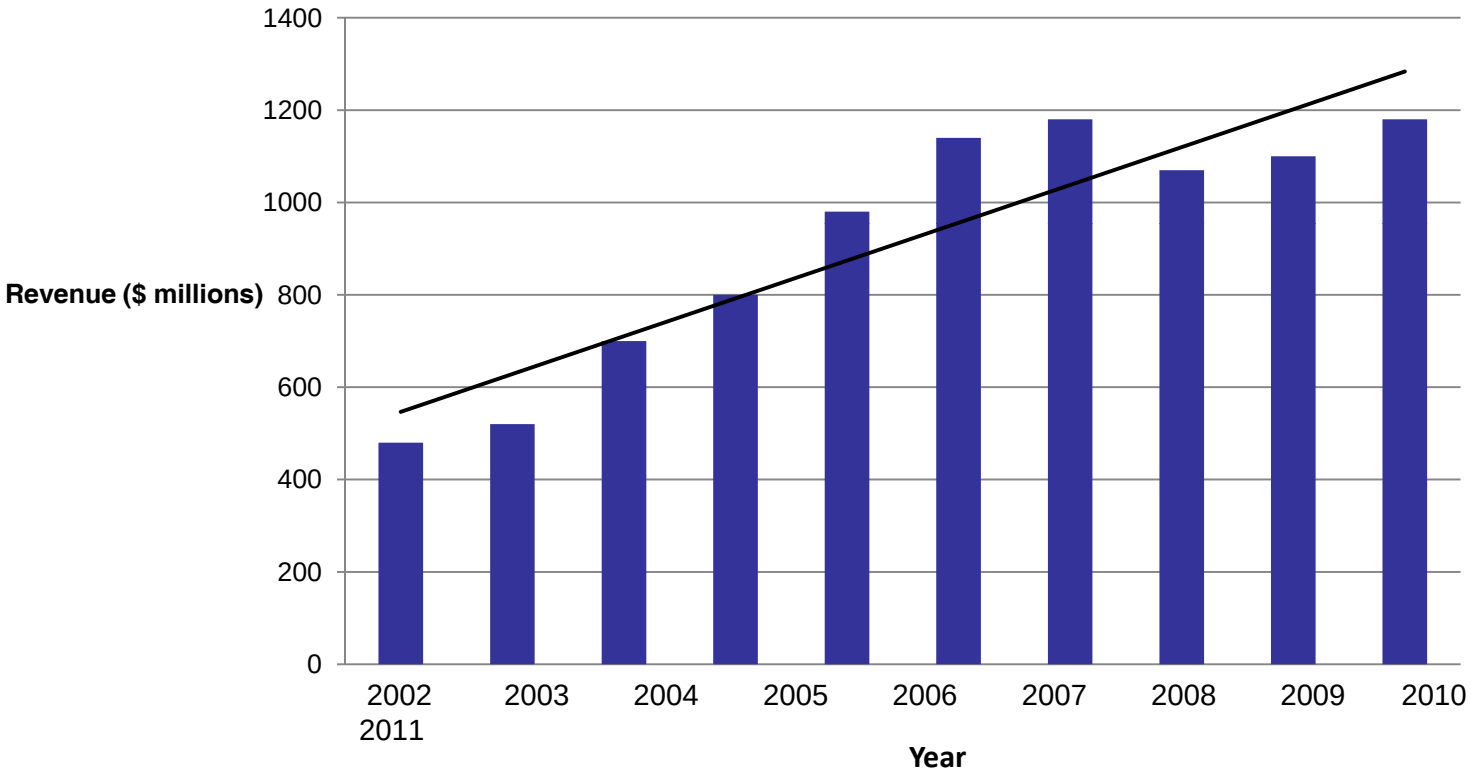

Figure 1. Revenues and forecasts in additive manufacturing industry over the last 10 years (data obtained from Wohler's Report 2010).

Explosive growth of AM industry

Table 1. Revenue growth in additive manufacturing industry from 2000-2009 (data obtained from Wohler's Report 2010).

Year	Overall % Growth/Decline
2000	+11.5%
2001	-10.5%
2002	-10.0%
2003	+9.2%
2004	+33.3%
2005	+14.6%
2006	+21.7%
2007	+16.0%
2008	+3.7%
2009	-9.7%

US dominates AM industry

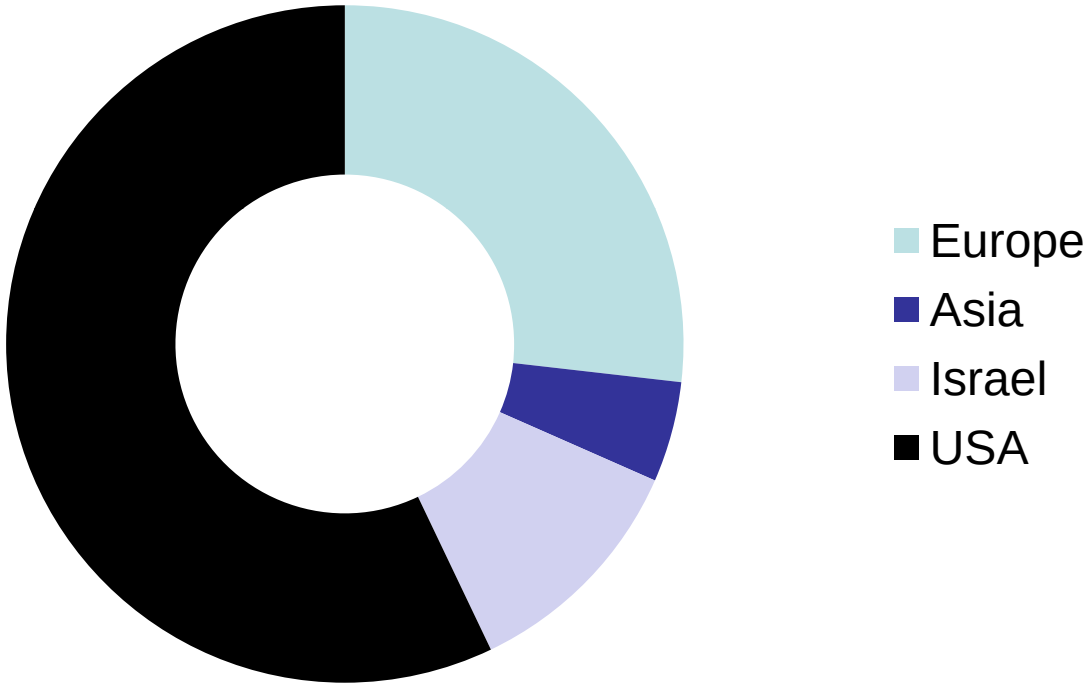

Figure 2. Global leaders in additive manufacturing industry by market share (data obtained from Wohler's Report 2010).

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LLNL's additive manufacturing techniques

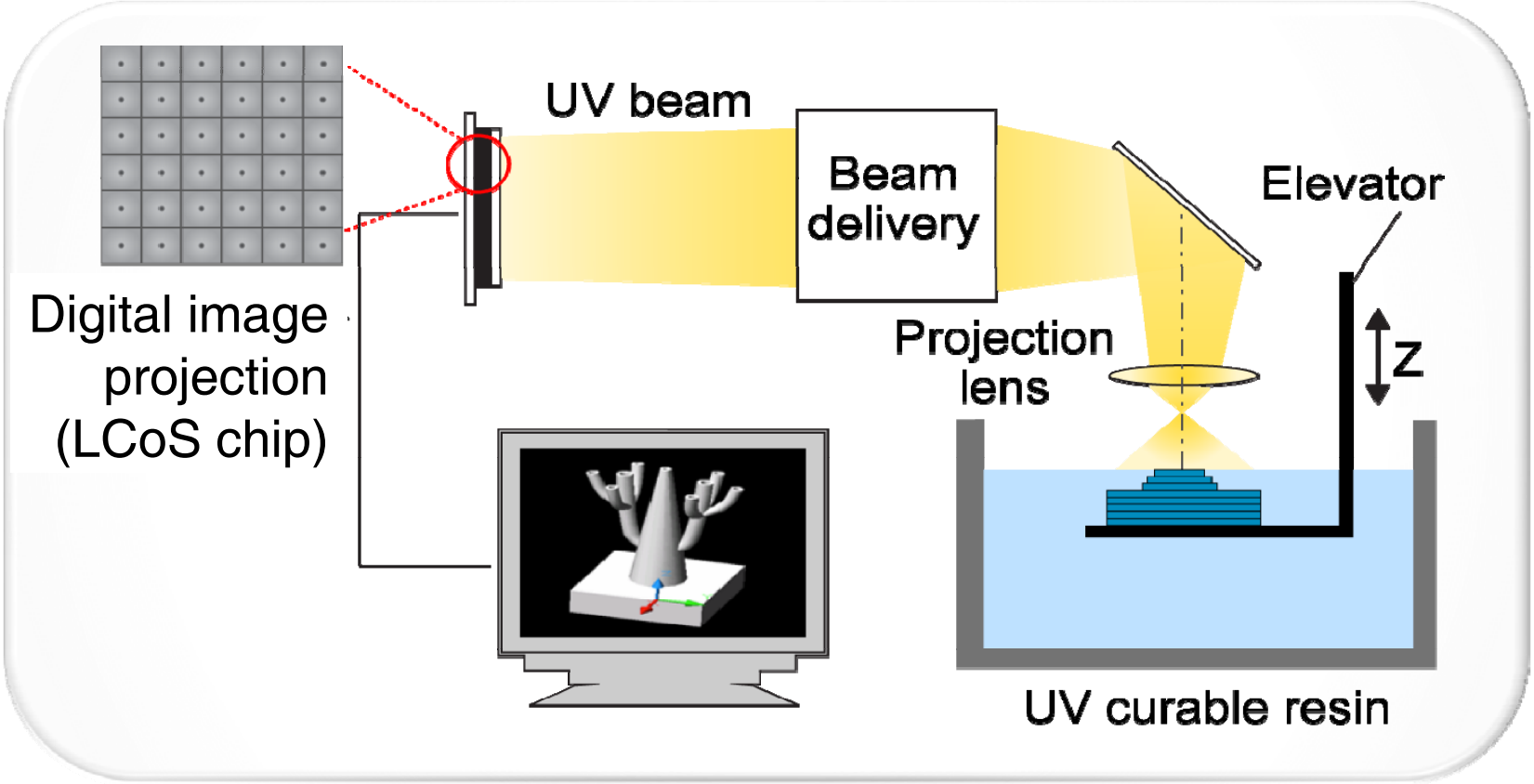
- **LLNL Engineering division uses three additive manufacturing techniques:**

  1. Projection microstereolithography (PμSL)

  2. Electrophoretic deposition (EPD)

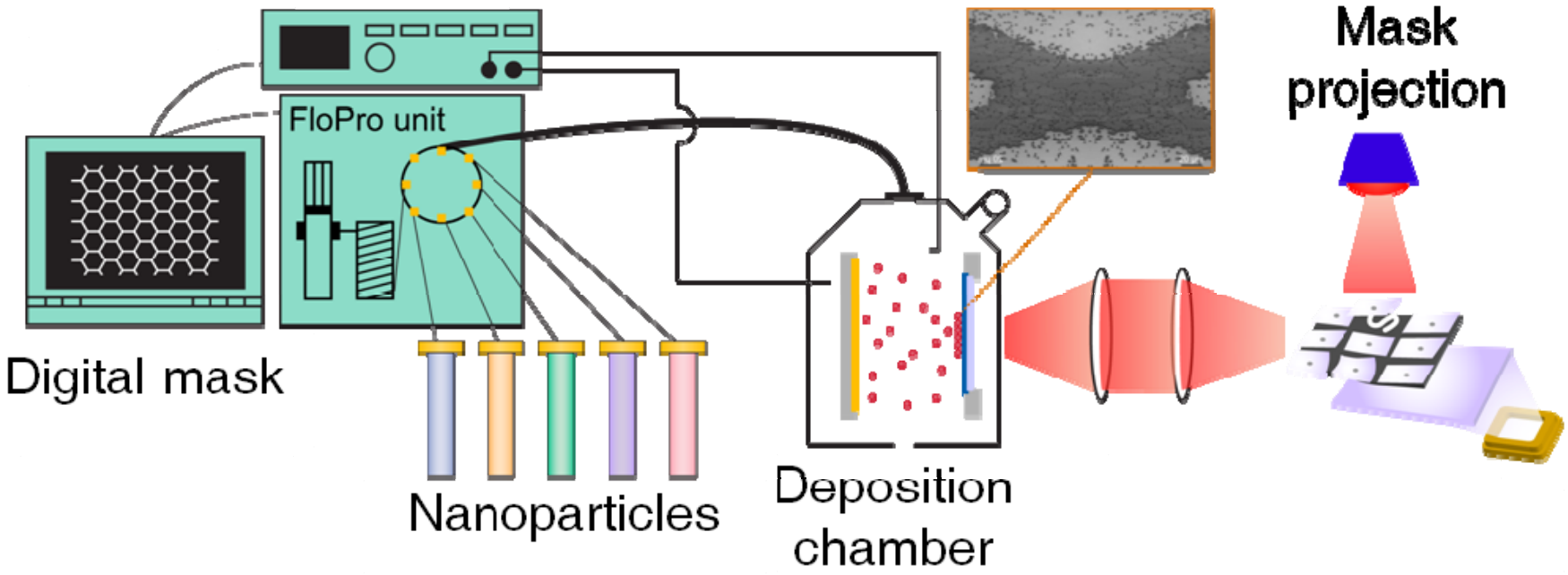
  3. Direct Ink Writing (DIW)

Projection Microstereolithography (PμSL)

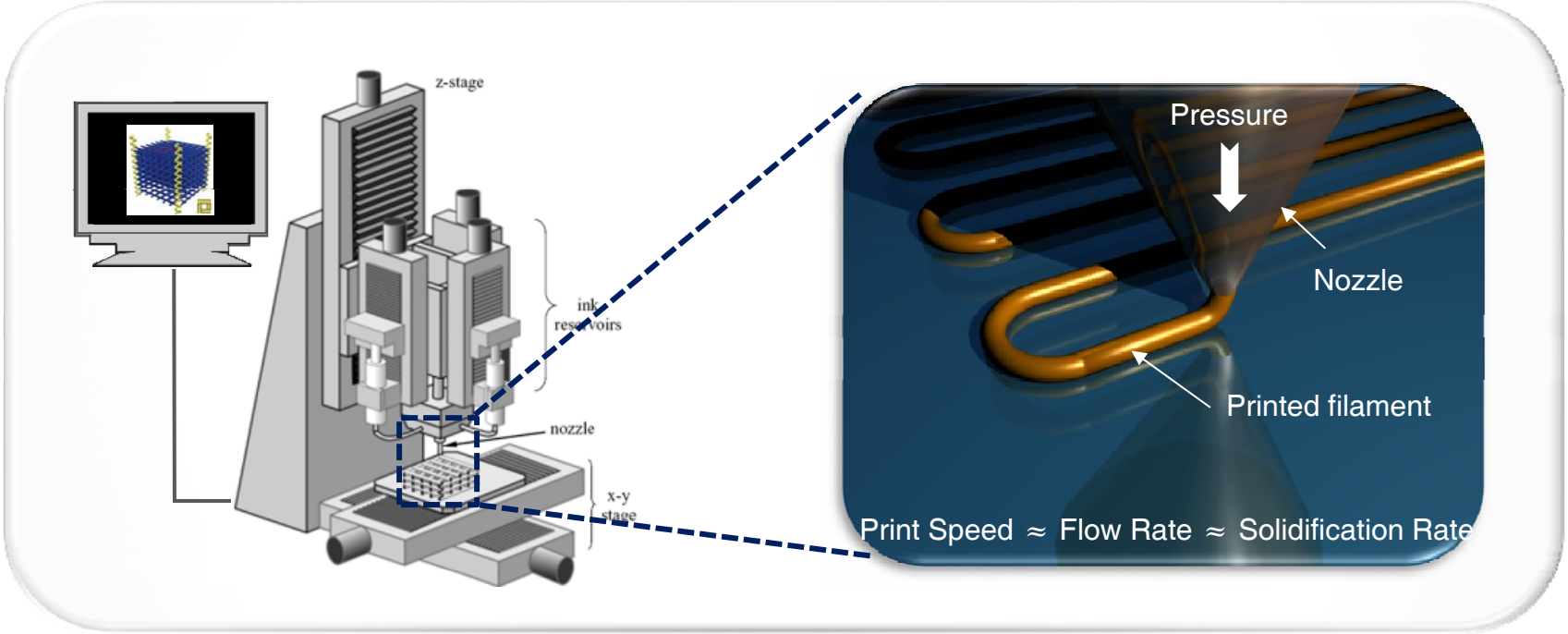


Electrophoretic deposition (EPD)

Flexible – Automated process with rapid design to fabrication



Direct Ink Writing (DIW)



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Project Setup

Hypothesis: **Additive manufacturing will lose out to conventional manufacturing processes for simpler items but capitalize on its key advantages for more complex and customized systems.**

Table 2. Comparison of bullet and knee implant markets.

	Bullet Market	**Knee Implant Market**
Type of product	Simple, highly refined process	Complex, multi-material
Ability for AM to penetrate market	**Low**	**High**
Prediction	AM bullets will be more expensive than those from conventional processes	Knee implants will be less expensive and hold key advantages over those from conventional processes.

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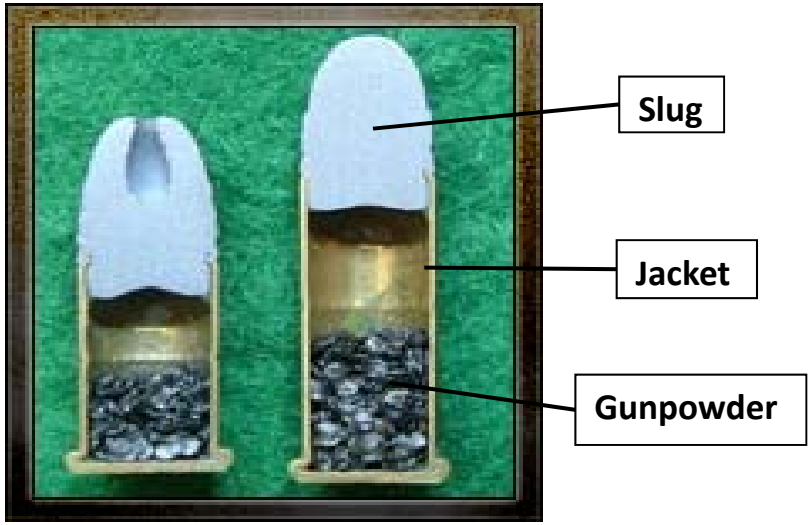
Introduction to bullet market

- **Small firearms and ammunition market is projected to reach $6.5 billion in 2012, and continues to grow**
- **85-118 million pounds of lead used each year in bullet production**
- **Trend toward customized bullets for sport and gaming**
- **Market leaders: Winchester, Smith & Wesson, Remington, Federal**
- **0.22 caliber bullet is most common type**

Diagram of .22 caliber bullet

- **Bullet for case study: .22 caliber Winchester Magnum Rimfire (WMR) bullet**
- **Costs ~20 cents per bullet to purchase**



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Conventional process to make .22 caliber bullets

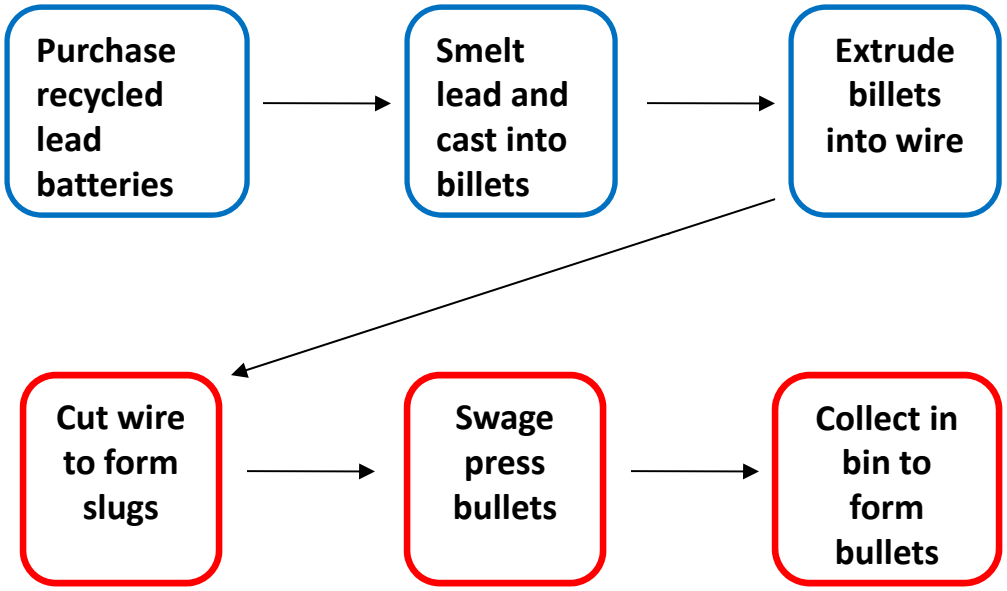

Figure 3. Flowchart of conventional bullet making process using swaging technique.

Cost to make bullets using conventional method

Tables 3 & 4. Cost to make bullet slug from conventional method using recycled lead batteries (left) and extruded wire (right).

Cost Variable	Conventional process
Raw material cost - lead	0.06479 cents
Smelting lead cost	0.00718 cents
Extruding wire cost	0.02743 cents
Cutting wire cost	0.00056 cents
Swaging bullet cost	0.024 cents
Total Cost	0.12396 cents

Cost Variable	Conventional process
Raw material cost - wire	2.22857 cents
Cutting wire cost	0.00056 cents
Swaging bullet cost	0.024 cents
Total Cost	2.25313 cents

Making bullet using Projection Microstereolithography (PµSL)

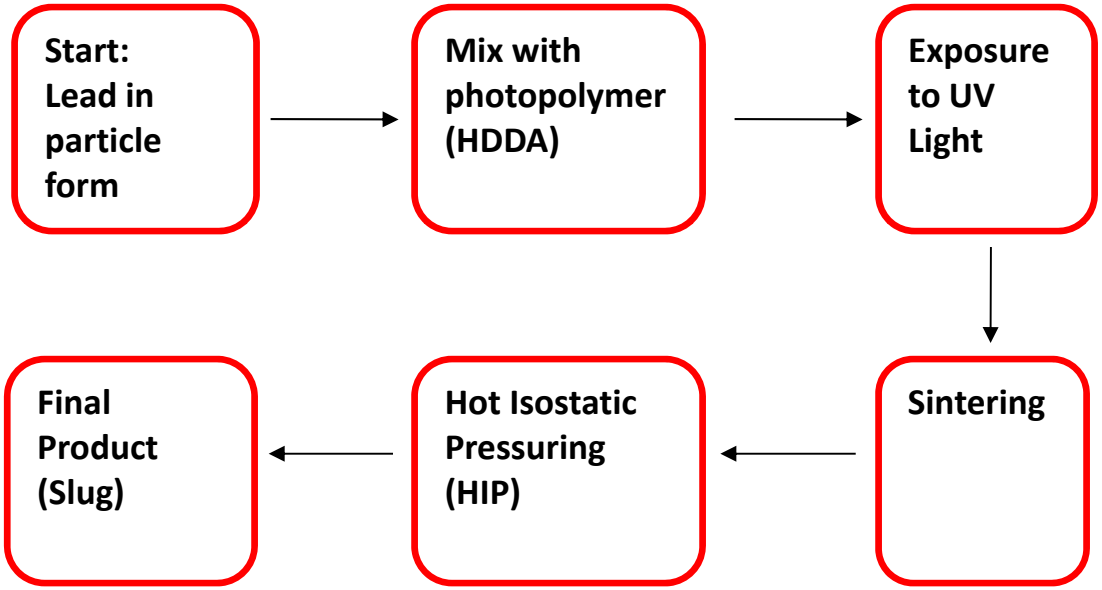

Figure 4. Flowchart of AM bullet making process using PµSL.

Making bullet using Electrophoretic Deposition (EPD)

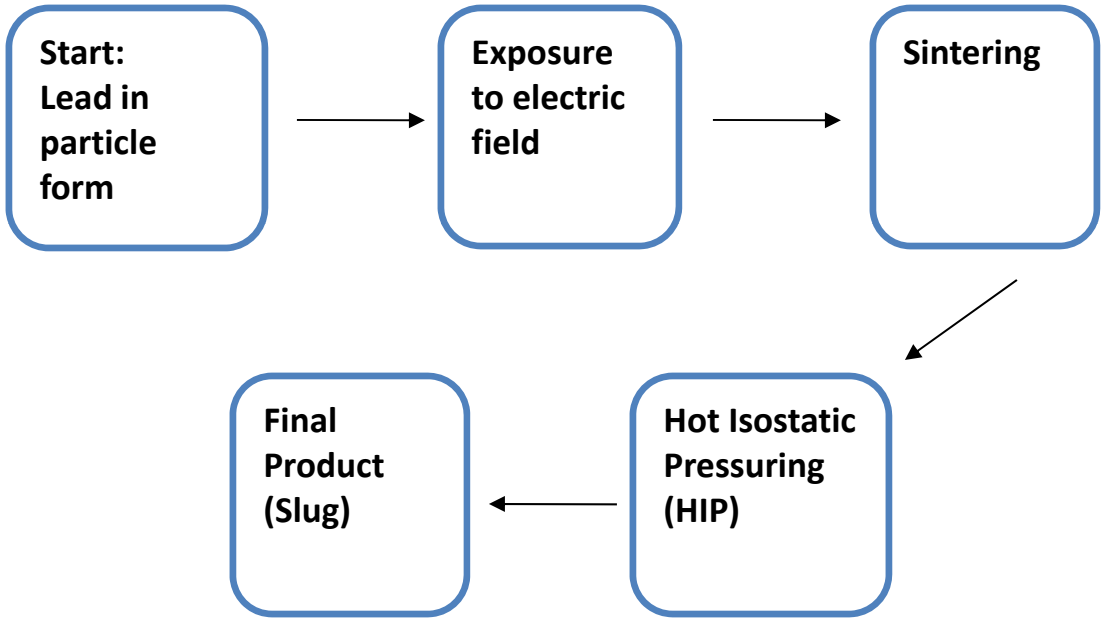

Figure 5. Flowchart of AM bullet making process using EPD.

Making bullet using Direct Ink Write (DIW)

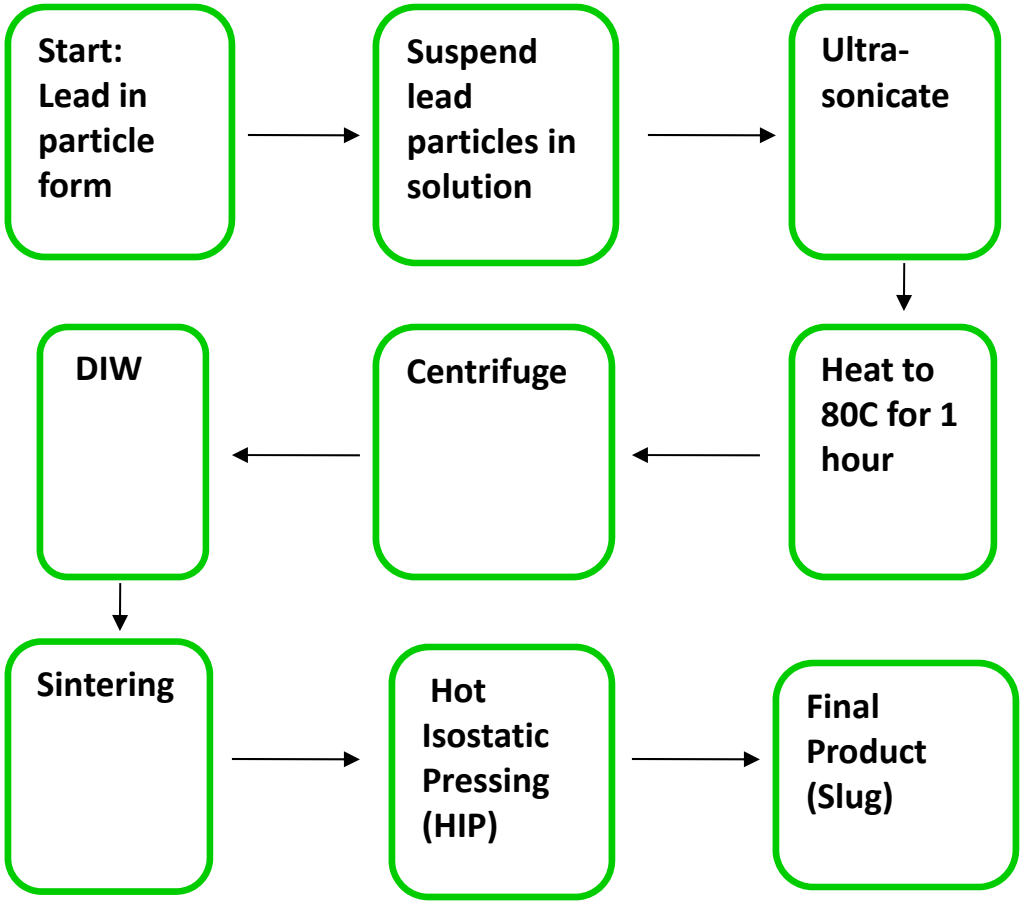

Figure 6. Flowchart of AM bullet making process using DIW.

Cost to make bullets using conventional method

Tables 5,6, & 7. Cost to make bullet slug using additive manufacturing techniques using PμSL (left), EPD (middle), and DIW (right).

Cost Variable	PμSL
Raw material cost	5.3892 cents
HDDA cost	79.9092 cents
UV lamp energy cost	0.02 cents
Sintering cost	0.0041 cents
HIP cost	0.0615 cents
Total Cost	85.384 cents

Cost Variable	EPD
Raw material cost	5.3892 cents
Electric field energy cost	0.032 cents
Sintering cost	0.0041 cents
HIP cost	0.0615 cents
Total Cost	5.48679 cents

Cost Variable	DIW
Raw material cost	5.3892 cents
PAA cost	0.57311 cents
Ultrasonication energy cost	0.70 cents
Heating cost	0.0593 cents
Centrifugation energy cost	1.2 cents
DIW process energy cost	58.1646 cents
Sintering cost	0.0041 cents
HIP cost	0.0615 cents
Total Cost	66.1518 cents

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Mechanism of the knee and how a knee implant works

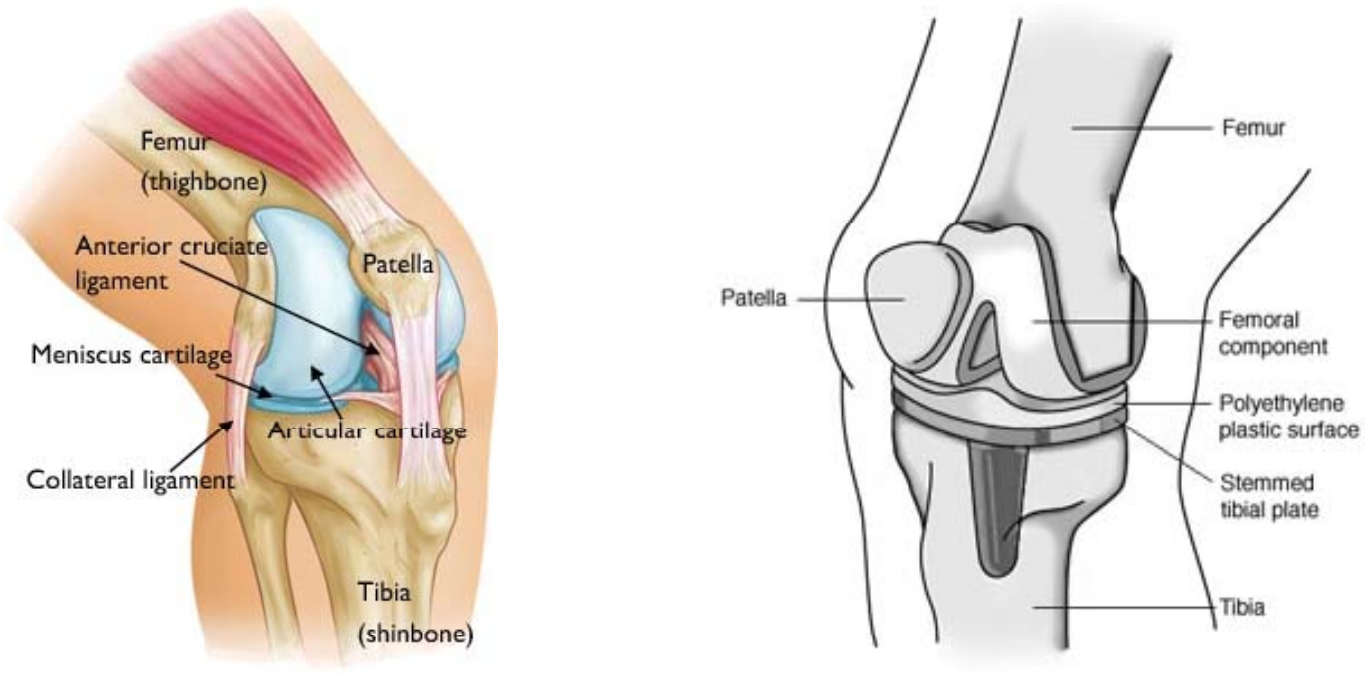

Figure 10. Comparison of actual knee to knee implant.

The knee implant market is attractive and rapidly growing

- **$3.21 billion in revenues for total knee implant market in 2008**
- **Growing at compounded annual growth rate (CAGR) of 7.1%**
- **Revenues projected to reach $5.21 billion in 2015**
- **Key market drivers:**

1. Introduction of new and better technology

2. Increase in aging population (baby boomer market)

3. More active patient lifestyles

(Data obtained from Frost & Sullivan report on US Orthopedic Implant Market)

The price of knee implants is increasing

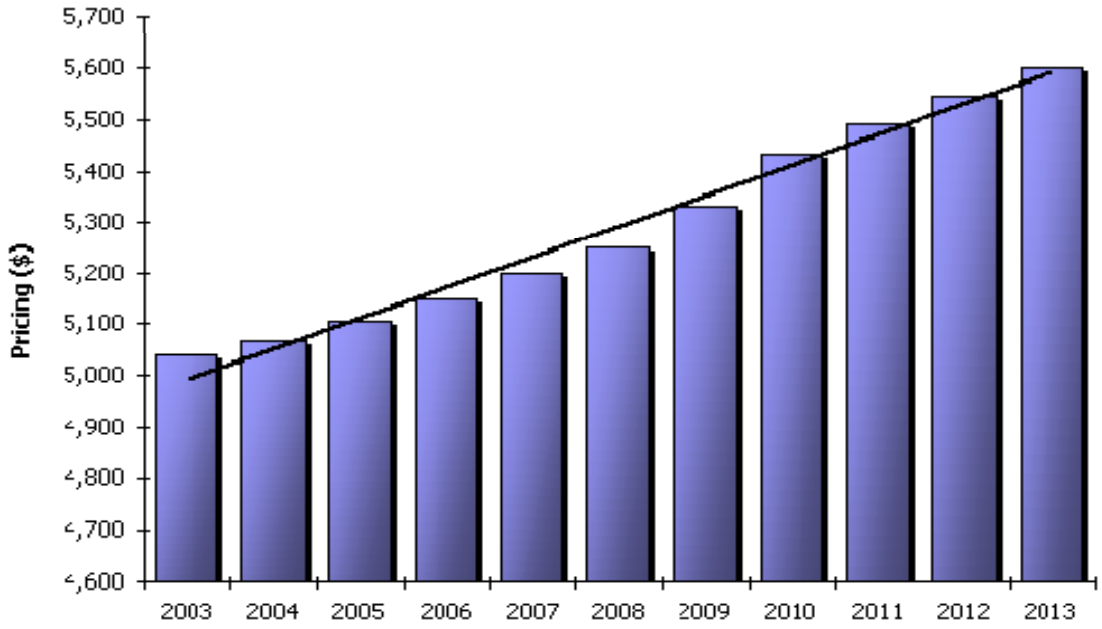

Figure 12. Price of primary knee implant procedure from 2003 to 2013 (Graph obtained from Frost & Sullivan report on US Orthopedic Implant Market).

The number of knee implant procedures is increasing

Figure 11. Number of primary and replacement knee implant procedures from 2002 to 2012 (Graph modified from Frost & Sullivan report on US Orthopedic Implant Market).

Zimmer has largest market share in knee implant market

Market Leaders: Depuy Orthopedics, Zimmer, Stryker, Biomet, Smith and Nephew Orthopedics

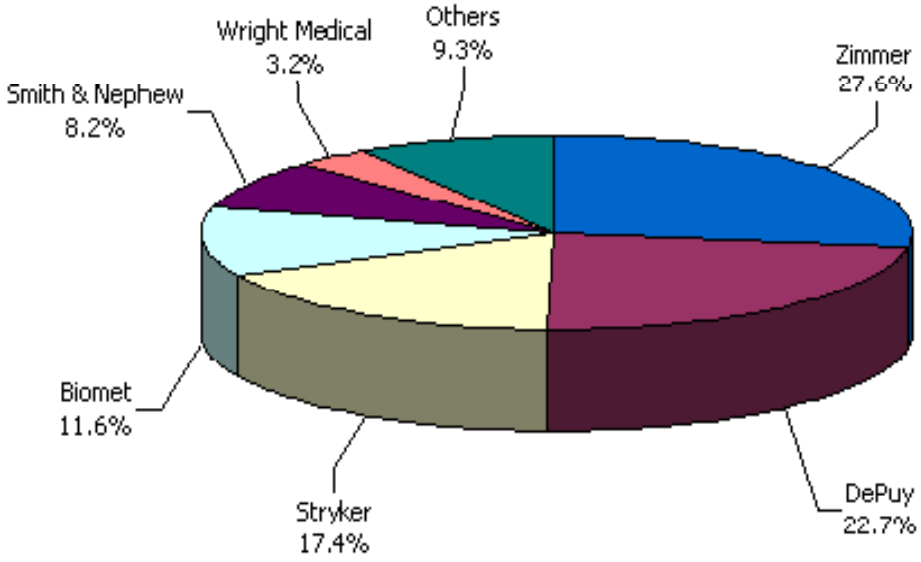

Figure 9. Market leaders in knee implant market by market share (Graph obtained from Frost & Sullivan report on US Orthopedic Implant Market).

Knee implant for case study: Zimmer NexGen knee system

- **Zimmer has largest market share in knee implant market, will play key role in future market**
- **Zimmer is well-known for its innovative ability in the field (e.g. gender-specific knee implants)**
- **NexGen knee system is one of their most popular knee systems**

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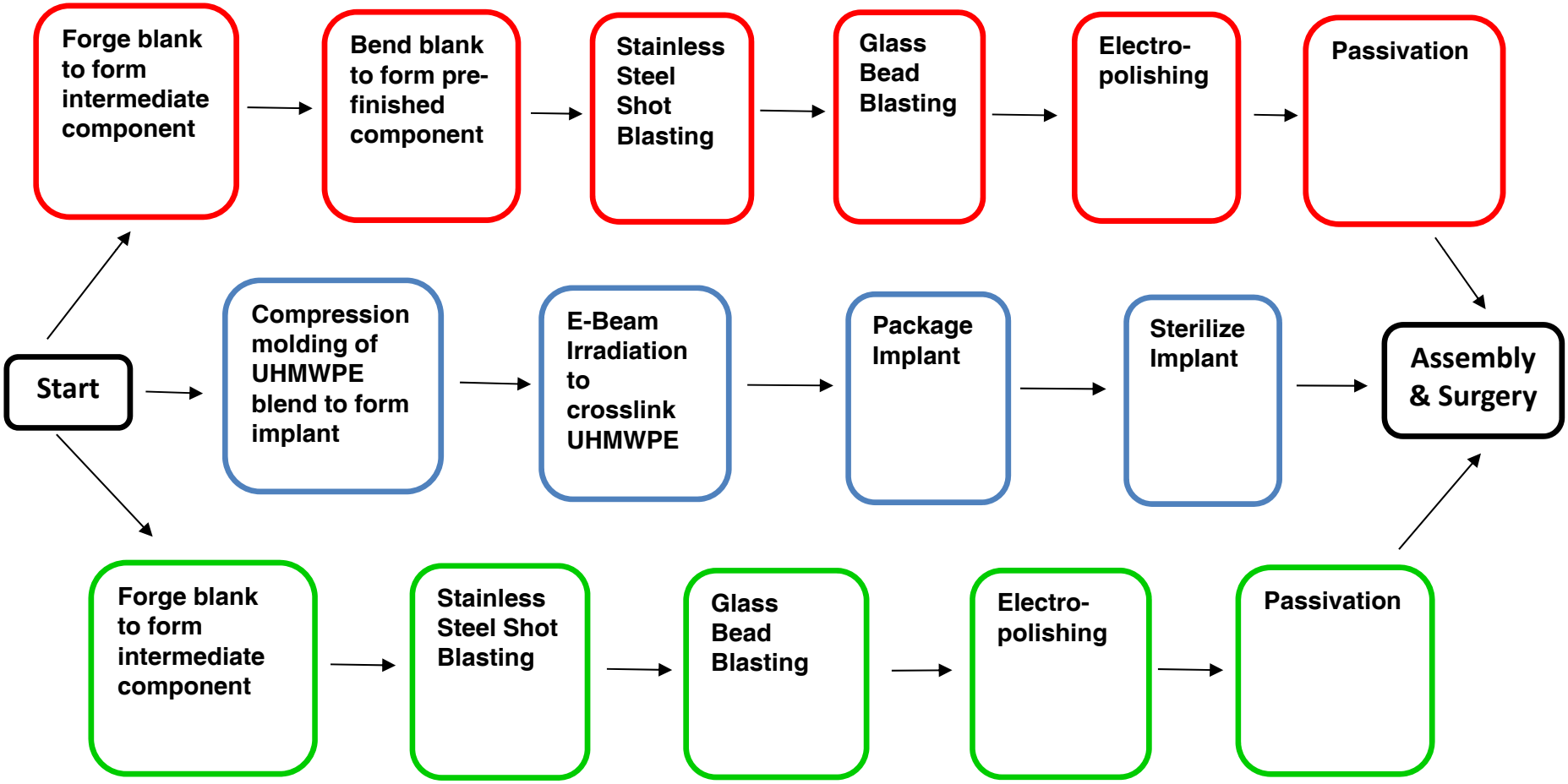
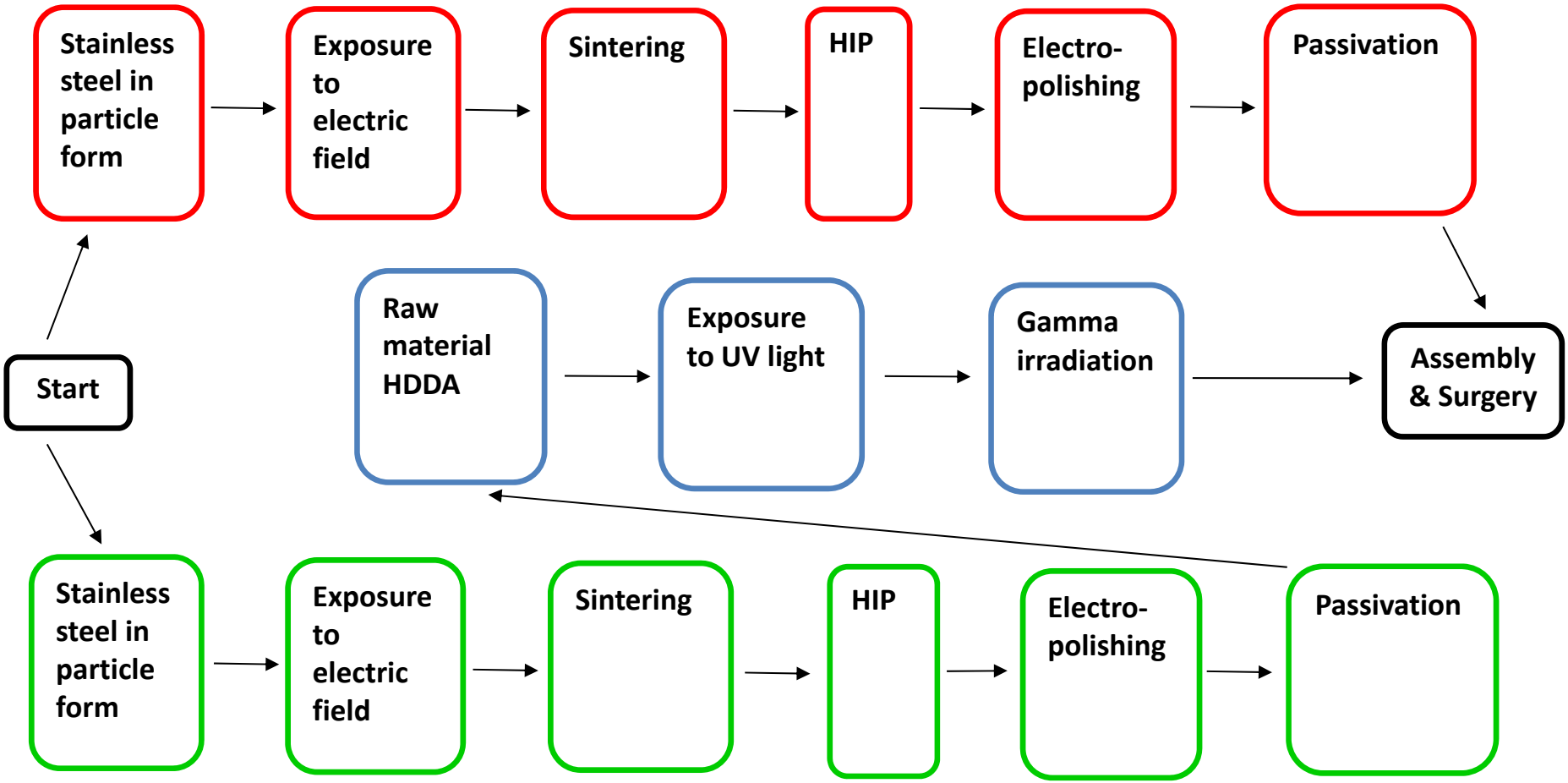
Process flow to manufacture knee implant using conventional methods



Process flow to manufacture knee implant using AM



Cost to make knee implant using conventional (left) and additive manufacturing techniques (right)

Cost Variable	Conventional
Raw material + forging	$259.804
Steel shot blasting	$0.152
Glass bead blasting	$2.88
Electropolishing	$31.0151
Passivation	$28.5
Raw material + forging	$344.887
Bending cost	$0.15
Steel shot blasting	$0.152
Glass bead blasting	$2.88
Electropolishing	$31.0151
Passivation	$28.5
Raw materials	$20.7025
E-beam radiation	$2.7
Sterilization	$1150
Total Cost	$1903.34

Cost Variable	AM processes
Raw materials	$204.902
Electric field energy	$0.48
Sintering energy	$0.01306
HIP energy cost	$0.24871
Electropolishing	$31.0151
Passivation	$28.5
Raw materials	$15.0138
UV lamp energy	$0.00133
Sterilization	$1150
Raw materials	$163.931
Electric field energy	$0.48
Sintering energy	$0.01045
HIP energy	$0.19898
Electropolishing	$31.0151
Passivation	$28.5
Total Cost	$1654.31

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Conclusion

- **Lab's additive manufacturing techniques lose out in simple processes but are competitive in producing complex systems**
- **These techniques can become even more competitive by fine-tuning production process to mitigate cost-limiting factors**

Production method	Cost to make bullet
Conventional – raw materials	0.12396 cents
Conventional – extruded wire	2.25313 cents
PµSL	85.384 cents
EPD	5.48679 cents
DIW	66.1518 cents

Production method	Cost to make knee implant
Conventional method	$1903.34
Additive manufacturing method	$1654.31

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