ADDITIVE MANUFACTURING PROCESS
APPLICATIONS AND CHALLENGES

Dr. J. Ramkumar

Professor

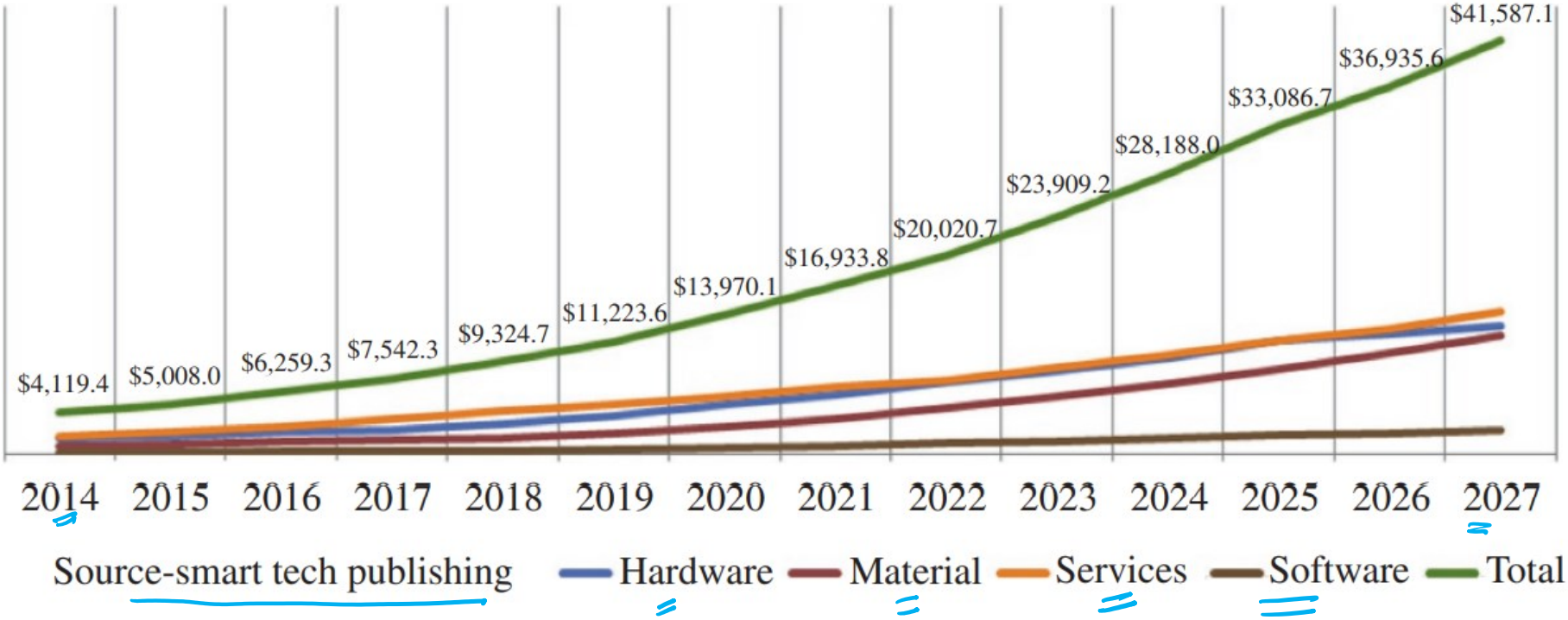
Department of Mechanical Engineering and Design

IIT Kanpur

CONTENTS

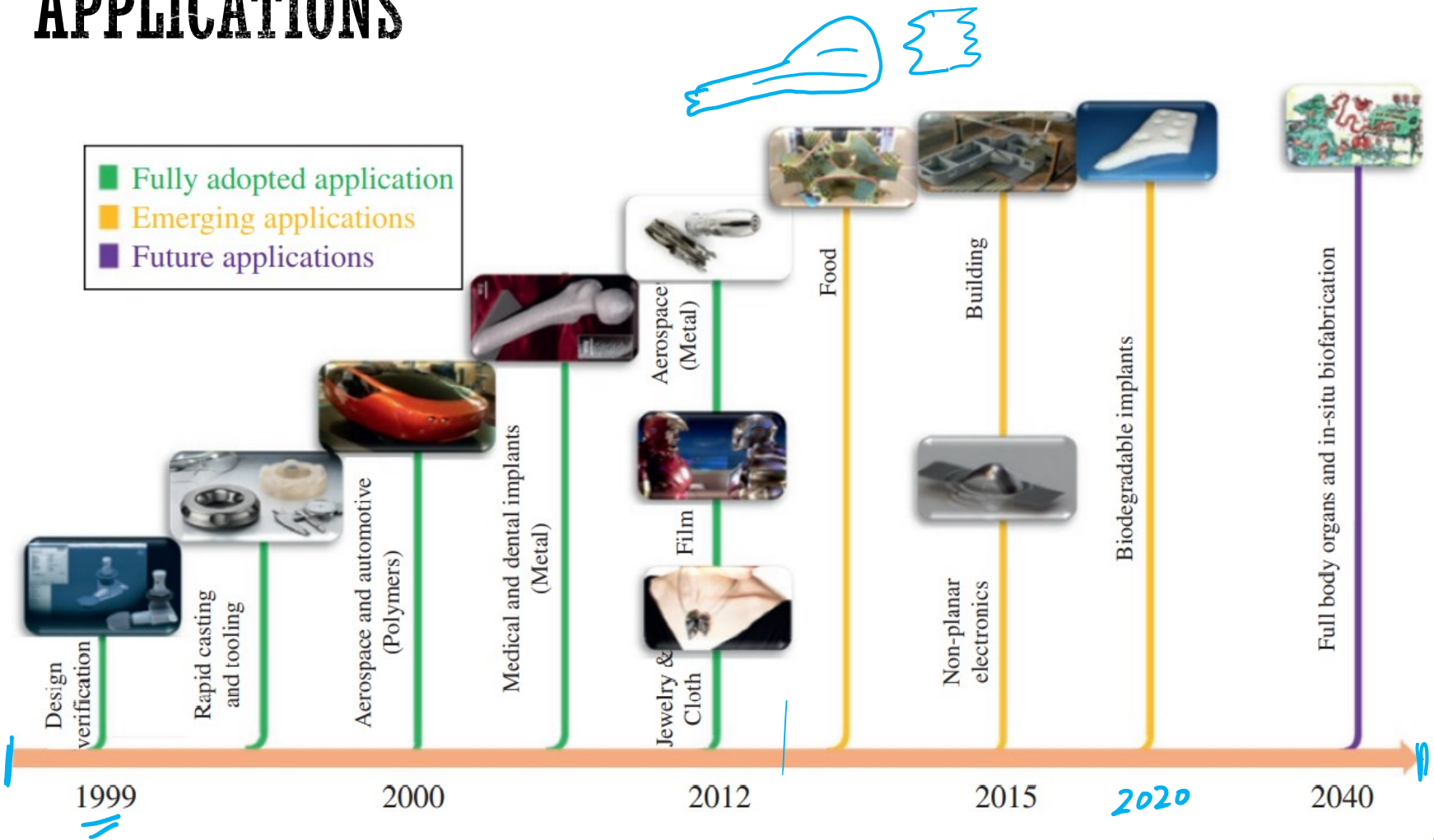
- Current and future estimation of AM market size.
- Application of metal AM in different sectors.
- AM Challenges and opportunities.

MARKET SIZE: CURRENT AND FUTURE ESTIMATION



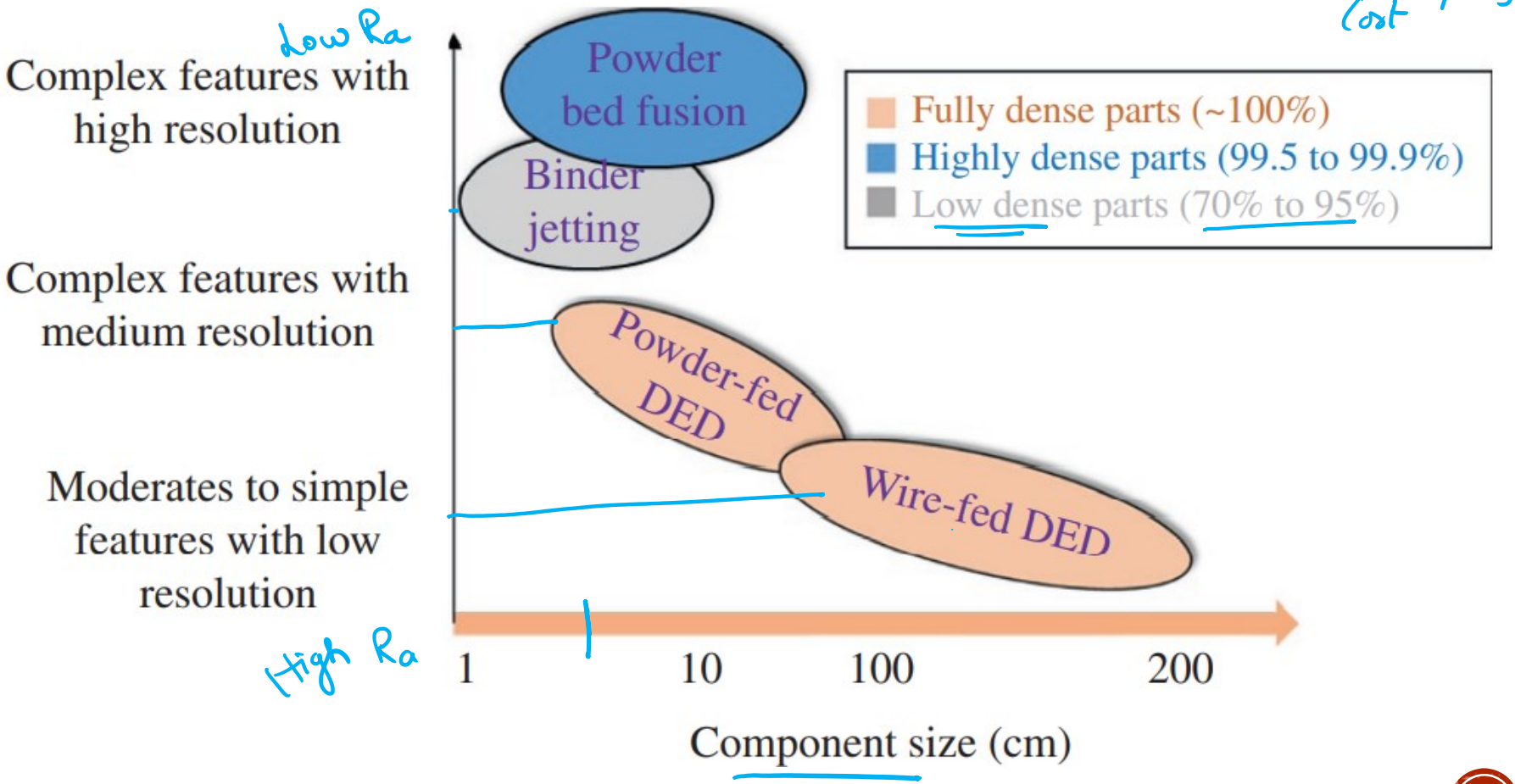
R. Nolan, "SmarTech publishing issues 2019 additive manufacturing market outlook and summary report, estimates AM industry grew 24% percent in 2018, total market of $9.3 billion," 2018. [Online]

METAL ADDITIVE MANUFACTURING APPLICATIONS



R. Nolan, "SmarTech publishing issues 2019 additive manufacturing market outlook and summary report, estimates AM industry grew 24% percent in 2018, total market of $9.3 billion," 2018. [Online]

ADDITIVE MANUFACTURING
BASED ON COMPONENT SIZE



R. Nolan, "SmarTech publishing issues 2019 additive manufacturing market outlook and summary report, estimates AM industry grew 24% percent in 2018, total market of $9.3 billion," 2018. [Online]

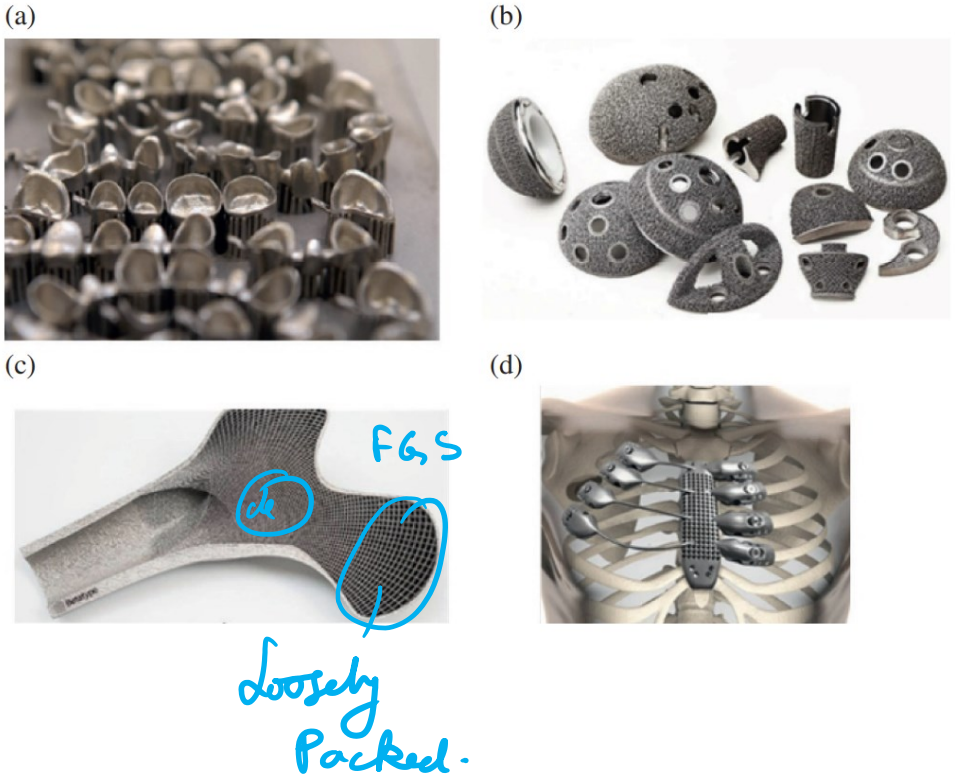
ADDITIVE MANUFACTURING IN MEDICAL AND DENTAL

a) Dental crowns printed by LPBF

b) Joint implants printed by E-LPF

c) Functionally gradient porous titanium load-bearing hip implant printed by LPBF → Laser Power bed Fusion.

d) Customized ribs and sternum printed by E-PBF
Electron beam.



S. Fournier, "The making of an orthopedics implant using 3D printing." [Online], 2018. Available: https:// orthostreams.com/2018/12/the-making-of-a-medical-metal-implant-using-3d-printing-from-black-to-greymetal-powder-magic-of-3d-printing.
Metal AM, "Renishaw showcases metal AM implants to American Academy of Orthopaedic Surgeons," 2018. [Online]. Available: https://www.metal-am.com/renishaw-showcases-metal-implants-americanacademy-orthopaedic-surgeons.
H. R. Mendoza, "3D printing gives cancer patient new ribs and sternum in first-of-its-kind surgery," 2015. [Online]. Available: https://3dprint.com/95371/3d-printed-ribs-and-sternum

ADDITIVE MANUFACTURING IN AEROSPACE AND DEFENSE

→ Complex Size Shape features

Volume is low

A mold insert with (a) conformal cooling channels, and (b) conformal and lattice structures to improve heat dissipation.

R. Botsford End, "SpaceX's superdraco engine: Abort capability all the way to orbit," 2015. [Online]. Available: https://www.spaceflightinsider.com/organizations/space-exploration-technologies/spacexssuperdraco-engine.

ADDITIVE MANUFACTURING
IN COMMUNICATION

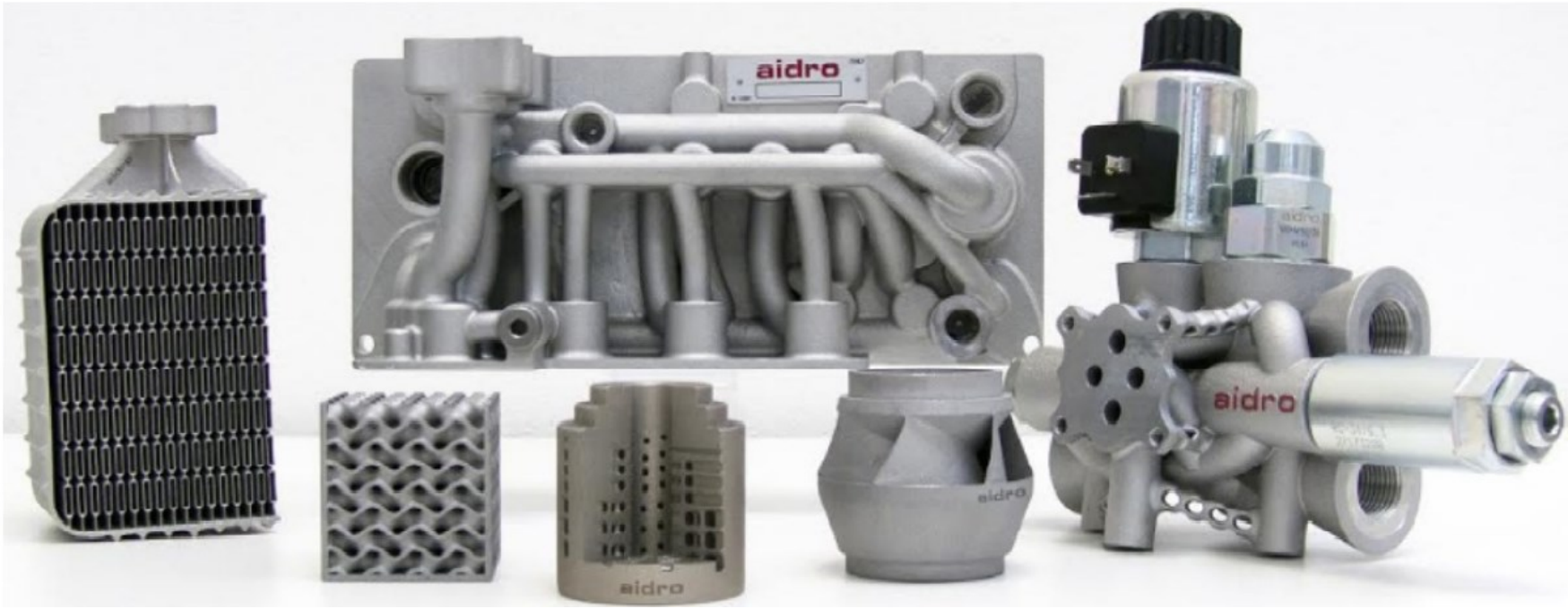
Conformal antennas

3-D

Small-size, lightweight, one-piece, AM-made antenna.

Optisys, "Additive manufacturing transforms RF antenna design," Metal AM, 2017. [Online]. Available: https://www.metal-am.com/additive-manufacturing-transforms-rf-antenna-design

ADDITIVE MANUFACTURING
IN HEAVY ENGINEERING INDUSTRY



Hydraulic parts made for the oil and gas industry

R. Nolan, "SmarTech publishing issues 2019 additive manufacturing market outlook and summary report, estimates AM industry grew 24% percent in 2018, total market of $9.3 billion," 2018. [Online]

ADDITIVE MANUFACTURING IN AUTOMOTIVE INDUSTRY

a) Ford's custom anti-theft wheel lock being printed by PBF system

b) Ford's custom anti-theft wheel lock

c) Custom titanium door handle frame in DS3 Dark Side edition from DS Automobile

(a)

(b)

(c)

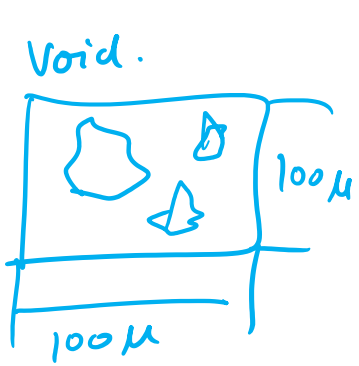
EOS, "The potential of additive manufacturing for serially produced vehicles." [Online]. Available: https:// www.eos.info/en/3d-printing-examples-applications/mobility-logistics/automotive-industry-3d-printing/ serially-produced-vehicles.
Ford, "Ford develops 3D-printed locking wheel nuts to help keep thieves at bay," 2020. [Online]. Available:https://media.ford.com/content/fordmedia/feu/en/news/2020/01/28/ford-develops-3d-printed-lockingwheel-nuts-to-help-keep-thieves.html.

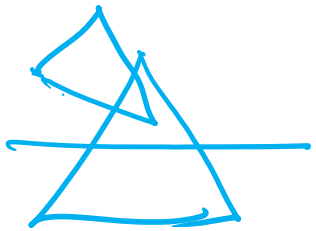
ADDITIVE MANUFACTURING
INDUSTRIAL TOOLING AND OTHER APPLICATIONS

- AM can be used to produce machinery components, heat exchangers, engineered structures, etc., either for redesigned parts or low-volume production of heritage parts.
- Mass customization promotes the expanding use of metal AM in consumer products such as decorative objects, jewelry, specialized sports gear, and bicycle frames.
- AM's design freeform, material graded structures, lightweighting, and the quick design-to-market cycle will revolutionize industrial and personal product markets.

ADDITIVE MANUFACTURING
CHALLENGES, AND OPPORTUNITIES

1. Qualified materials
2. Speed and productivity
3. Repeatability and quality assurance
4. Industry-wide standards
5. End-to-end workflow, integration, and automation
6. Software limitations
7. Initial financial investments
8. Security
9. Skillsets gap





2 1 Cr to 10 Cr

ADDITIVE MANUFACTURING CHALLENGES, AND OPPORTUNITIES

1. **Qualified materials**
   - Number of powders qualified for use with metal AM systems, including laser, electron beam, and binder-based AM techniques, is a key difficulty in metals and metal alloys.
   - More than 1000 steel alloys are commercially accessible for conventional casting, but only a handful have been validated for AM.
   - Aluminum alloys are 600:12.
   - The lack of parts limits the number of companies that can use the technology.

ADDITIVE MANUFACTURING
CHALLENGES, AND OPPORTUNITIES

1. Qualified materials

- The few qualified metals AM powders cost 5–10 times more than casting, machining, and other raw materials.
- Uncompetitive suppliers are part of the problem.
- Metal AM materials sales total less than $400 million a year, a fraction of the whole raw materials business.
- As AM gains popularity, pricing should drop drastically. This difficulty presents an opportunity to improve powder production procedures and maybe manufacture new powders to maximize metal AM

ADDITIVE MANUFACTURING CHALLENGES, AND OPPORTUNITIES

2. Speed and productivity

- AM procedures require speed. Mass production speeds are modest.
- Small working volume and post-processing for surface enhancement add steps to manufacturing time.
- To boost AM production, surface quality must be improved.
- To boost AM productivity, modular flexibility is being added.
- Process scalability and modularity can help achieve quality and speed.

ADDITIVE MANUFACTURING CHALLENGES, AND OPPORTUNITIES

2. Speed and productivity

- Multiple heat sources (e.g. laser beams) are being combined into a larger operating envelope.
- Automation and intelligent software are being developed to improve subsystem production.
- Computer modeling of AM processes can enhance production through dependable simulation rather than costly experimentation.
- Few models have been developed, adding R&D costs to high material costs to prevent enterprises from using AM.

ADDITIVE MANUFACTURING CHALLENGES, AND OPPORTUNITIES

3. Repeatability and quality assurance

- Reliability and reproducibility remain major AM issues, especially for mass manufacturing.
- AM is sensitive to environmental and process disturbances including shifting temperature, humidity, and particle size.
- Full control of the process and environment is difficult, thus solutions that use sensors to monitor conditions and quality control algorithms to automatically modify process parameters, such as laser power or process speed, are preferred.
- Due to their speed, DED is adding closed-loop control while PBF is adding intermittent controllers.
- For PBF operations (e.g. LPBF), hardware speed and accuracy are bottlenecks for closed-loop control.

ADDITIVE MANUFACTURING
CHALLENGES, AND OPPORTUNITIES

4. Industry-wide standards

- Despite AM's recent advances, the industry lacks a complete set of technical standards.
- Lack of standards may hamper industrial AM adoption.
- Several key players have identified the challenge and begun acting. ASTM, ANSI, ISO, and other organizations are developing AM standards platforms and methods.

ADDITIVE MANUFACTURING CHALLENGES, AND OPPORTUNITIES

4. Industry-wide standards

- ASTM's F42 committee is creating standards for metal AM, particularly LPBF.
- The created standards could assist the industry to analyze AM system performance and part quality.
- Despite these efforts, new, dependable standards are needed.
- Concrete standards should be published rather than partially created ones with shortcomings.
- If standards are repeatedly retracted and amended owing to weaknesses, the industry will suffer.

ADDITIVE MANUFACTURING
CHALLENGES, AND OPPORTUNITIES

5. End-to-end workflow, integration, and automation

- All major industrial and nonindustrial AM system providers propose end-to-end workflow integration.
- Any integration/automation must consider AM's limitations and features.
- The lack of digital infrastructure hinders the AM industry's progress to automated workflows.

ADDITIVE MANUFACTURING
CHALLENGES, AND OPPORTUNITIES

5. End-to-end workflow, integration, and automation

- Design for AM (DfAM) solutions, driven by digital warehouses and digital twins, expedite the part design and optimization for automation.
- Manufacturing execution software should automate material supply lines (e.g. powders) for AM systems and workflow stations.
- Machine learning, AI, simulation, inline process monitoring software, and nondestructive testing (NDT) should oversee the AM process to fix faults by having robots for depowdering and recycling powder for AM machines.
- The workflow should include automated post-processing heat treatment, polishing, etc. Automated AM is part of the factory of tomorrow and the industry 4.0 revolution.

ADDITIVE MANUFACTURING CHALLENGES, AND OPPORTUNITIES

6. Software limitations

- Commercial software systems for AM component design, support structure construction, and machine interface have limitations in assessing print feasibility and recognizing process limits.
- In many cases, 3D-modeled ideas are difficult to print due to unaccounted-for process restrictions.
- Current workflow software limits AM's ability to track individual goods through each process stage to manage resources and delivery timelines.
- The quality of information and transmission mechanisms affects inter-and intra-communication and collaboration.
- Current software and hardware need enhancements for AM communication.

ADDITIVE MANUFACTURING
CHALLENGES, AND OPPORTUNITIES

7. Initial financial investments

- A large investment in AM money and ecosystem is required to put metal AM into production.
- AM includes software, supplies, experts, post-processing equipment, certification, and employee training.
- This investment may prevent companies from adopting this technology.
- AM service firms can be integrated throughout the supply chain to derisk early AM adoption.
- Universities and R&D institutions can help companies implement AM by providing basic R&D and training platforms.

ADDITIVE MANUFACTURING CHALLENGES, AND OPPORTUNITIES

8. Security

- AM's cyber-physical nature has caused considerable problems.
- When AM promotes distributed manufacturing, hackers exist.
- They can change AM designs to generate purposeful faults with catastrophic effects in real systems.
- Commercial AM services' weaknesses and large-scale tasks may make it hard to verify printed parts' quality.

ADDITIVE MANUFACTURING
CHALLENGES, AND OPPORTUNITIES

8. Security

- To solve security problems, process and supply chains must be firewalled.
- These measures could be the same as other manufacturing industries like electronic printing
- However, due to typical applications of AM-made parts in critical applications like jet engines, special validation procedures must be developed to give assurance that the parts are not affected by a malicious attack involving undetectable design alterations.

ADDITIVE MANUFACTURING CHALLENGES, AND OPPORTUNITIES

9. Skillsets gap

- AM expertise is in scarce supply.
- Lack of AM knowledge and competence hinders adoption.
- There is a restricted workforce and highly qualified specialists to help new enterprises adopt AM.
- A thorough understanding of AM capabilities minimizes significant misconceptions and introduces decision-makers to difficulties correctly.
- Companies struggle to establish successful metal AM business cases due to a knowledge gap.
- Mechanical engineers educated in traditional production can't design for AM. Mastering it will be difficult.
- Education and training must modify their perspective.
- Metal AM's capabilities and limitations will help organizations design effective applications.

POINTS TO PONDER

- AM process and ASTM definition.
- Importance of AM and its major classification.
- Application in different sectors.
- Challenges and opportunities in Metal AM

ASSIGNMENT

1. Google and make a list of seven major categories of AM process, advantages and limitations of each process.
2. Point out the AM process which can manufacture metal parts.

- Spoon → eating
- Hydraulic Valve
- Heart Valve

THANK YOU