INL/CON-17-42460-Revision-0

Direct Energy Deposition Additive Manufacturing (AM):Manufacturing unique parts for DOE applications

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Direct Energy Deposition Additive Manufacturing (AM): Manufacturing unique parts for DOE applications

Unique advantages of a new technology address problems in spent fuel storage applications

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Presentation outline

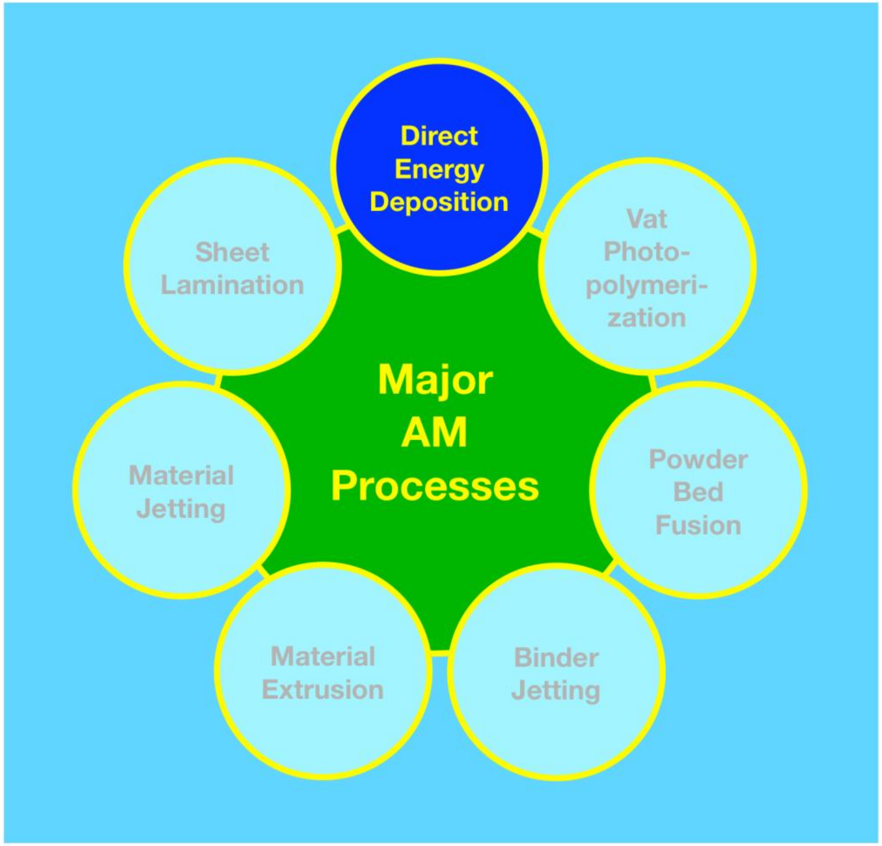
- Bringing a new technology to bear on the spent fuel problem that offers
  - Increased flexibility
  - Reduced costs
  - Opportunities for productive collaboration
- Additive Manufacturing to address DOE needs and research on spent fuel storage issues
- AM – industry, applicable technologies, benefits and challenges
- A new vision

DOE spent fuel issues

- DOE spent fuels less standardized than commercial fuels
  - Different geometries
  - Different materials
  - Stringent requirements for
    - Cladding integrity
    - Corrosion
    - Criticality
- Current storage designs
  - Canisters and casks, standardized
  - Baskets and other internals, not standardized
- Additive manufacturing is suited to nonstandardized applications
  - Based on readily changed software designs
  - Flexible as to materials

AM Processes

- ASTM/ISO definition:
  Process of joining materials to make parts or objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing technologies
- Synonyms include:
  Additive fabrication, Additive processes, Additive techniques, Layer manufacturing, Additive layer manufacturing, Freeform fabrication, Solid freeform fabrication, Rapid tooling, Rapid prototyping, Rapid manufacturing, Direct digital manufacturing, 3D printing

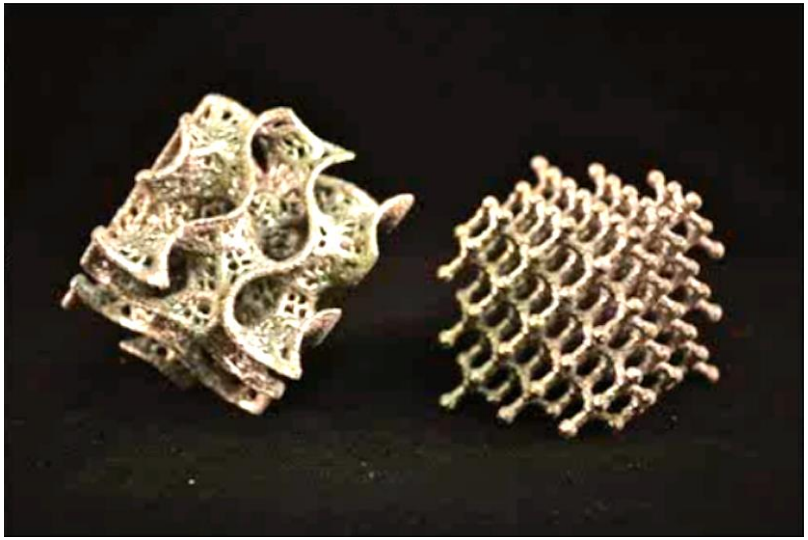


State of the industry

- Growth took off ca. 2003
- $5B industry in 2015, wide interest in many manufacturing sectors
- Many materials: polymers, metals, ceramics
- Worldwide: US, Europe, Asia

LEAP jet engine fuel nozzle

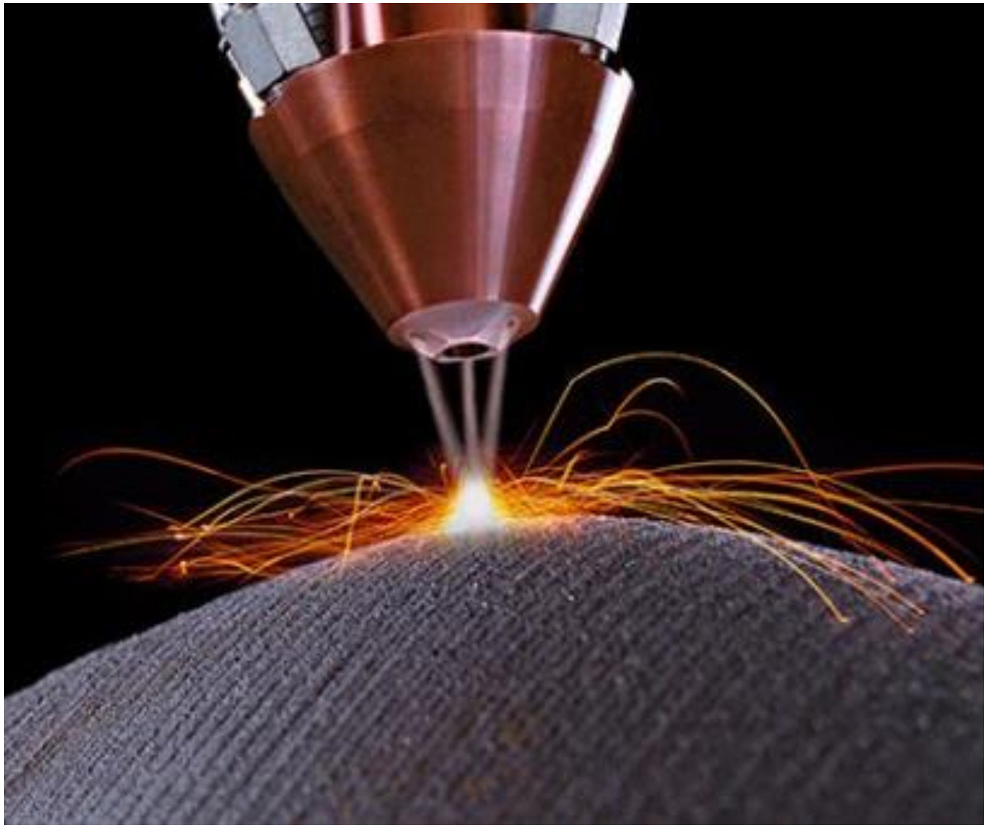
Airbus hydraulic reservoir rack



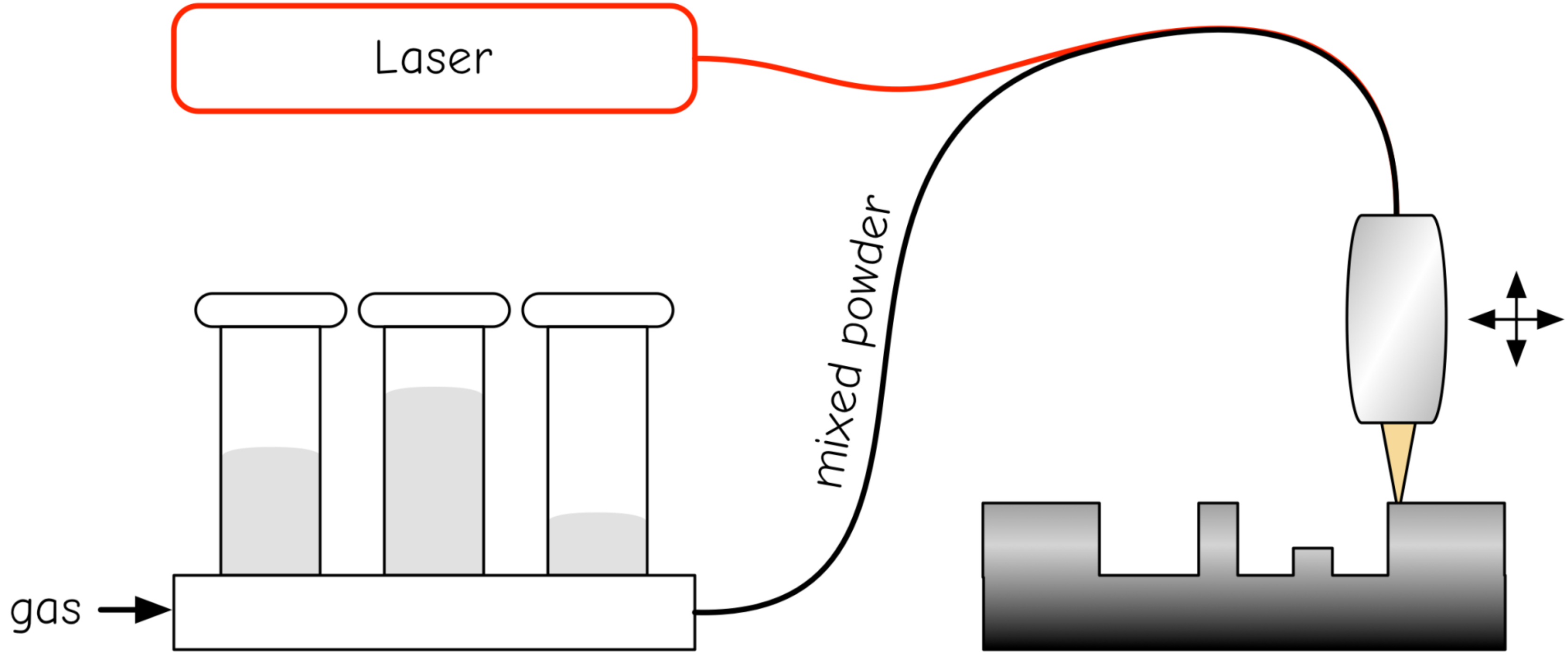
Space-filling networks

Why Direct Energy Deposition?

- Based on laser fusion of deposited powder
- Adaptable to large parts
- Any powdered material
  - Structural alloys
  - Coatings
  - Poisons
- Multiple powder sources:
  - Multi-materials
  - Functional gradient materials

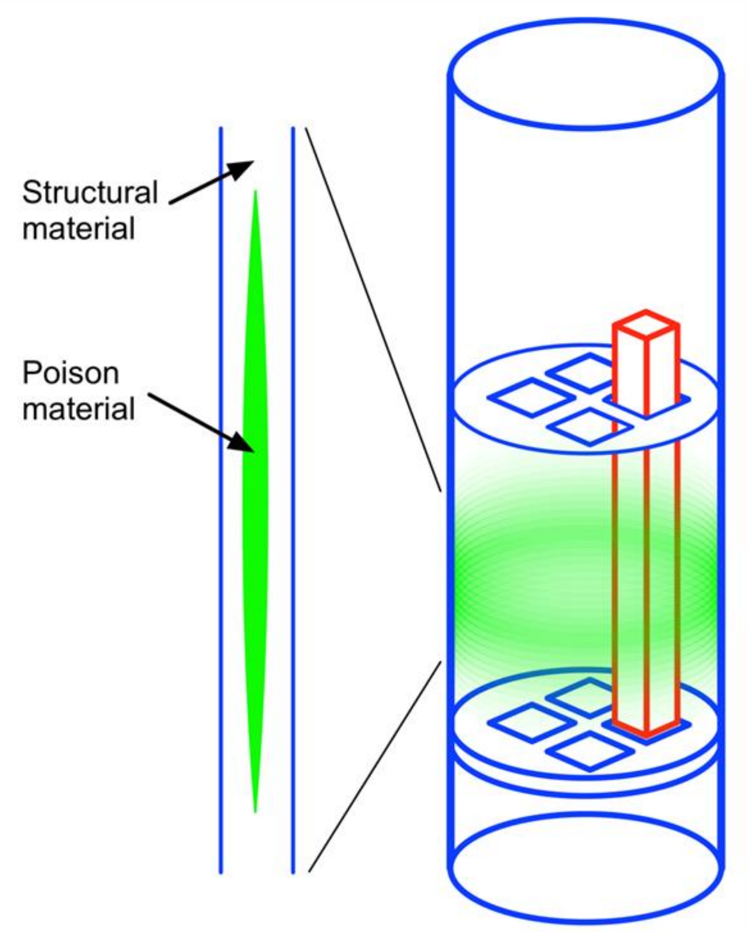


Multimaterial and functional gradient capability of Direct Energy Deposition AM



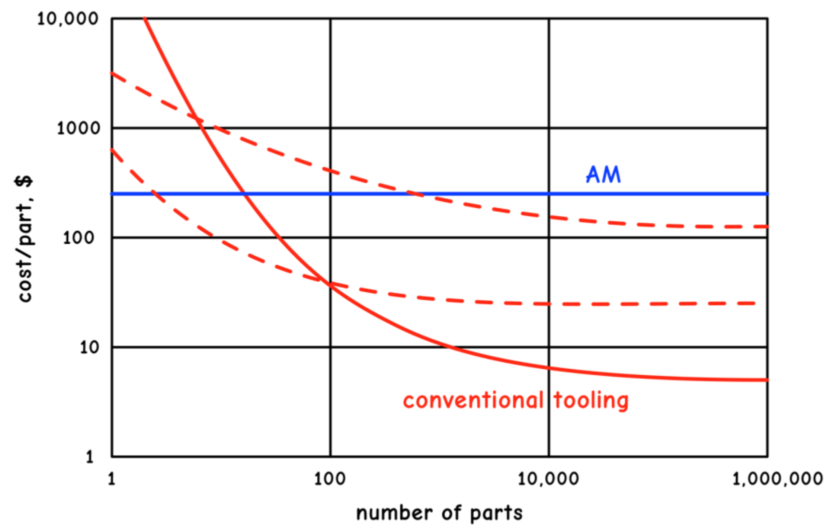
AM placement of neutron poisons

- Neutron poison additions, even at a few percent, usually degrade ingot metallurgy workability, weldability, and final properties
- Multimaterial capability of AM allows poison to be placed where needed; functional gradient capability of AM allows poison material to grade into structural materials, which retain a standard alloy composition
- Result: better structural properties, corrosion resistance, weldability, and tailored neutronics



Economics

- Machines are flexible, and <u>are</u> the tooling
- Costs are higher but tend not to change with production runs
- Small variations (e.g., for a different size or kind of spent fuel element) can be handled in software on a per-build basis, i.e., not a change order for a conventional fabrication process



- Build times are slow, but need to be compared with the entire conventional process, e.g., design, change orders, material procurement, fabrication
- Development cycles can be shortened by making partial or subscale test articles

Challenges

- QA – how can we be sure material is sound
  - Uniformity
  - Properties
  - In-process sensing and control probably essential
- Relatively early stage of development for AM
  - “Material library” not as developed as for conventional materials
  - Effects of build parameters need to be explored for particular applications
- Residual stress
  - A challenge for layer-based methods such as AM
  - Can rise to levels that fracture a part during building
- Multi-materials and functional gradients
  - Metallurgical phase relationships within the build
  - Unexpected property changes within gradients

Other potential applications

- Pressure vessels
- Graded transitions from very expensive alloys needed for high performance to cheaper ones adequate for lower performance areas
- Others?

Collaborations

- INL has knowledge of DOE fuel disposition needs and technology
- INL wants to apply the latest material and fabrication technologies to:
  - Decrease costs
  - Increase flexibility
- Additive manufacturing has developed to a useful stage
  - Developing fast as an industry and “it is the future”
  - “Material library” is incomplete, needs further development
    - We can concentrate on spent fuel materials needs
- Possible collaborations to address:
  - Material and process expertise
  - Needs of government spent fuel storage
  - Nuclear applications beyond fuel storage