3D METAL PRINTING EXPERIENCE

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WEBINAR SERIES

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PMA PRECISION METALFORMING ASSOCIATION

3D METAL PRINTING MAGAZINE

Qualification of Metal AM Parts

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EWI®
We Manufacture Innovation

EWI®

We Manufacture Innovation

An advanced engineering services provider

addressing business challenges by developing tailored engineered technical solutions

$27 Million Annual revenues across range sectors

160+ Staff Working together to find solutions

$40+ Million In state of the art capital equipment

Additive Manufacturing Efforts at EWI

Additive Manufacturing efforts at EWI generally fall within three core focus areas:

MATERIALS

- Process Development for AM Materials
  - Weldability
  - Microstructure
  - Mechanical Properties
- Material Development for AM
- Material Property Database Generation
- Heat Treatment Development
- Functionally Gradient Materials

PROCESSING

- AM Process Development
  - Energy Delivery
  - Feedstock Delivery
  - Monitoring Systems
  - Control Systems
  - Defect Detection and Mitigation
- Process Validation
- Application Development
- Powder
  - Characterization
  - Spheroidization
  - Recycling

QUALITY

- In-situ Process Monitoring
  - Thermal History Control
  - Quality Scenario Monitoring
  - Feedback Control
- Process Qualification Development
- Surface Characterization
- Dimensional Metrology
- Destructive and Non-Destructive Evaluation

Additive Manufacturing Equipment at EWI

Additive Equipment

L-PBF
- EOS M280
- EOS M290
- EWI Open Architecture Machine

EB-PBF
- Arcam A2X
- Wayland Calibur3 (coming soon)

Ultrasonic AM
- Fabrisonic

Cold Spray
- Spee3D
- VRC
- Centerline

L-P-DED
- RPMi 557
- Open Architecture Cell

EB-DED
- Sciaky VX110

L-W-DED
- Open Architecture Cell

Binder Jet Printing
- Innovent

Laser & Electron Beam **Powder Bed Fusion**

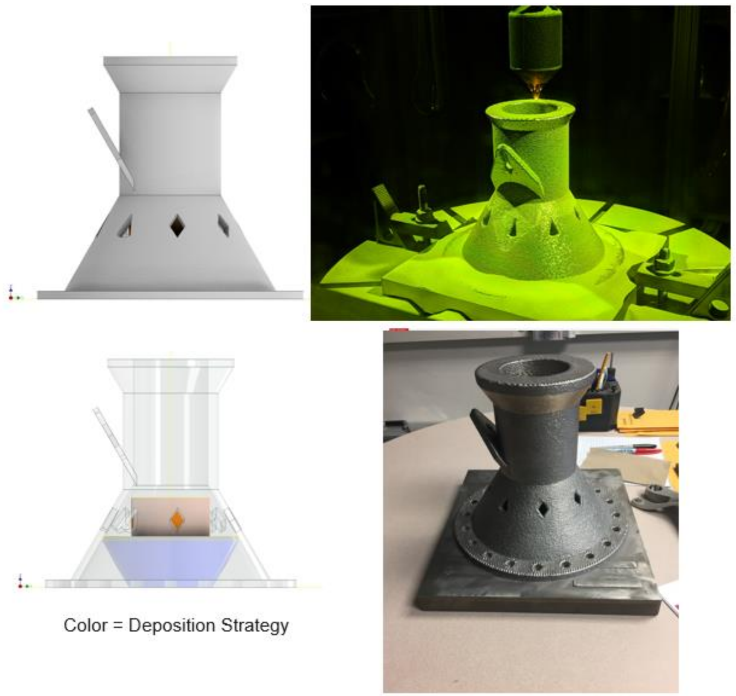
Ultrasonic AM

Additive Manufacturing, low- and high-pressure **Cold Spray**

Arc/Laser/E-Beam Powder & Wire **Directed Energy Deposition**

Binder Jetting

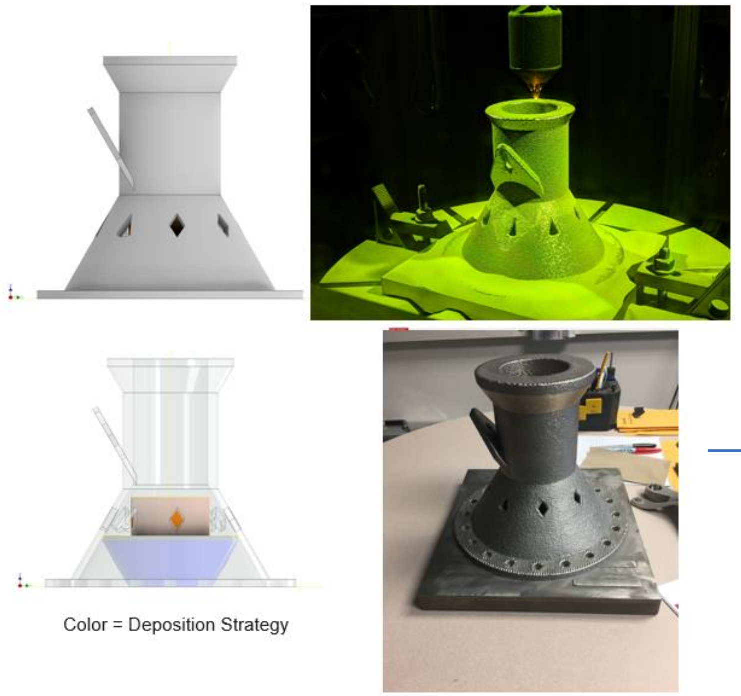
Metal AM Part Qualification



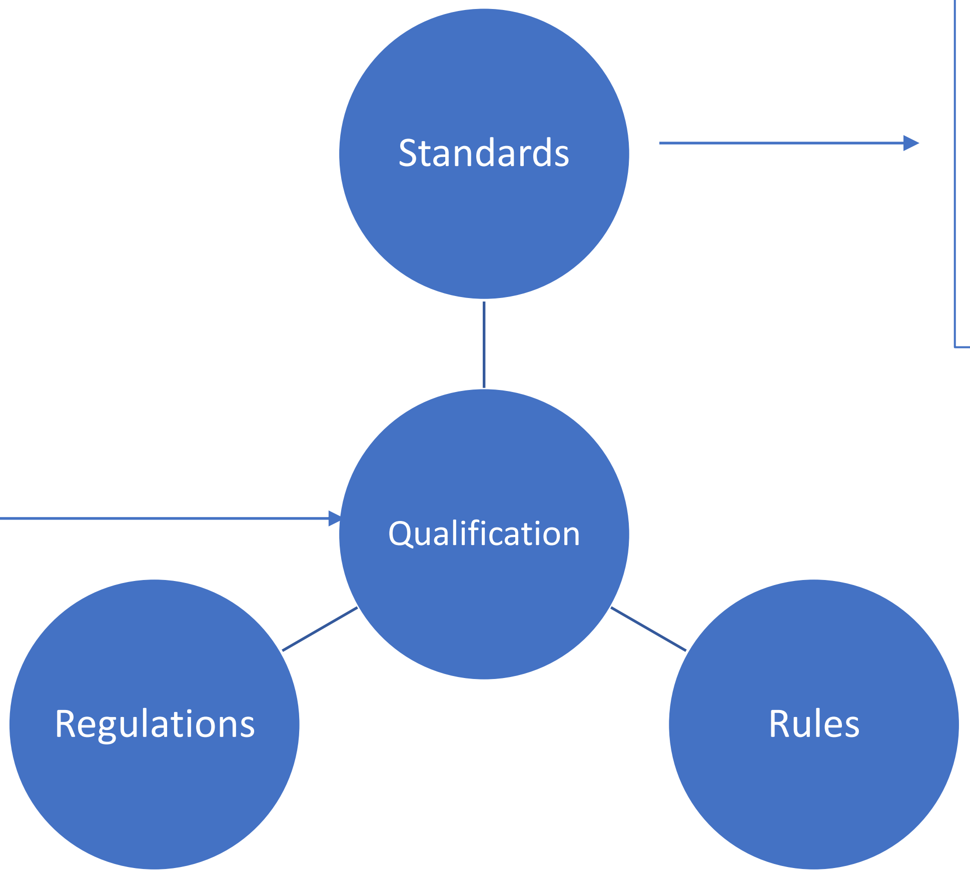
Target part with features [1]

(1) This research was performed through the National Center for Defense Manufacturing and Machining under the America Makes Program entitled “Maturation of Advanced Manufacturing for Low Cost Sustainment (MAMLS)” and is based on research sponsored by Air Force Research Laboratory under agreement number FA8650-16-2-5700.
(2) Chen, Ze, et al. "A review on qualification and certification for metal additive manufacturing." *Virtual and Physical Prototyping* 17.2 (2022): 382-405.

Metal AM Part Qualification



Target part with features [(1)]



AM Standards Bodies:

- ASTM
- ISO
- AWS
- SAE
- ASME

Best practices, often formalized with procedures

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(2) Chen, Ze, et al. "A review on qualification and certification for metal additive manufacturing." *Virtual and Physical Prototyping* 17.2 (2022): 382-405.

Considerations

- Has the materials technology been developed and standardized?
- Has the materials technology been fully characterized?
- Has the materials technology been demonstrated?

Frazier, William E., Donald Polakovics, and Wayne Koegel. "Qualifying of metallic materials and structures for aerospace applications." *Jom* 53.3 (2001): 16-18.

Typical Qualification Pathway

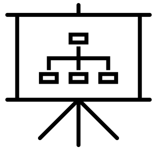
Equipment/Operation Qualification

Installation (IQ)

Equipment and support systems installed and operational

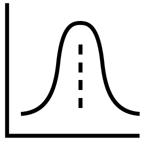
Operational (OQ)

Equipment tested for procedures, control limits, failure modes, etc.



Performance (PQ)

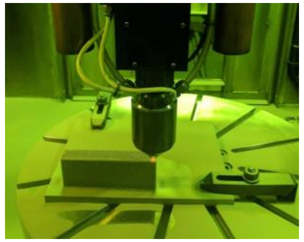
Performance consistency and acceptable results



Program Qualification

Material (Level 1)

Qualification procedure to validate material performance behavior on a specific process, equipment and material



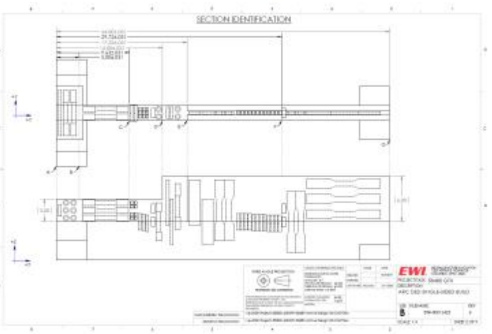
Geometry (Level 2)

Qualification procedure to validate geometric performance for a particular part

Almost any change requires requalification

Program Material Qualification Example

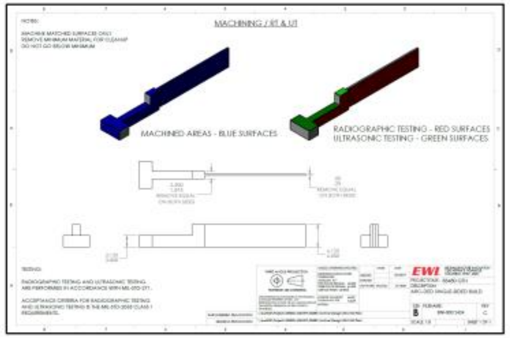
Design



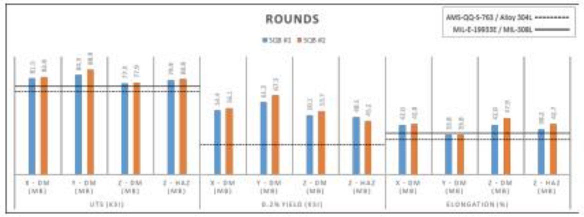
Build

Machine

NDE



Property Test



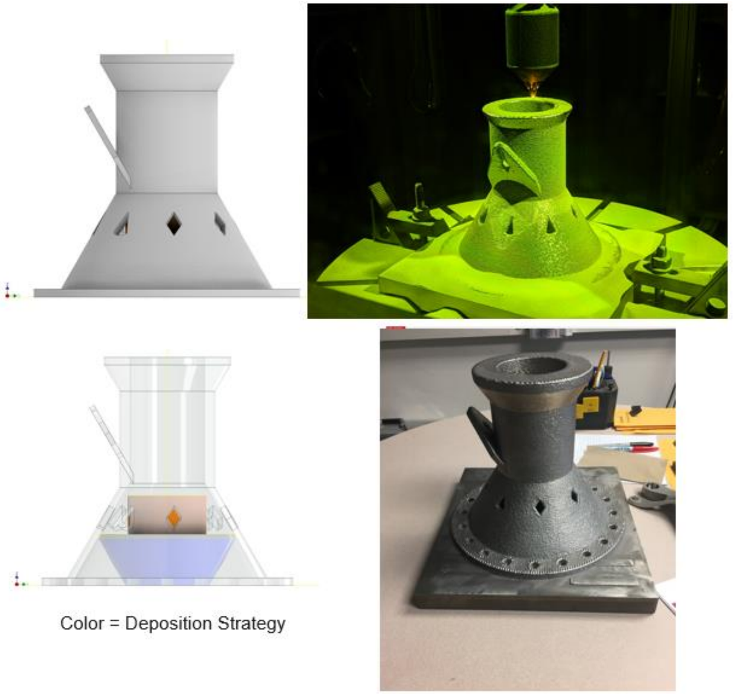
Report

Carney, N., Harwig, D., and Kaputska, N., “Robotic Arc Directed Energy Deposition Additive Manufacturing: GMA-P DED Standard Qualification Builds – Stainless Steel Demonstration”, 2021, NSRP,

Program Material Qualification

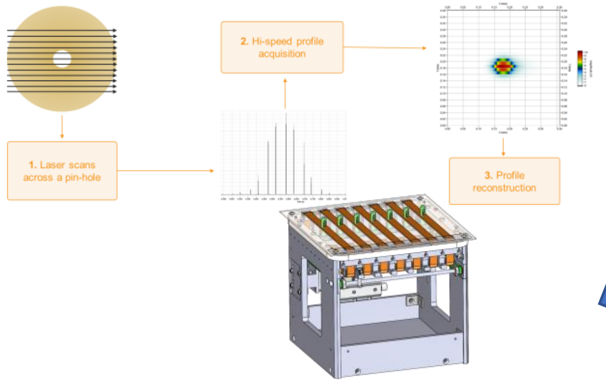
- A particular Materials Technology
- On a particular machine
- With a particular material
- Using a particular material supplier
- With specific parameters

- Achieves a material performance



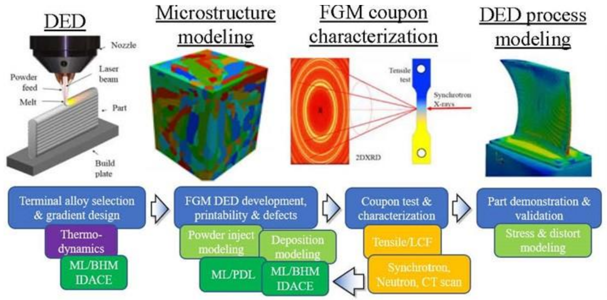
Color = Deposition Strategy

Approach

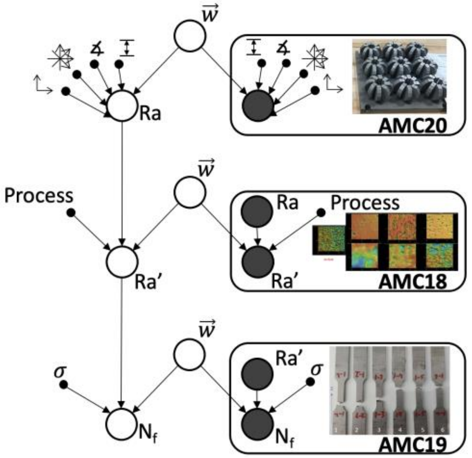


Machine health monitoring

Modeling

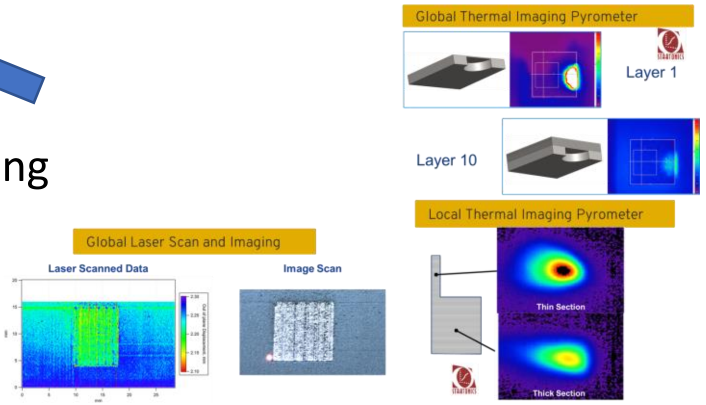


AM Materials Technology



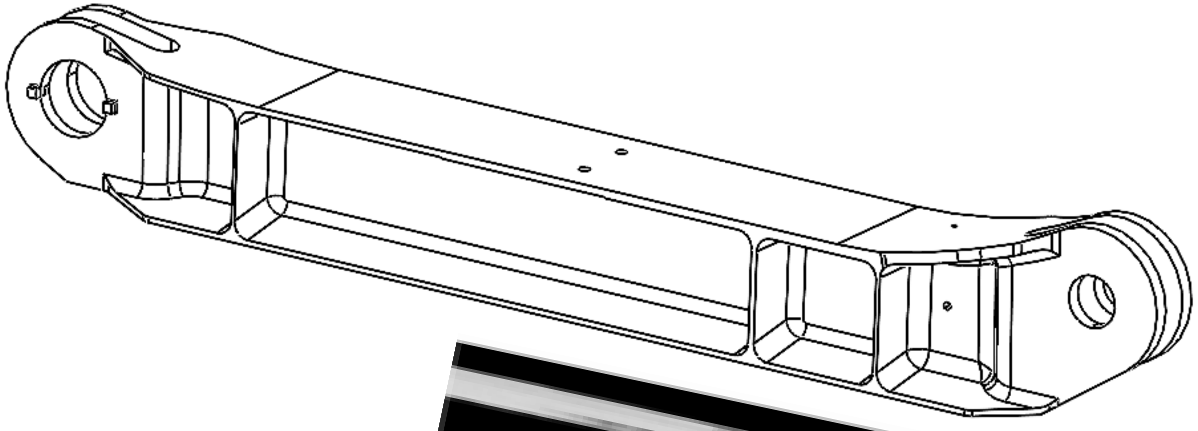
Data science

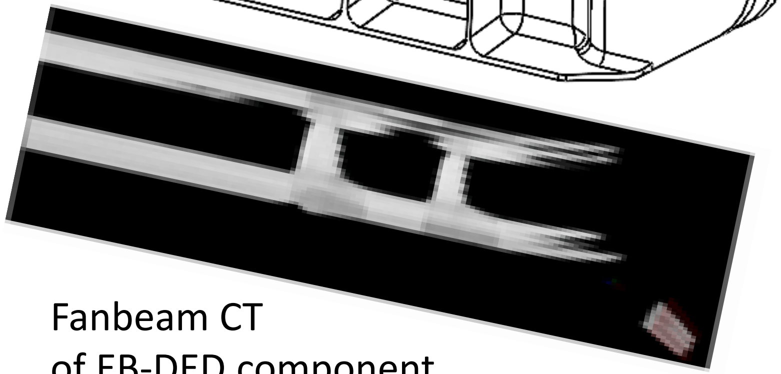
In-situ monitoring



Project Background

- Customer, experienced with EB-DED, identified a potential component for production
- Component was a good fit for EB-DED.
    - Material: Ti-6Al-4V
    - Production volumes in 10s to 100s per year
    - Size ~32 in. long and ~4 in. in cross section
    - High Buy-to-Fly ratio

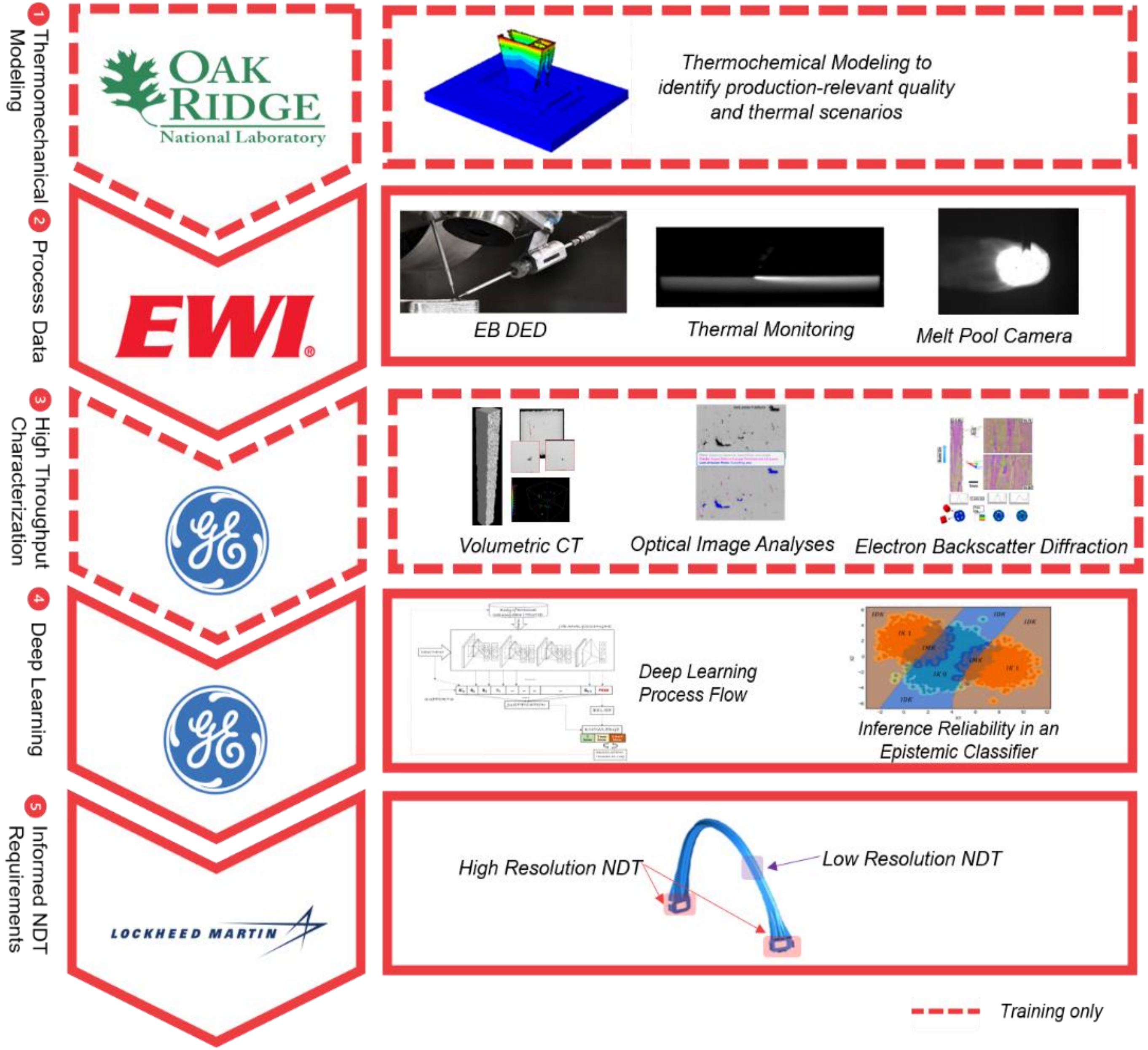




Fanbeam CT
of EB-DED component

Inspection costs were approximately the same as the cost of deposition - making the EB-DED production method cost prohibitive.

How can we gain confidence in process to reduce inspection requirements?



INNOVATIONS

> Enhanced EB DED process monitoring

> Neural network with reliability

> Zone-based informed NDT requirements

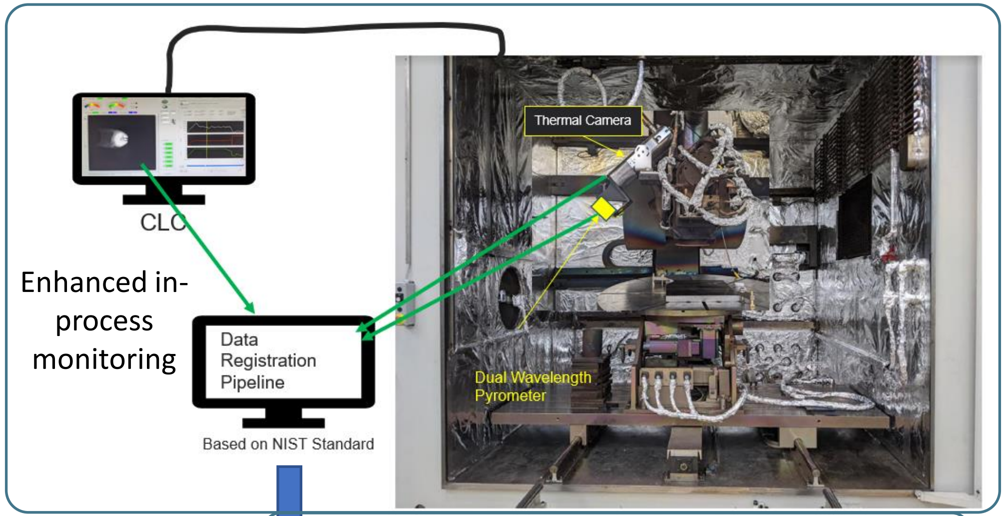
BENEFITS

> Reduced cost of post-process NDT by 25% to 50%

> Reduced NDT cycle time by 12% to 25%

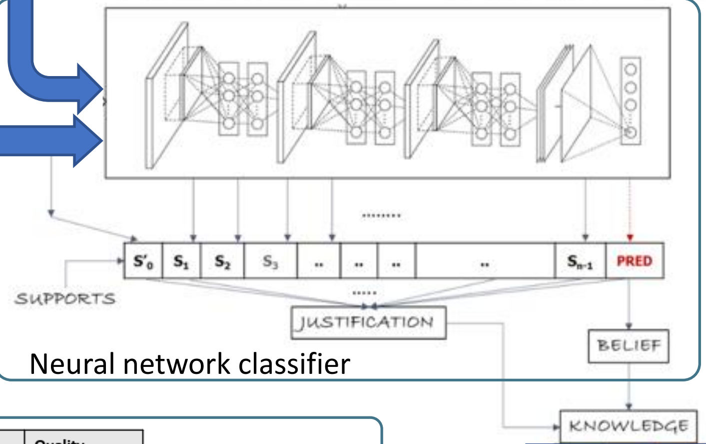
> Improved material utilization by 25% to 50%

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Advanced Manufacturing Office, Award Number DE-EE0009399.

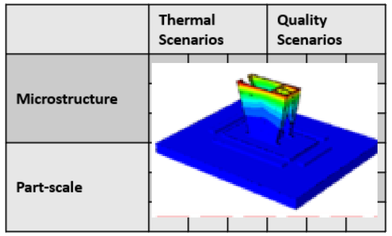


Enhanced in-process monitoring

Critical Success Factors	Metric	Minimum Target	Stretch Target	Baseline Performance/ Cost
Reduce cost of post-process NDT	$/component	-25%	-50%	*100% of highest criteria inspection costs*
NDT cycle time reduction	hrs/component	-12%	-25%	*100% of highest criteria cycle time*
Improved material utilization	lb/component	-25%	-50%	*100% of material utilized by forging process*



Neural network classifier



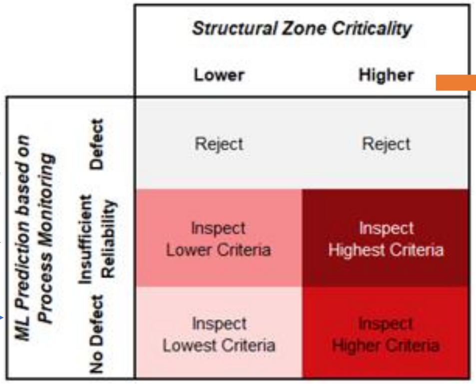
Thermo-mechanical modeling and quality scenario test matrix

Know

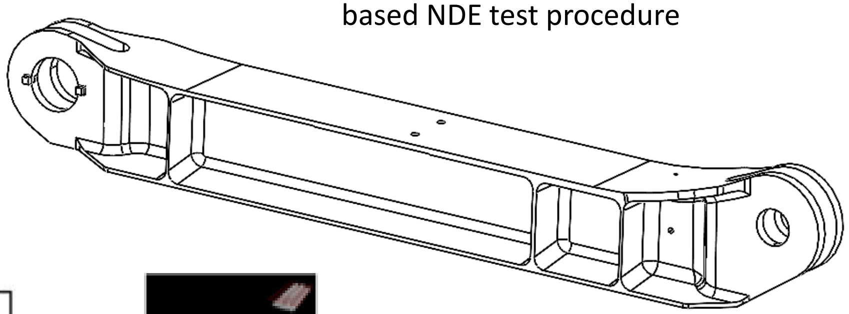
Don't know

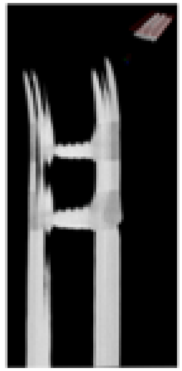
May Know

~$25-50



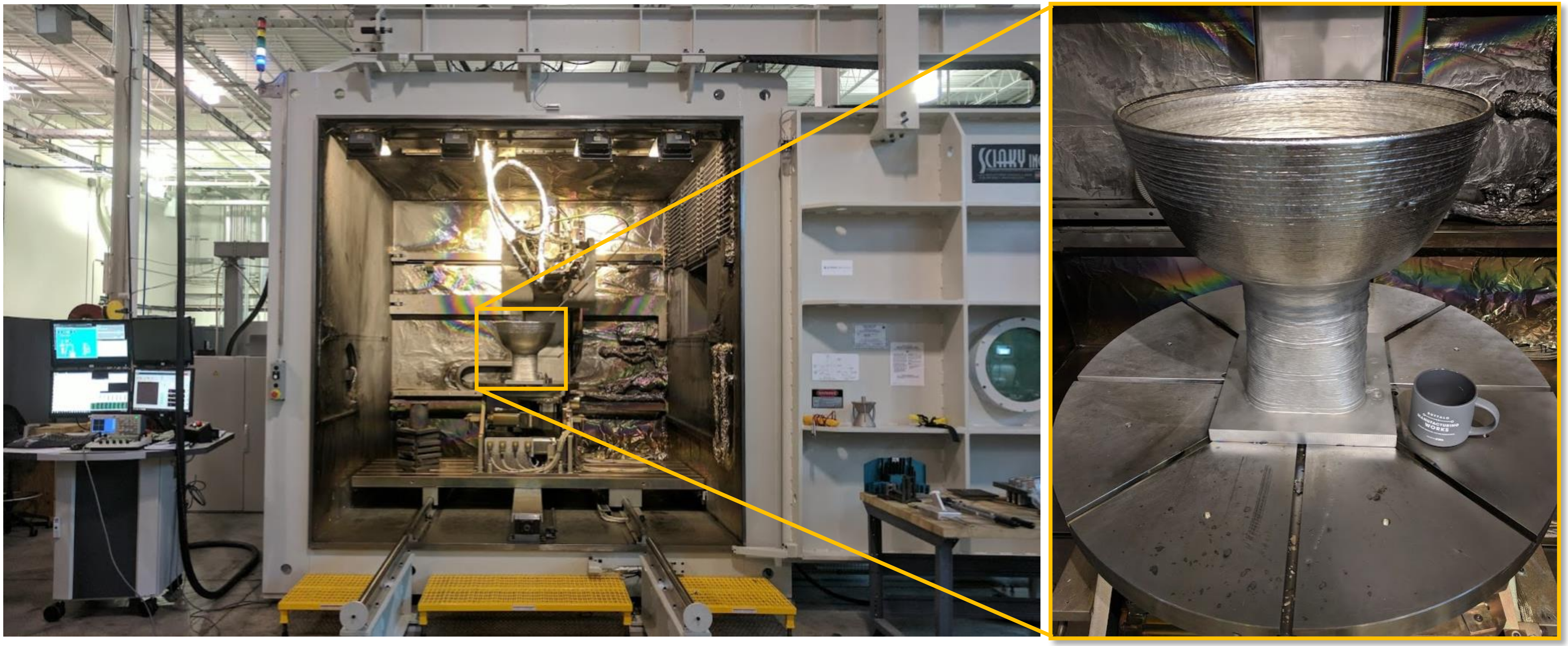
Confidence and criticality based NDE test procedure





~$6500-13000

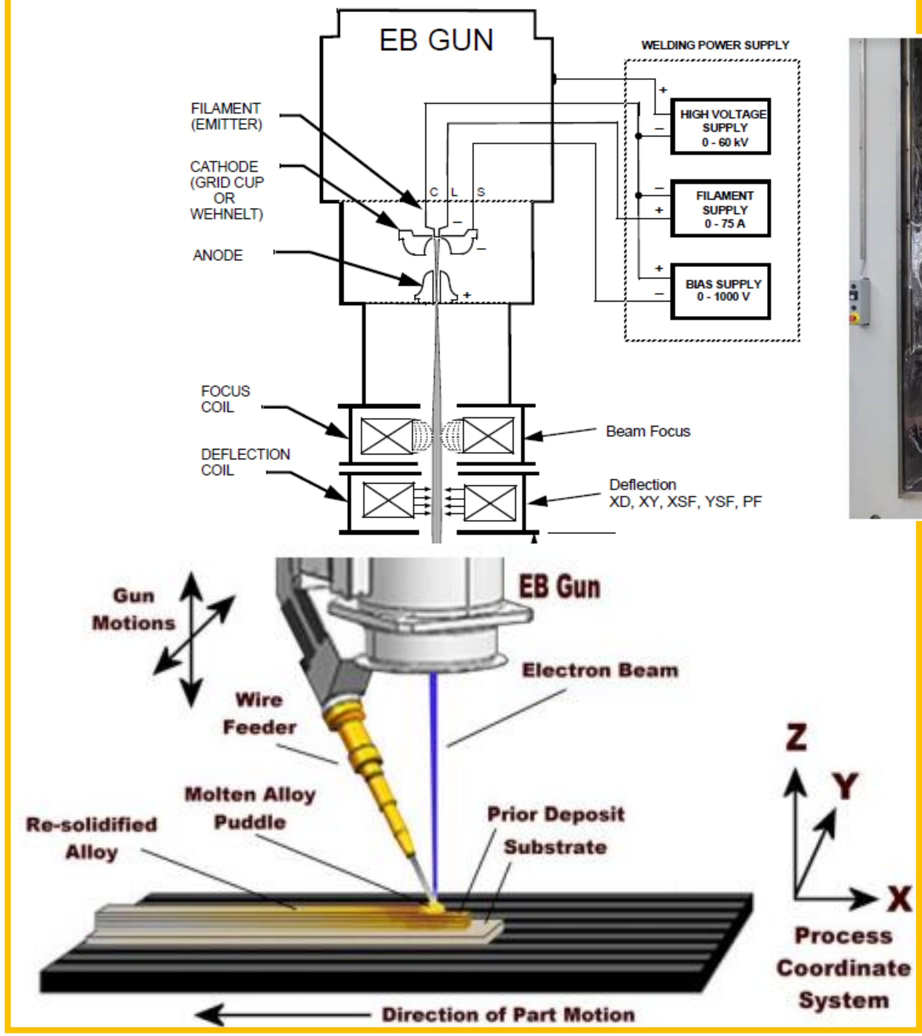
EB-DED Process Overview

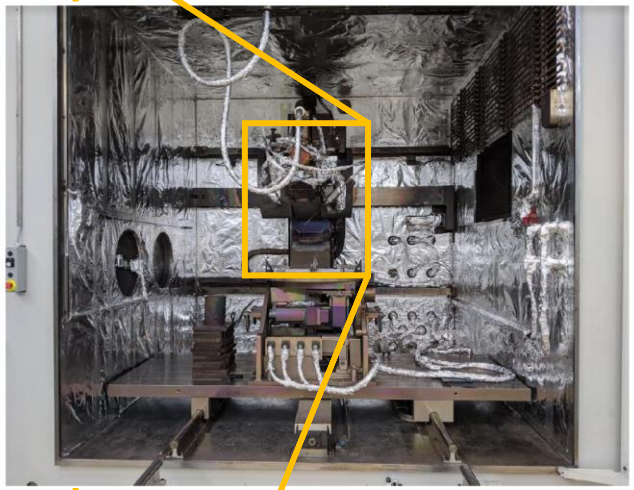


EB-DED Process Overview

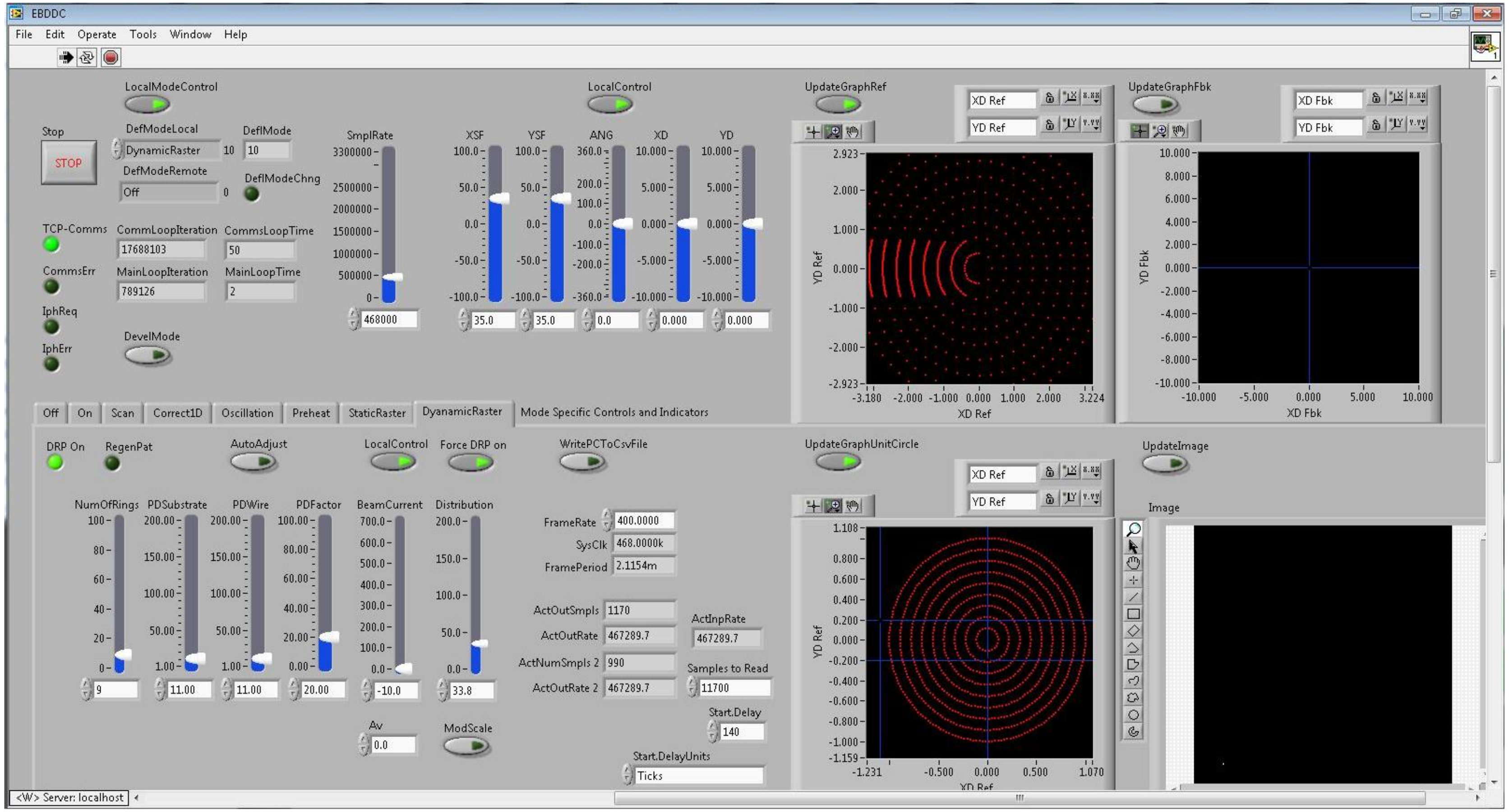
- Focused electron beam produced using high voltage (up to 60kV) and current up to 500mA (30kW)
- Process under vacuum (<100µTorr)
- Beam deflection possible to spread intensity and focus on regions of interest (up to MHz possible)
    - Static raster or Dynamic raster

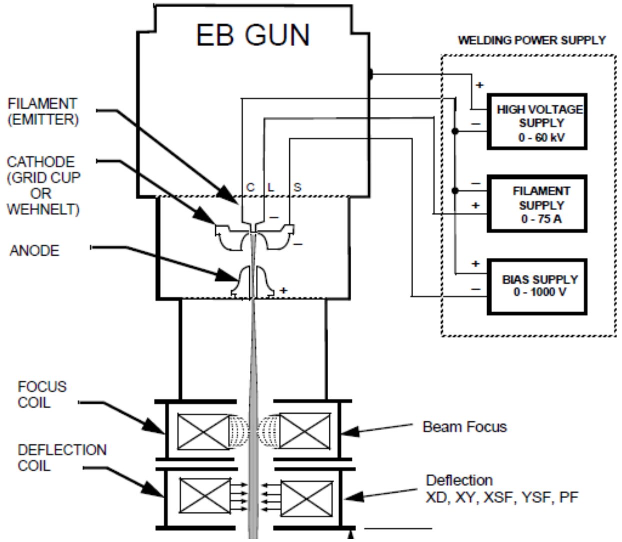
Value Proposition: High cleanliness, high deposition rate (~40lbs/hr), high coupling, high efficiency

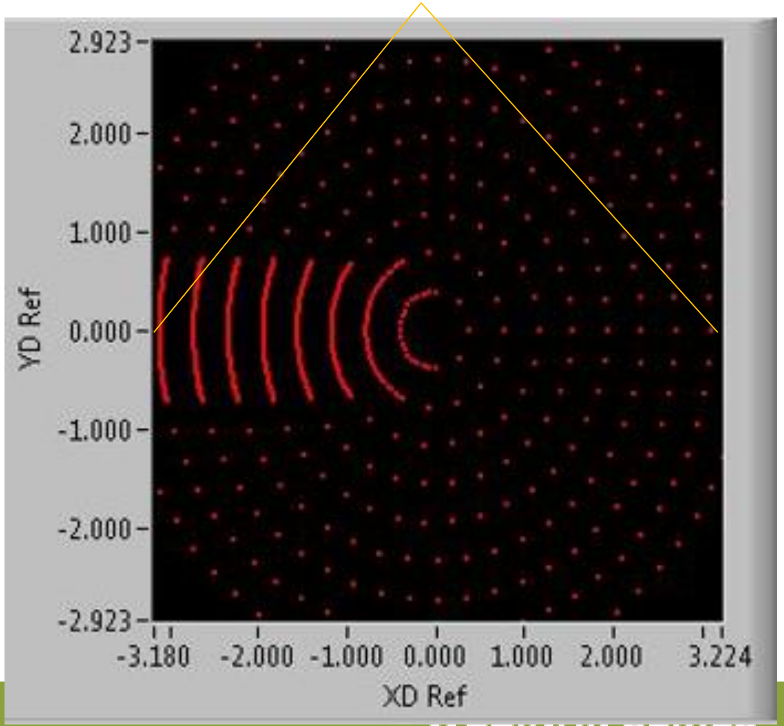




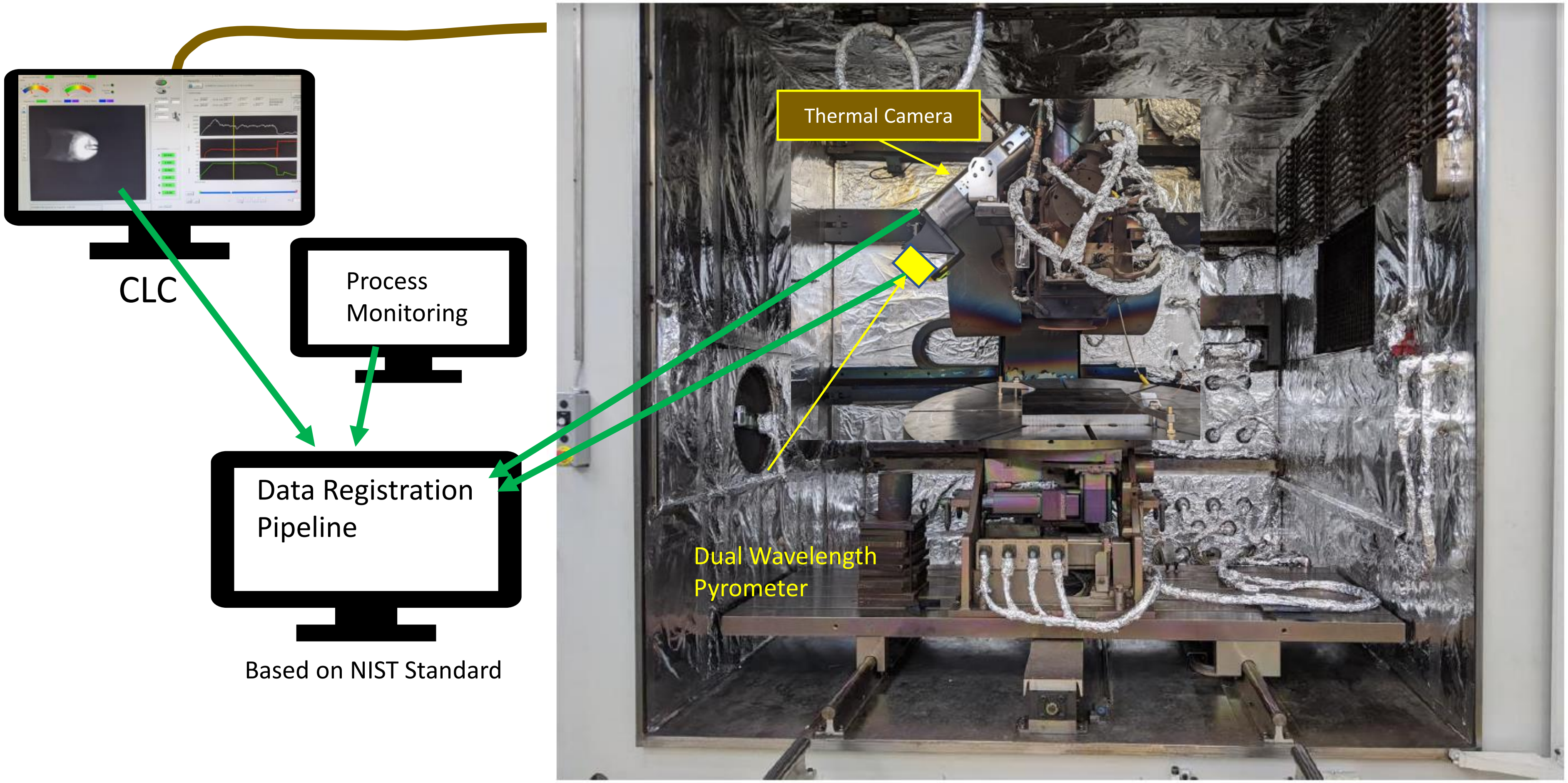
EB Deflection Control







Process Monitoring and Data Registration



Thermal Camera
- Thermal history of additive manufacturing materials

Pyrometer
- Interpass temperature monitoring

Process Monitoring and Data Registration

Ratio Pyrometer

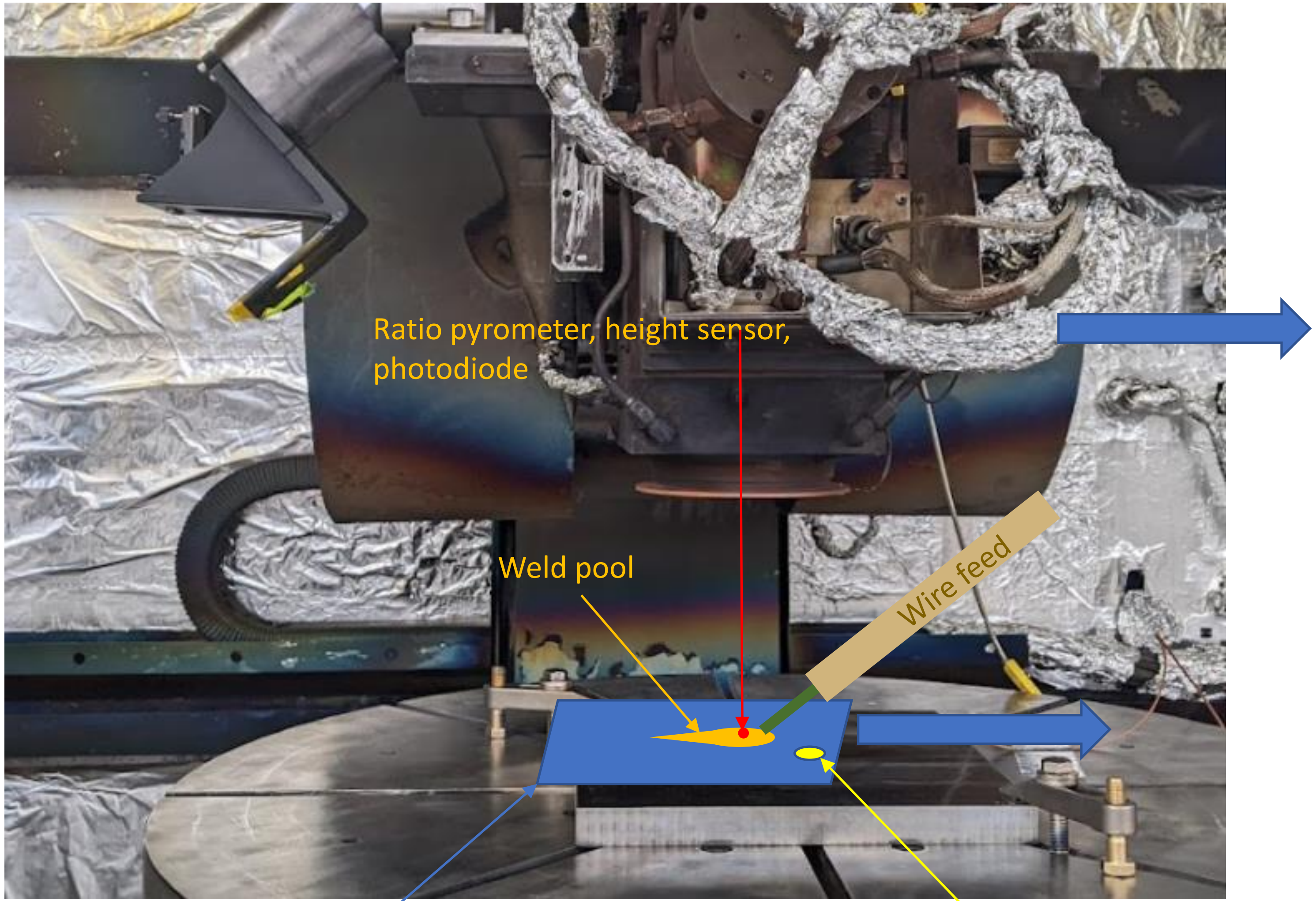
- Weld pool temperature (superheat)

Height sensor

- Time of flight laser sensor to indicate wire position relative to weld pool

Photodiode

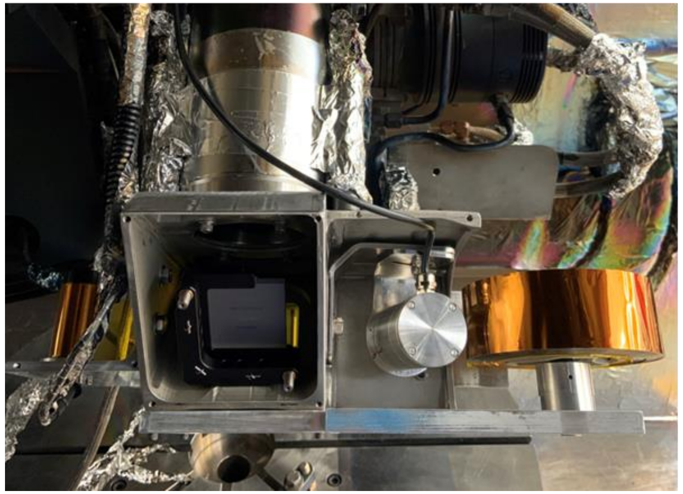
- High bandwidth indicator of process anomalies

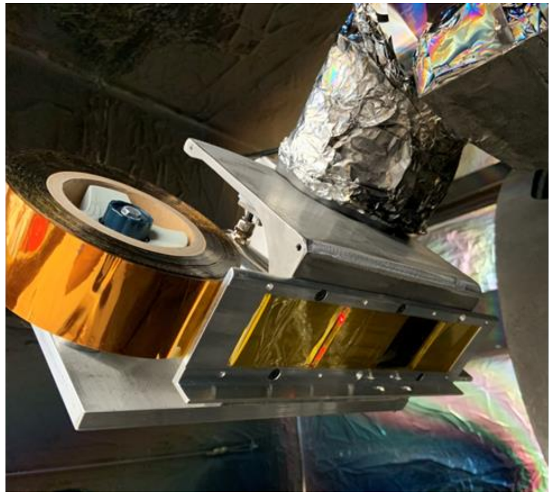


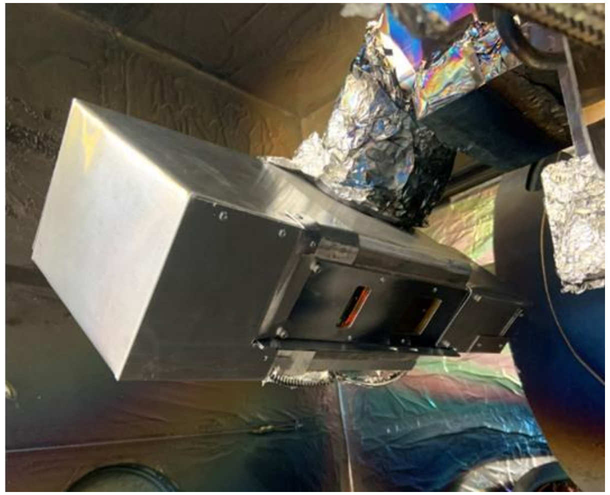
Thermal camera (thermal history, ~150x100mm with ~0.6mm resolvable feature)

Pyrometer (inter-pass temperature)

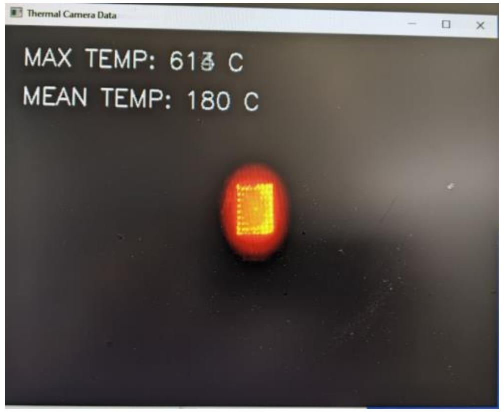
Thermal camera and pyrometer

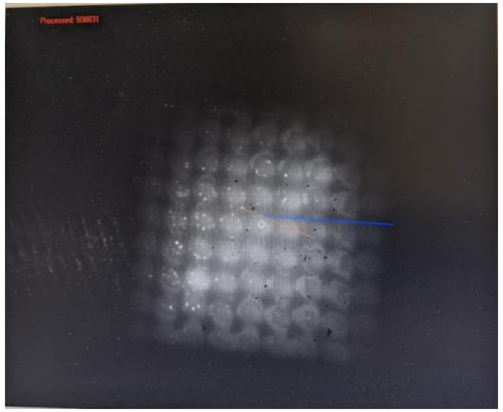






Thermal camera test

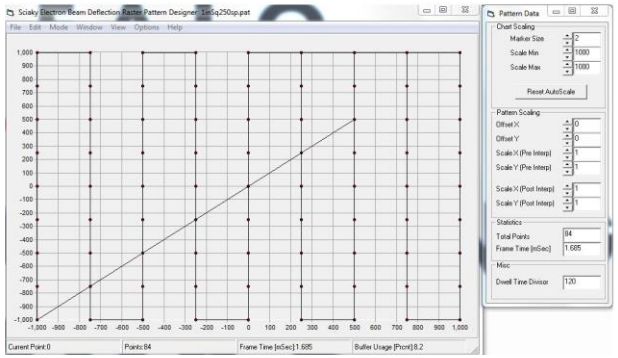




CLC Camera

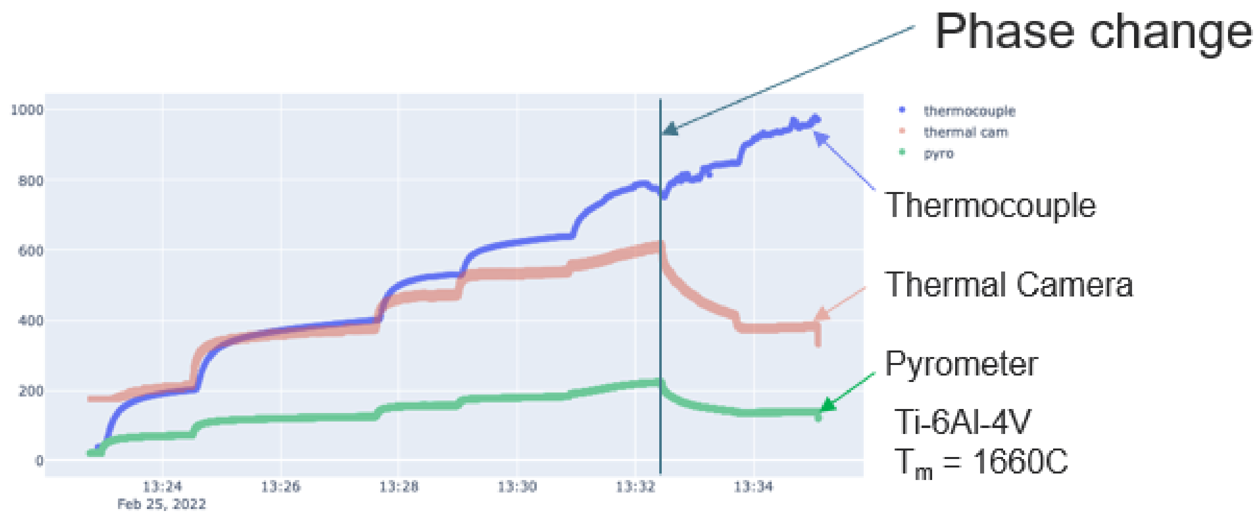
Thermal camera mounted at 45-degree angle

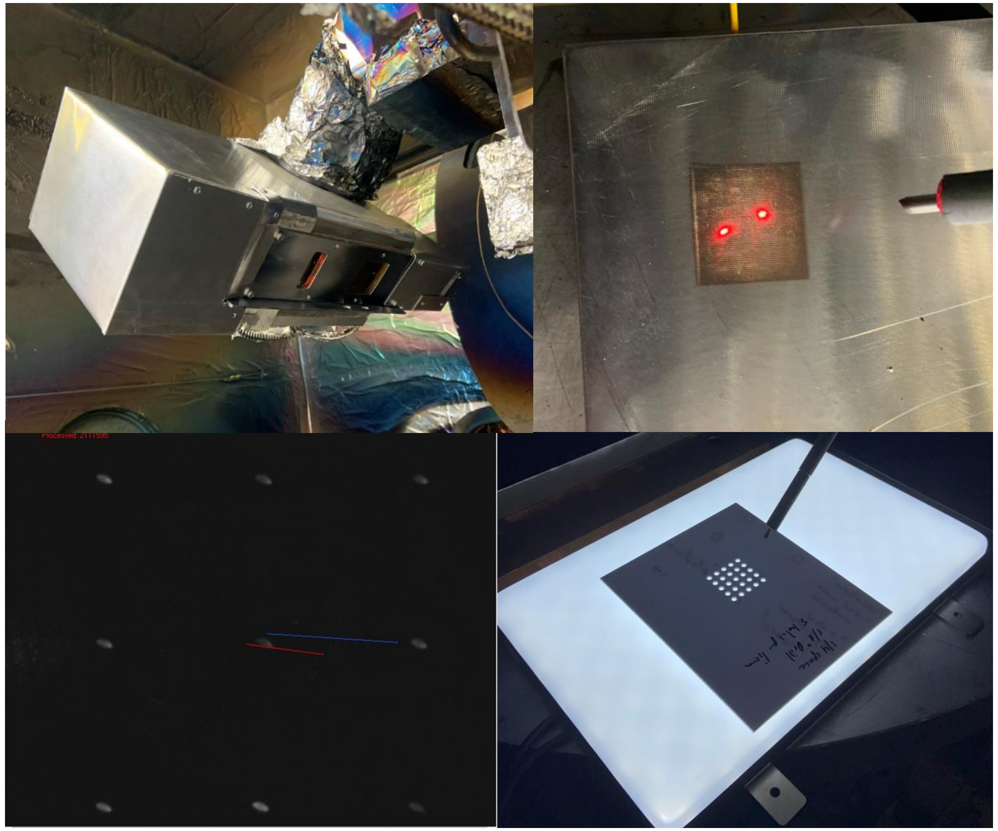
- Protect electronics from radiation
- Add metal vapor protection



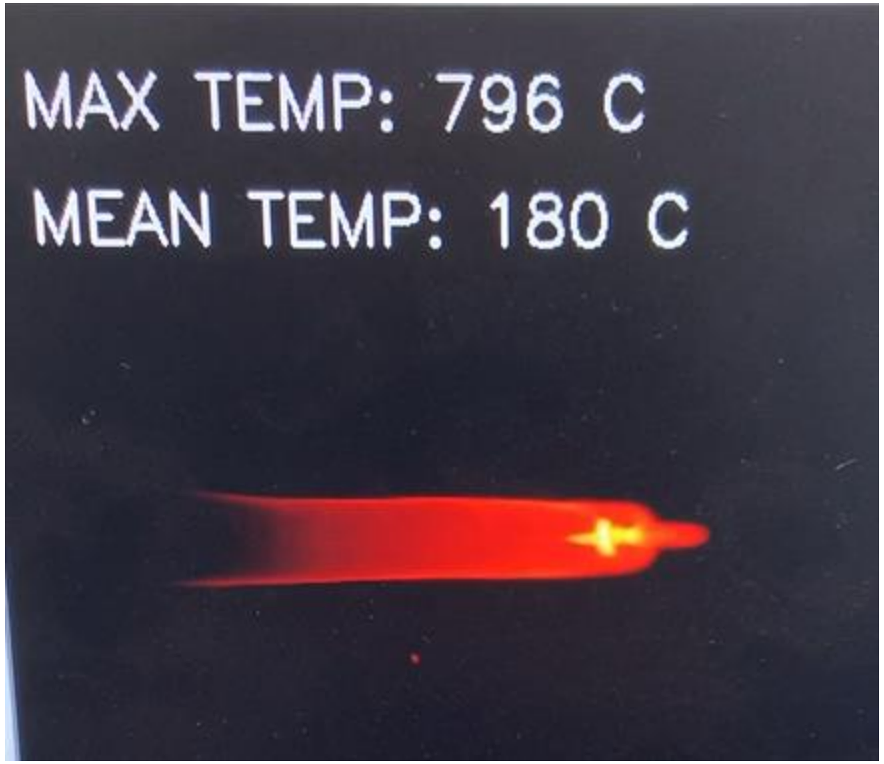
Calibration and Data Registration

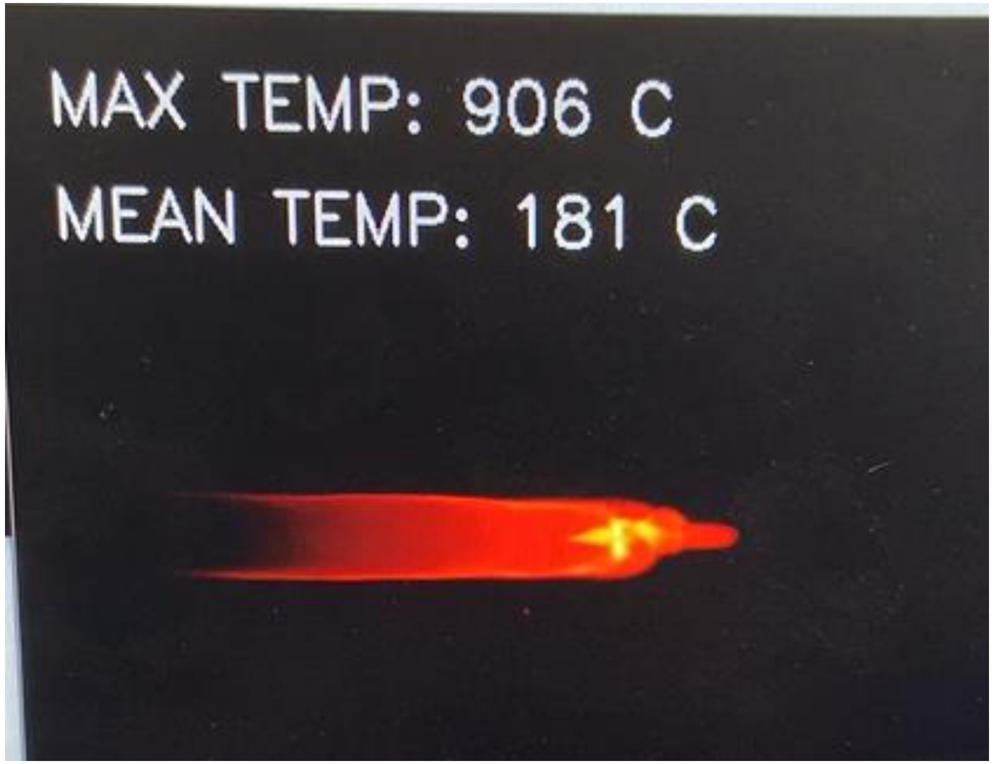
- All process monitoring devices undergo intrinsic and extrinsic calibrations as well as registration
  - Spatial, Temporal and Thermal



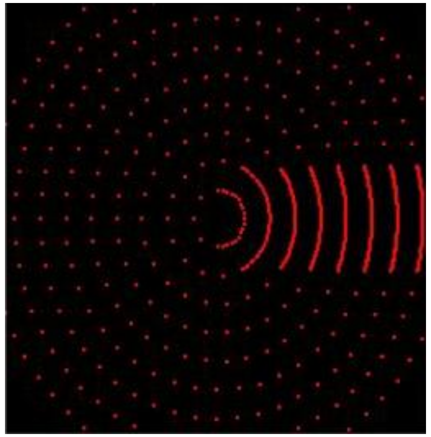


Thermal Camera Images



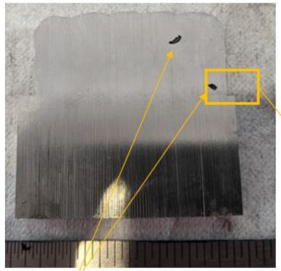


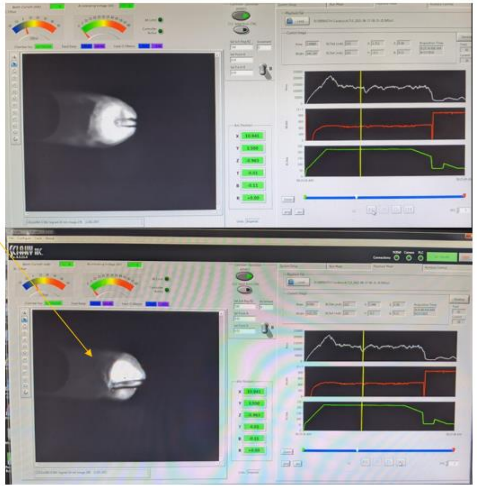
Deflection control system preheating wire



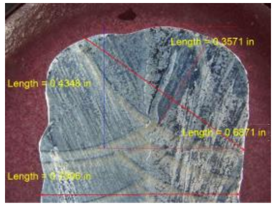
Capturing 640 x 480 pixels at 32Hz with approximate pixel resolution of 0.5mm

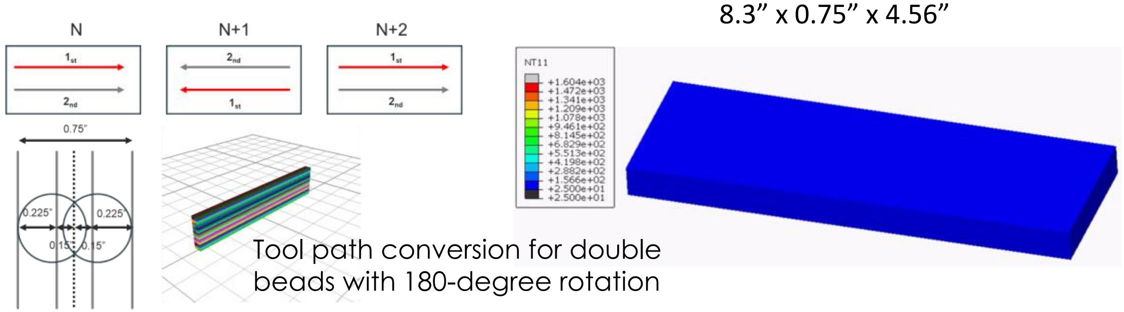
Test Matrix (ORNL)



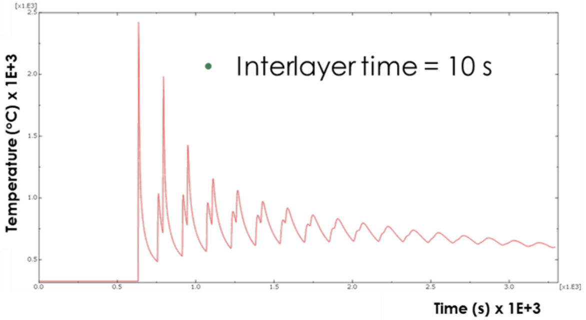


Quality Scenarios

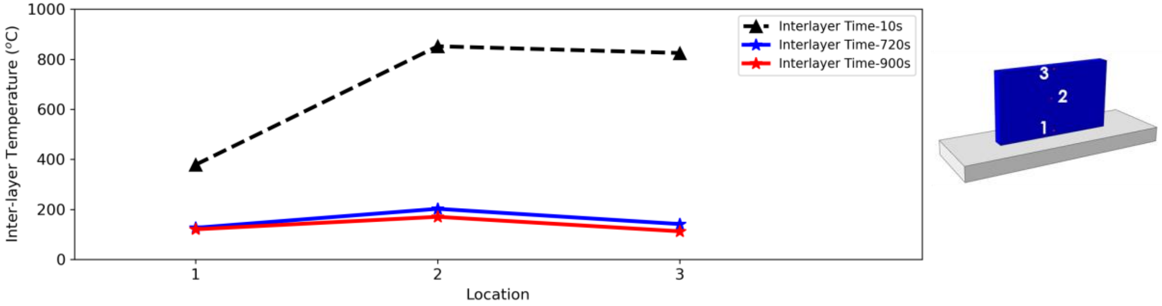




- Melt pool shape
- Temperature Profile



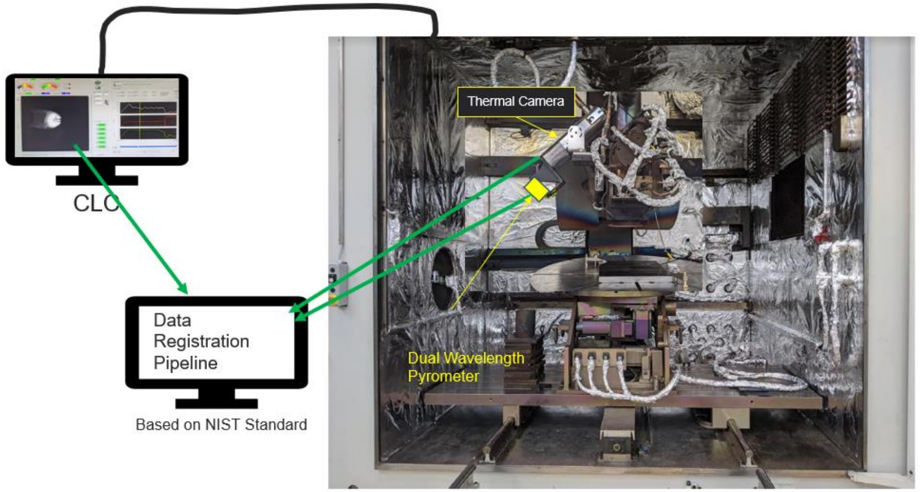
- Demonstration of inter-pass temperature at various interlayer time



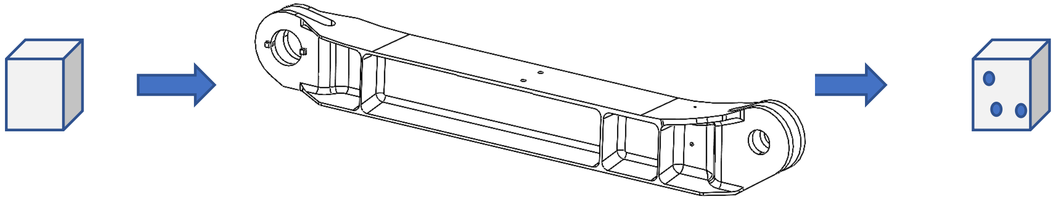
Courtesy: Yousub Lee and Matt Bement, ORNL

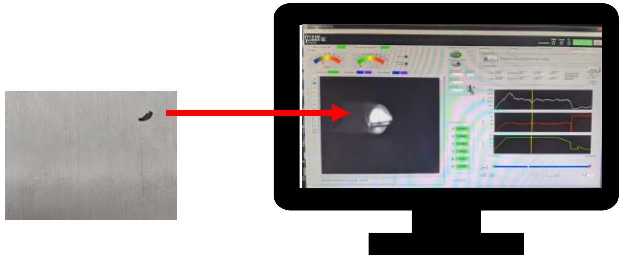
Initial Training Data Generation

- Data capture validation
- Full-scale drop-link - validate production relevance of test matrix
- Test coupons with embedded defects
- High throughput characterization used to label in-process monitoring data set based on pores >0.25mm
- Training Data Set with > 100 defects >0.25mm diameter
- Neural network classifier

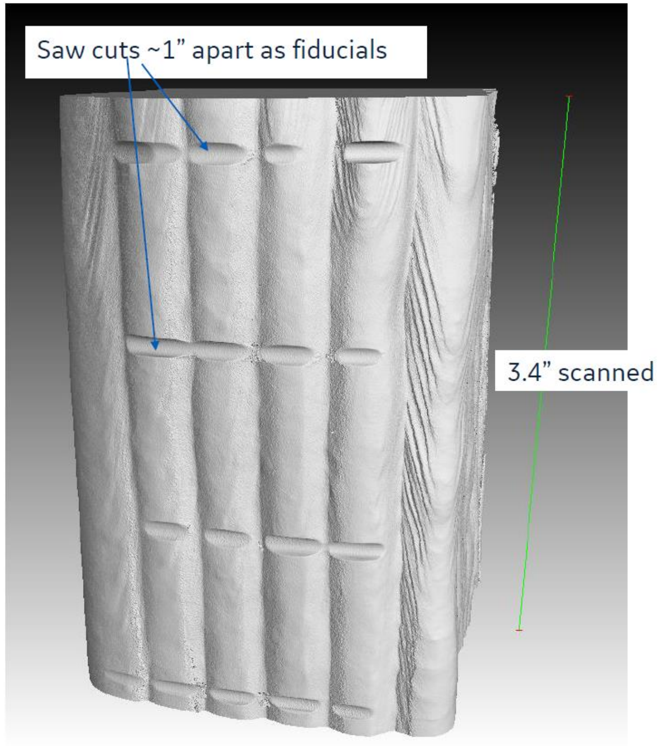


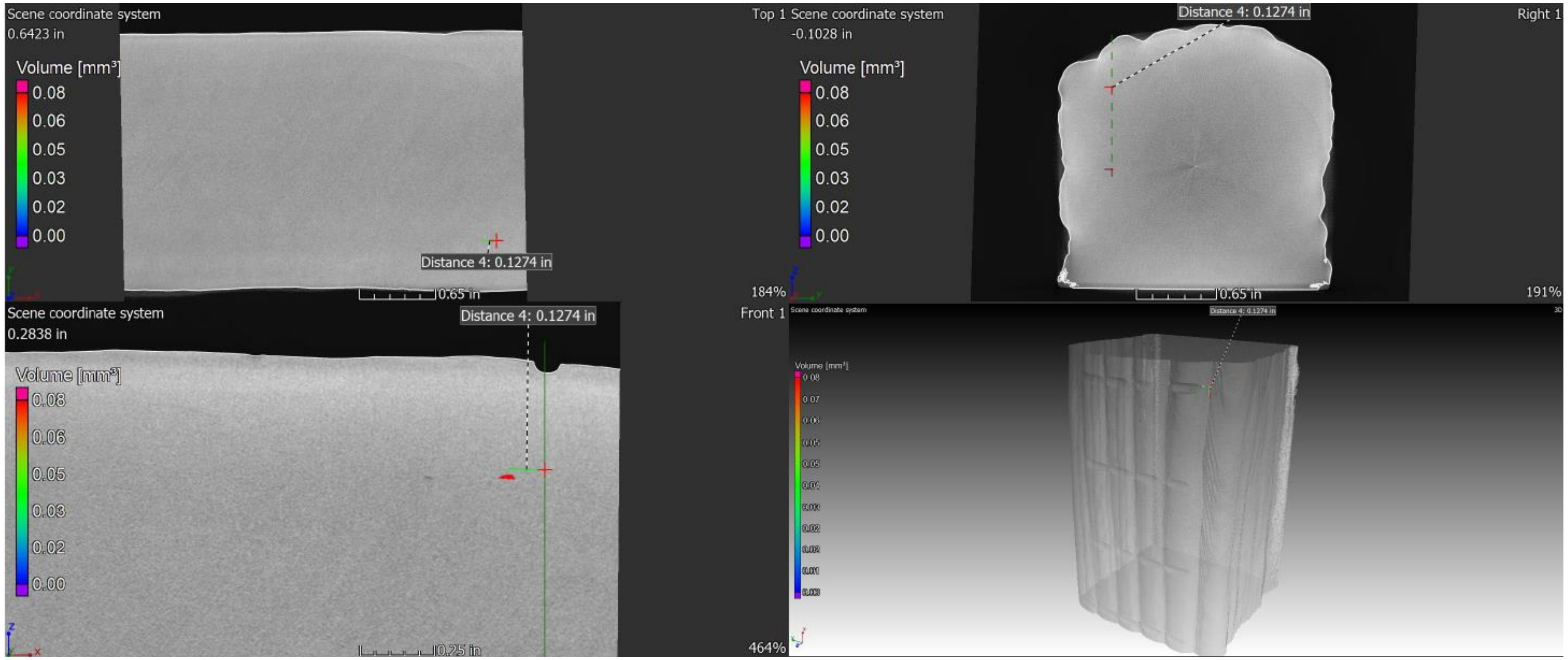
Produce:





High Throughput Characterization





Defect detection through 2in Ti-6Al-4V is approximately 135µm, target defect size = 250µm

Courtesy Naresh Iyer and Dan Ruscitto, GE Global Research

Summary

- Qualification of metal AM parts is advancing but significant barriers remain:
  - Standards development needs to continue to gain momentum
  - Rules (procedures and best practices) need to be shared more freely
  - Certification bodies are making progress, but a lot of work remains
  - Process is expensive and results in a static procedure in a rapidly advancing technology
  - Qualification process is linear – qualification needs to be performed for each machine, material vendor, material, etc. and may need to reperformed for changes in procedures, moving machines, etc.
- New methods of process monitoring with modeling, machine health monitoring and data science methods may prove essential in reducing qualification burden

Acknowledgement and Disclaimer

- **Acknowledgement**: This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Advanced Manufacturing Office, Award Number DE-EE0009399.

3D METAL PRINTING EXPERIENCE

WEBINAR SERIES

Thank you!

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