In-situ Data Analysis and Tool Development for Additive Manufacturing Metal Powder Systems

DE-EE00032038
SLAC, LLNL Ames
Q3FY16-Q4FY17

Christopher J. Tassone, SLAC National Accelerator Laboratory

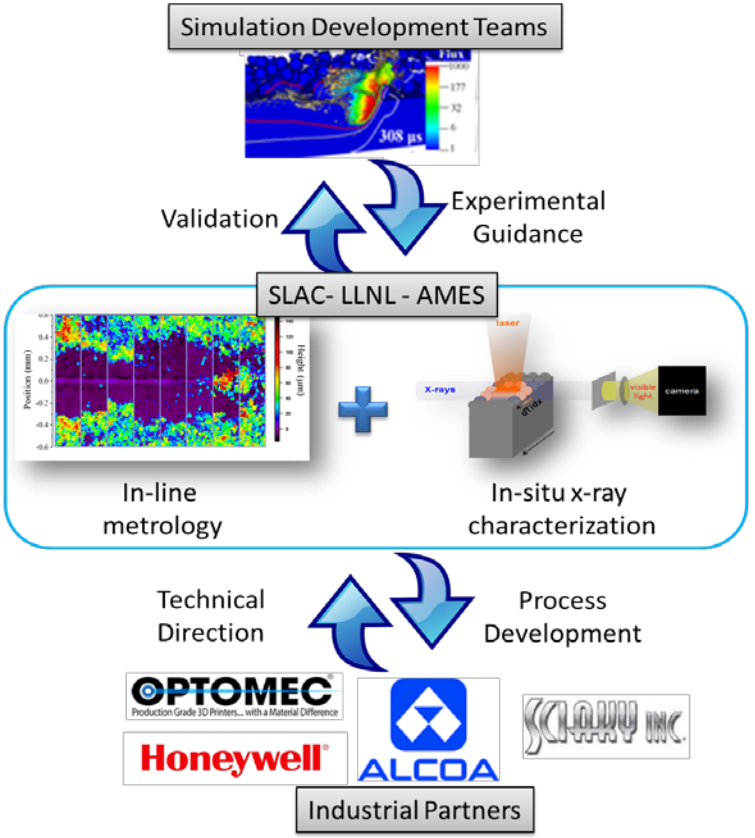
U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 13-14, 2017

Project Objective

Goal: Accelerate adoption of AM for metallic components by developing advanced AM testbed to enable rapid process development and qualification of the AM components

Problem Statement: Current models are inadequate for processing design and limit wide spread adoption of AM.

- Experimental observations are needed to vet existing models and identify new physical processes.

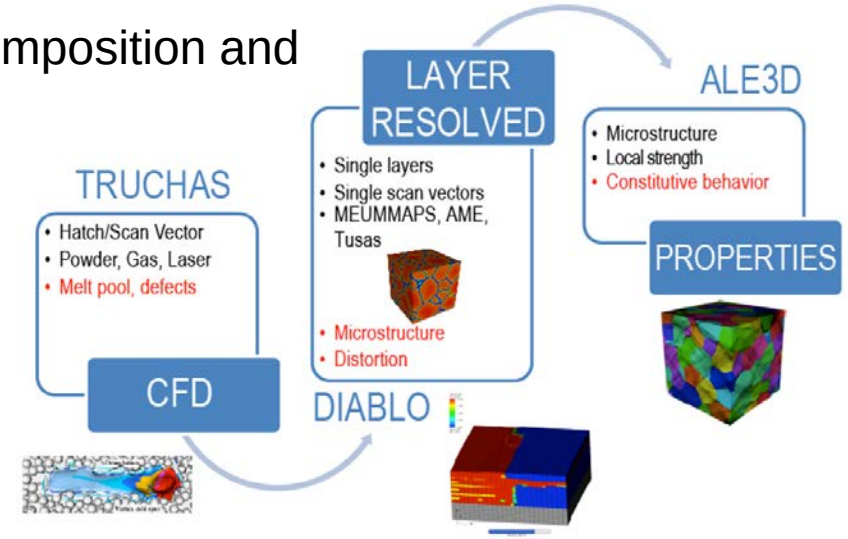


Challenges: Mutli-modal measurements at high spatial and temporal resolution.

- High energy X-Rays and in-line metrology integrated into process simulation tools with near-real time feedback.

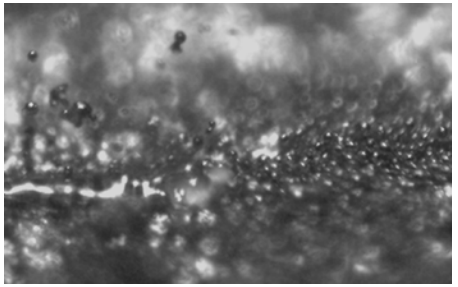
Technical Innovation

AM processing parameters and evolution of composition and microstructure are not well understood.

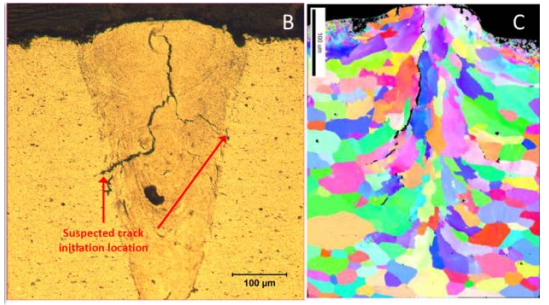


- Current models lack validation, poorly link processing parameters to build

- Current in-situ probes are surface sensitive and limit visualizing melt pool shape, porosity, and structural evolution, internal strain

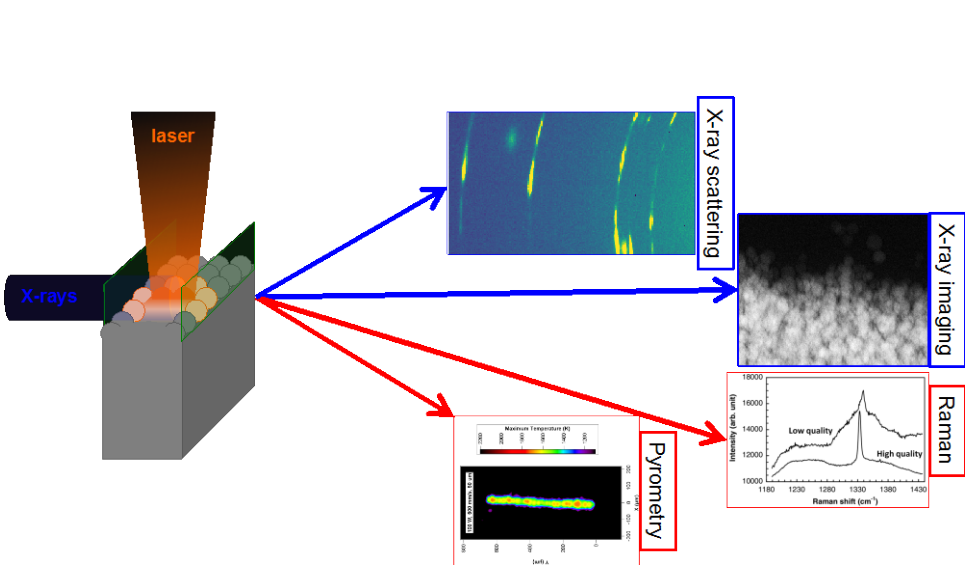


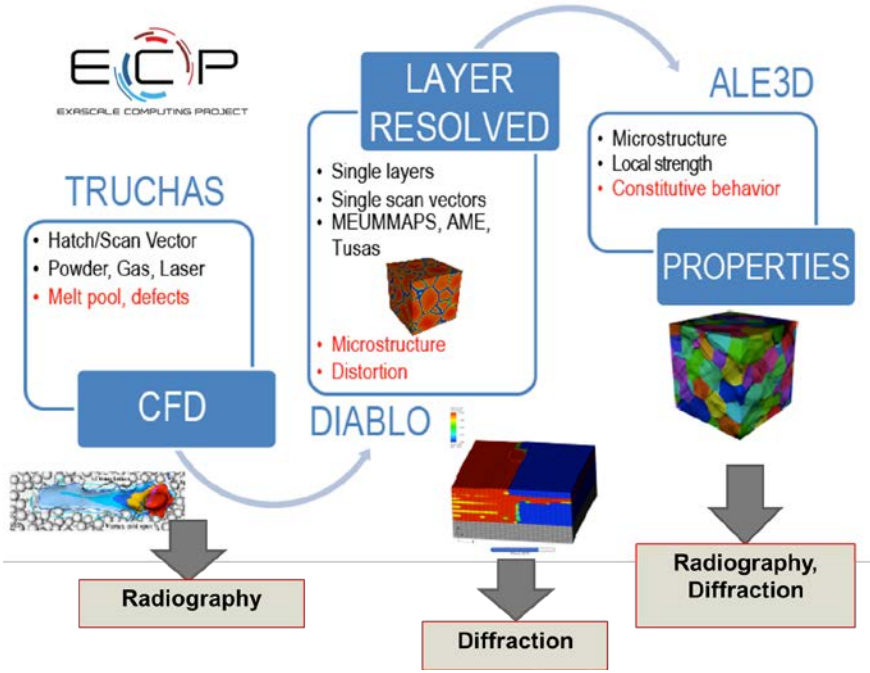
- Ex-situ cannot measure dynamics which lead to final microstructure



Technical Innovation

- In-situ X-ray characterization **coupled** to in-line metrology (e.g. ultra-fast imaging, pyrometer…) to create a testbed system for advancing AM processing.
  - Validate, inform and improve process modeling.
  - Accelerate process development.

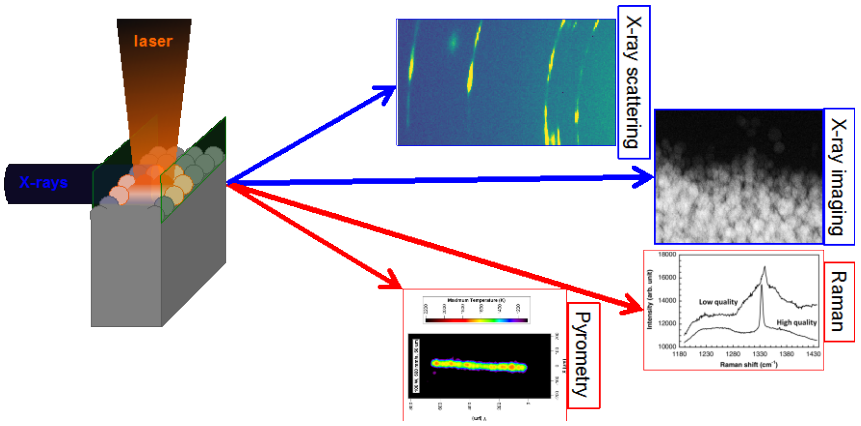


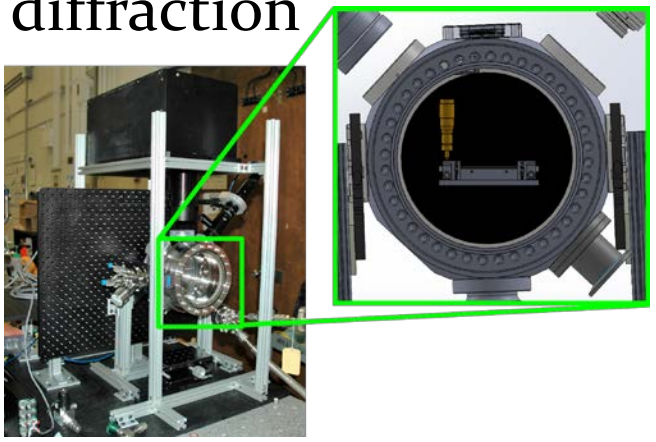


Actively engage AM community

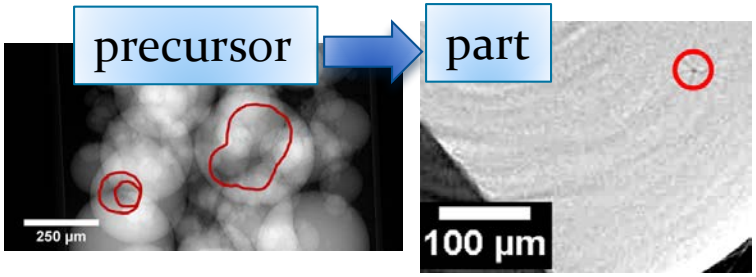
Technical Approach

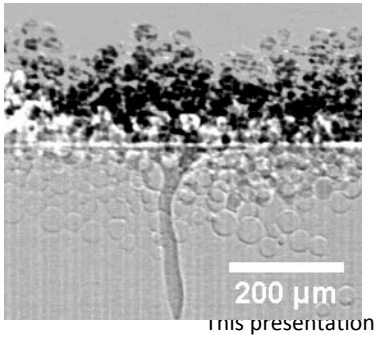
- Develop and deploy AM testbed system
  - Compatible with x-ray imaging and diffraction

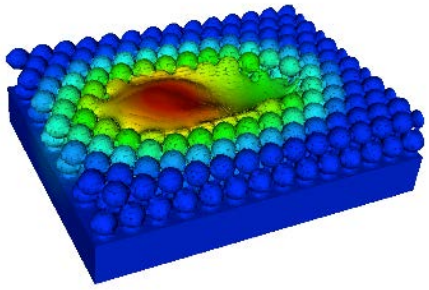


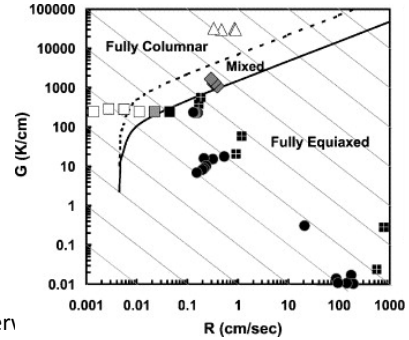


- Demonstrate value to end users
  - Relate precursor to build quality
  - Vet existing simulations



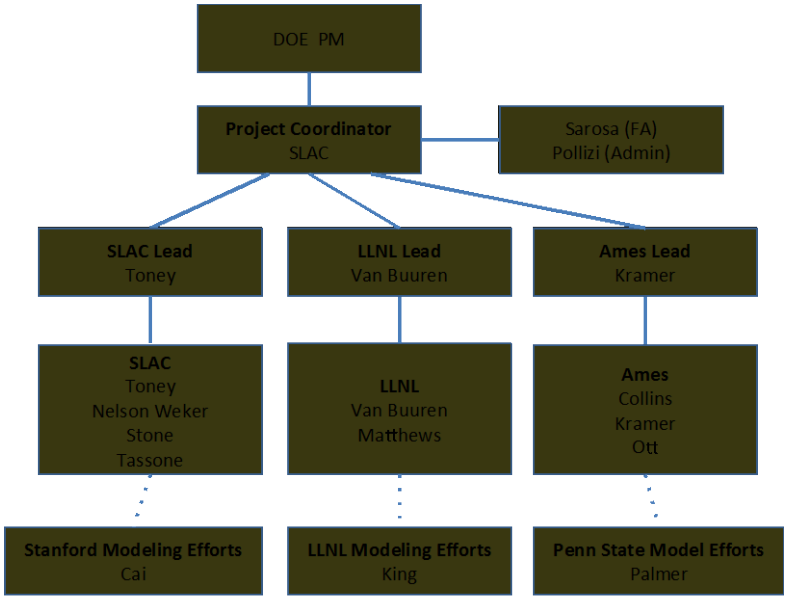






Technical Approach

- **SLAC:** lead implementation of in-situ X-ray probes
  - implement X-ray imaging - kHz & 1µm
  - implement X-ray diffraction - kHz & 50µm
  - industrial outreach and for coordinating the executive council
- **LLNL:** lead design, construction, testing in-situ X-ray selective laser melting chamber
  - Package x-ray characterization data for comparison to simulation
  - Actively engage with industry and America Makes partners to ensure that test bed capabilities and experimental campaigns align well with industry needs

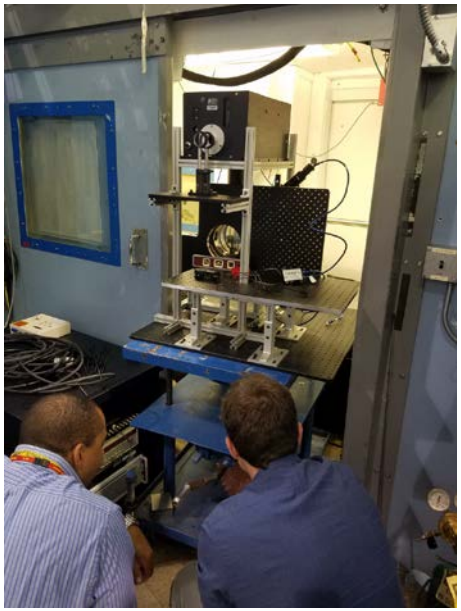


Dashed lines indicate that experimental data shared

- **Ames:** lead characterization of Ti-6Al-4V powder and design of directed energy powder feed system for in-situ x-ray studies
  - Lead planning and executing AM community workshop to prioritize the experiments that are perceived to be the greatest need by the AM community.
  - Actively engage with industry and America Makes partners to ensure that test bed capabilities and experimental campaigns align well with industry needs

Transition (beyond DOE assistance)

Goal: create a self-sustaining user facility for industrial partners to speed up AM process development



Targeted industrial partners include all stakeholders:

- Feedstock suppliers
- OEM Venders
- Industrial and government end users
- Modeling groups: Industry, Universities, National Laboratories

Industrial End Users	Material Suppliers	AM OEM Vendors	Software Developers
Honeywell	Alcoa	Sciaky	ITI
GE Aircraft Engineers	ATI	Optomec	UES
Boeing	Praxair	Government Users	ThermoCalc
Pratt & Whitney	Crystal Metal Powder	NASA	QuesTek
John Deere	Ametek	Air Force Research Lab	
Queen City Forging		Army Research Lab	
Quad City Manf. Lab		Oak Ridge National Laboratory	

Measure of Success

- Enable model validation
  - Rapid AM deployment through informed qualification
  - Model driven process optimization
    - Advance existing model accuracy through experiments
- Expedite process development
  - Rapidly map process parameter space for new precursor materials and advanced alloys
    - Provide process parameter maps for new alloys to AM community
  - Reduce material discovery to component deployment
    - Quantify process development time with toolset utilization and benchmark against existing practices
- Accelerate adoption of additive manufacturing for metallic components across the manufacturing sector

Project Management & Budget

Task 1 Guiding toolset and experimental design through community engagement

✓ Organize workshop with participation from at least ten companies and three simulation groups (Q1Y1)

✓ Outlining and prioritizing experiments desired by the theory and simulation communities (Q1Y1)

Task 2 Development of AM testbed system

- Establish the validity of single layer system for understanding defect formation (Q4Y1)
- Package x-ray data for comparison to simulation (Q4Y1)

Task 3 Flexible multilayer test for in-situ AM

✓ Design powder spreader coupled to single layer powder test bed for in-situ x-ray studies (Q2Y1)

- Design powder feed system for in-situ x-ray studies (Q4Y1)

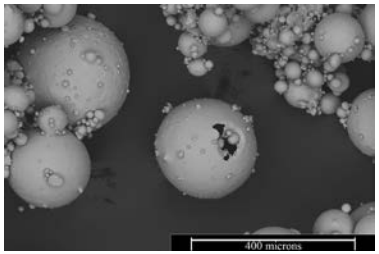
Task 4 Relate microstructure of precursors to build quality

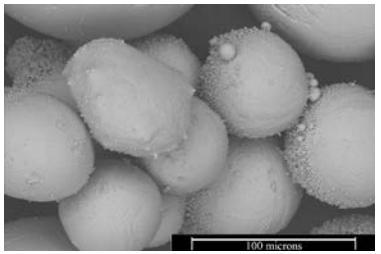
- Analyze size/morphology distribution, tap density, chemical compositions, flow characteristics of feedstock powders (Q3Y1)
- Ex situ x-ray, SEM/EBSD characterization of bed/feed printed materials using analyzed feedstock powders (Q4Y1)

Total Project Budget	
DOE Investment	$3,500K ($2,000K FY17, $1,500K FY 16)
Cost Share	$0
Project Total	$3,500K

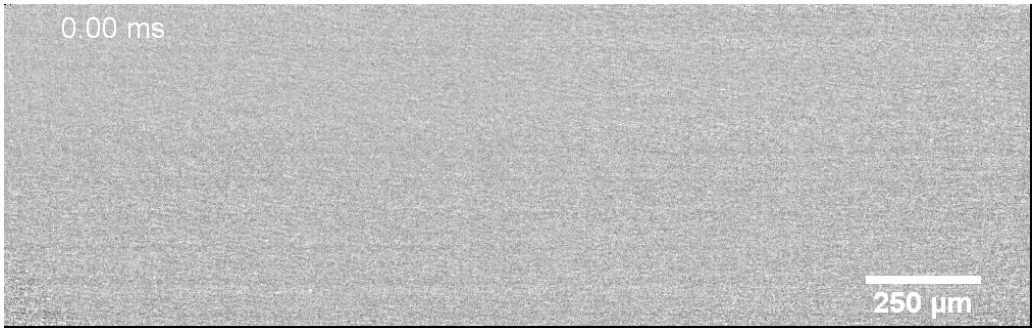
Results and Accomplishments

- Q3Y1 Results
  - ☑ System commissioned
  - Precursor quality analysis – in progress
  - In-situ diffraction – in progress
  - Compare to simulation – in progress
  - Correlate to in-situ pyrometry – in progress

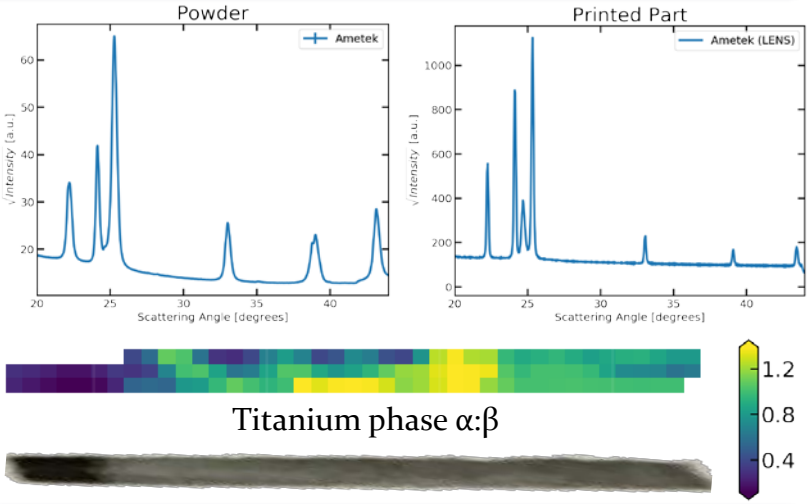




Assessing industrial supplied precursor



In-situ 4 KHz X-ray Microscopy



Phase evolution from precursor to part

Go:NG:Evaluate the fidelity of x-ray scattering by demonstrating the ability to achieve a spatial resolution of < or = 50 microns and a frequency of >1 kHz during AM processing of Ti64 powder. Evaluate fidelity of x-ray microscopy acquisition by demonstrating the ability to achieve spatial resolution of < or = 2 microns and a frequency of >1kHz during AM processing of Ti64 powder