



MANUFACTURING  
DEMONSTRATION  
FACILITY

# The MDF Digital Factory Project

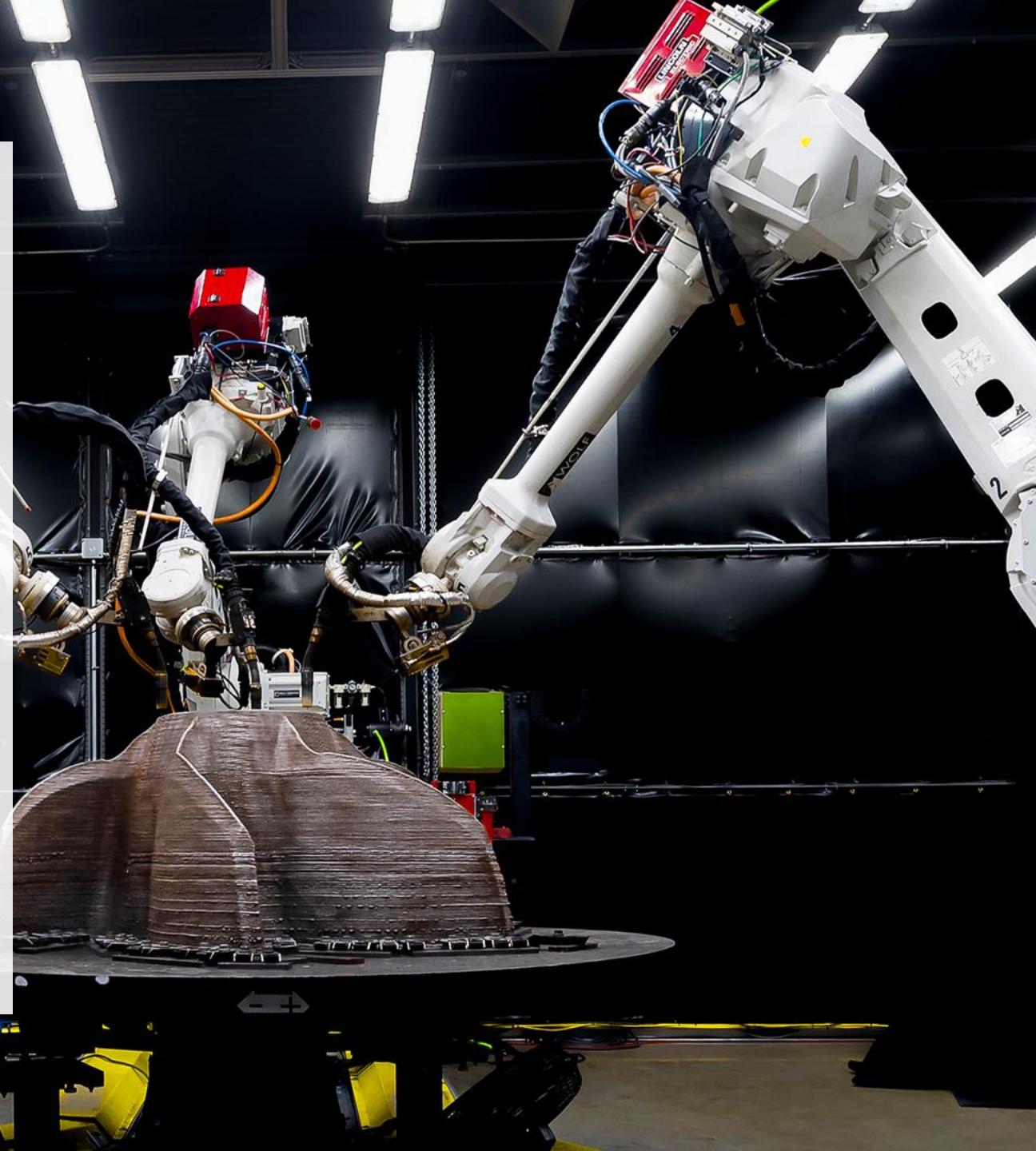
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Vincent Paquit

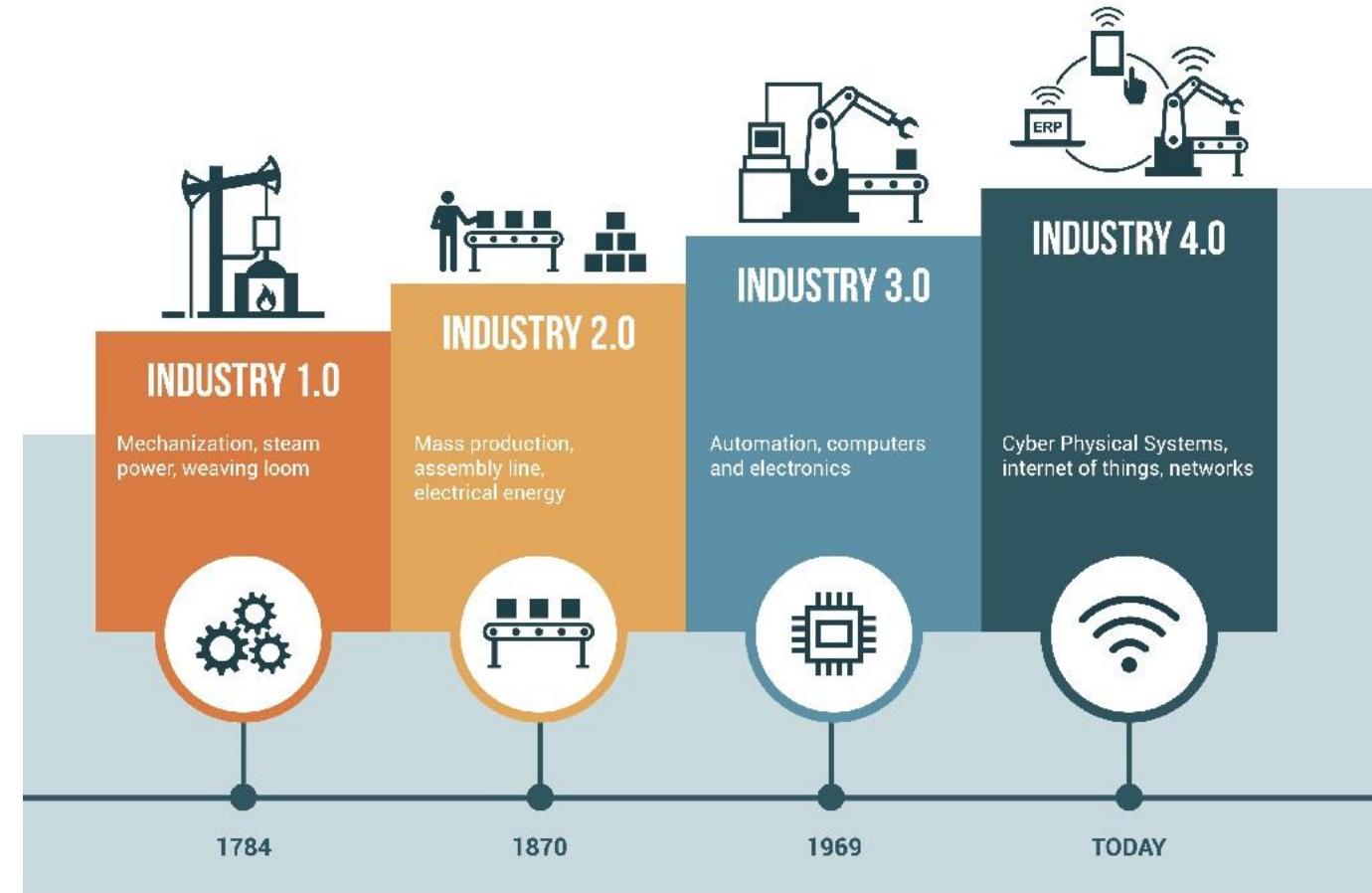
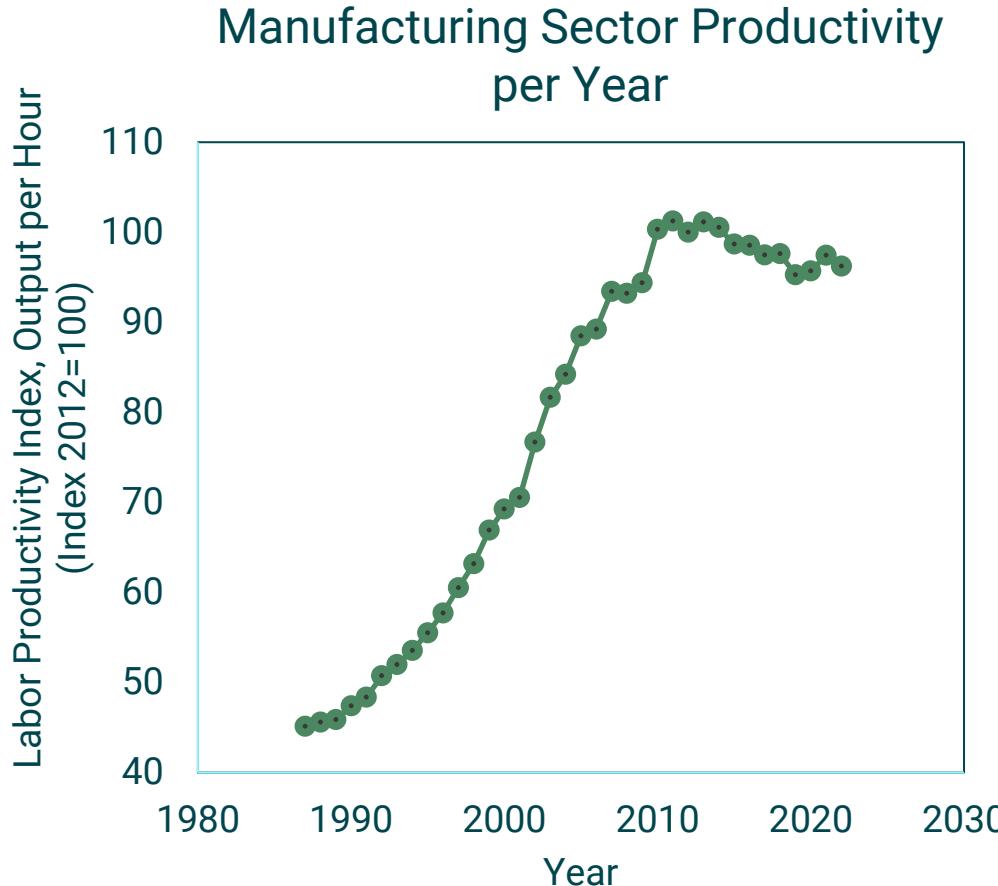
Section Head, Secure & Digital Manufacturing  
Manufacturing Sciences Division



ORNL IS MANAGED BY UT-BATTELLE LLC  
FOR THE US DEPARTMENT OF ENERGY



# Industry 4.0 is required to increase U.S. manufacturing productivity



Source: <https://www.aberdeen.com/opspro-essentials/industry-4-0-industrial-iot-manufacturing-sneak-peek/>

# Artificial Intelligence is defining Industry 4.0

Deloitte – Smart Manufacturing and Operations Survey (2025)

Rockwell Automation – State of Smart Manufacturing Report (2025)

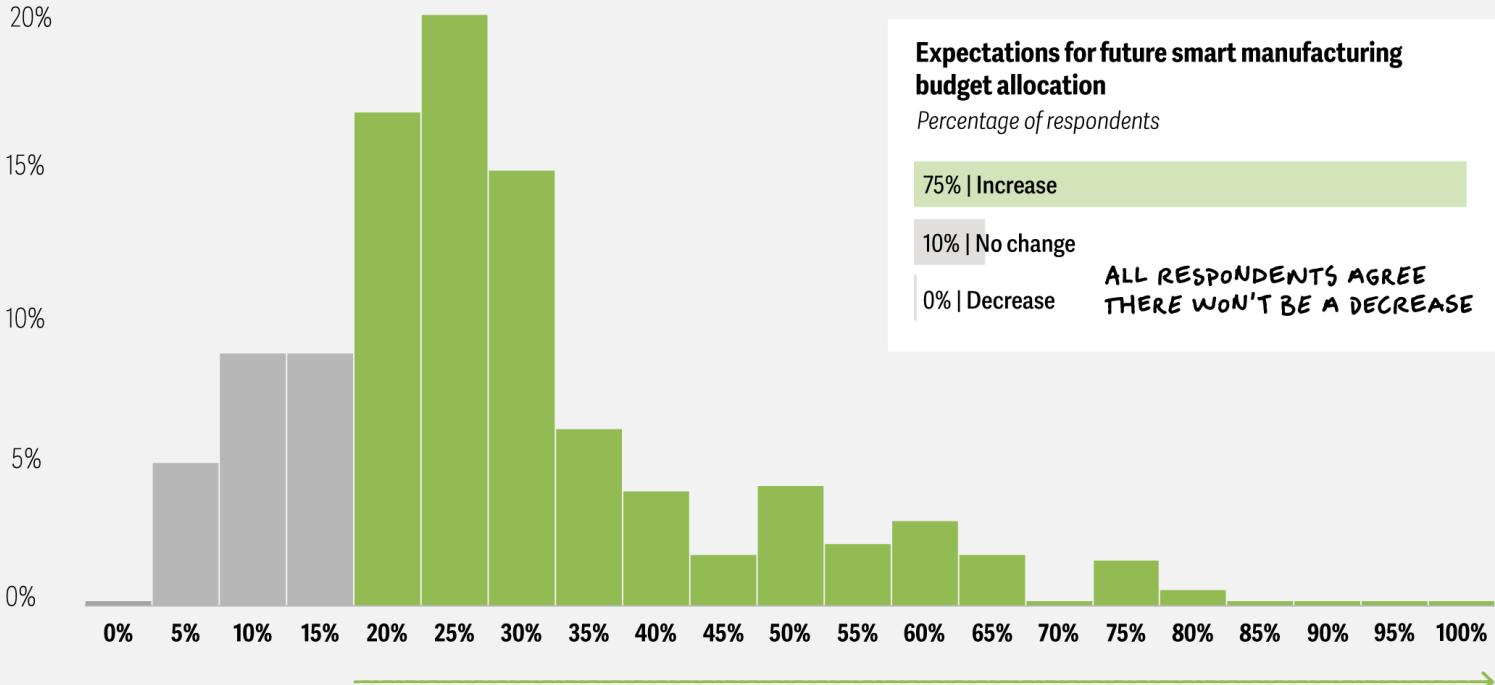
McKinsey – Adopting AI at speed and scale: The 4IR push to stay competitive (2024)

Figure 3

## Organizations plan to increase investments in smart manufacturing and operations

How much of your improvement budget are you allocating to smart manufacturing initiatives?

Percentage of respondents



Expectations for future smart manufacturing budget allocation

Percentage of respondents

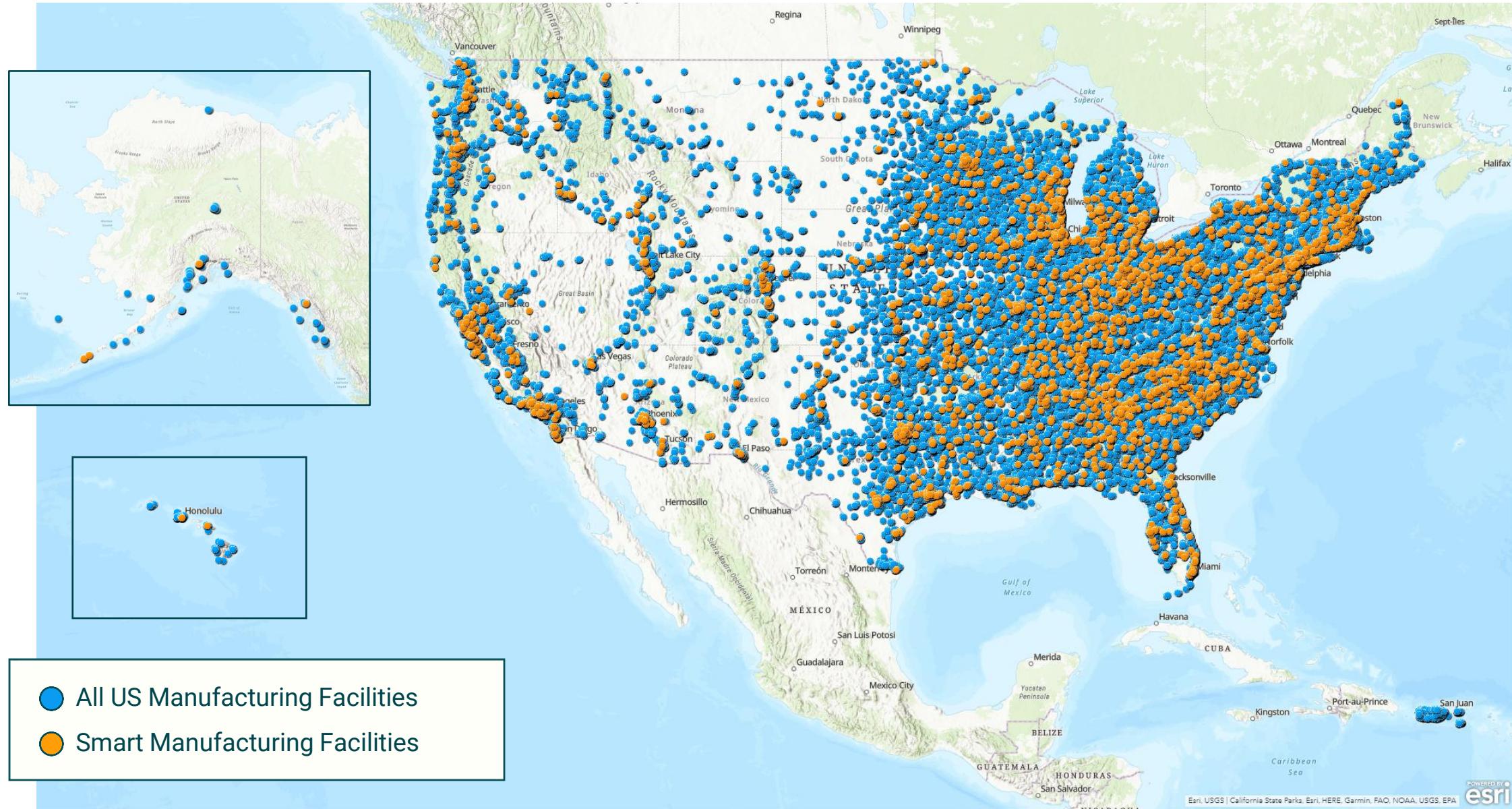


**78%** OF TOTAL RESPONDENTS PLAN TO ALLOCATE AT LEAST 20% OF THEIR BUDGET FOR SMART MANUFACTURING INITIATIVES

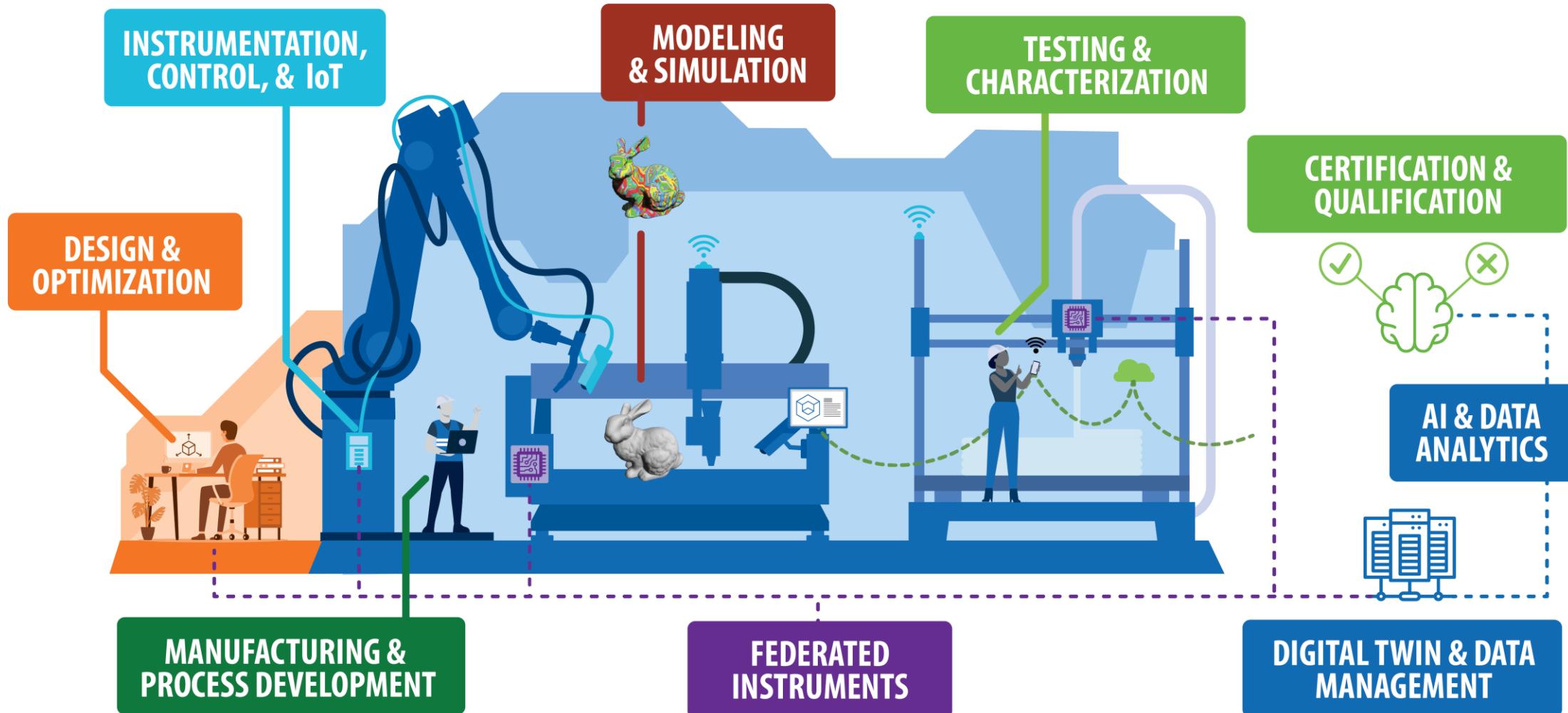
Source: Deloitte analysis.

**Deloitte.** Insights | [deloitte.com/insights.com](https://deloitte.com/insights.com)

# The opportunity ahead: building a U.S. Smart manufacturing ecosystem

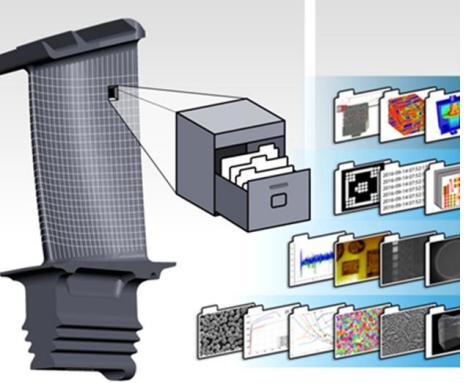


# MDF is a Knowledge Factory—information gained from one material or system informs all others, expediting innovation



# Digital Factory Project Background

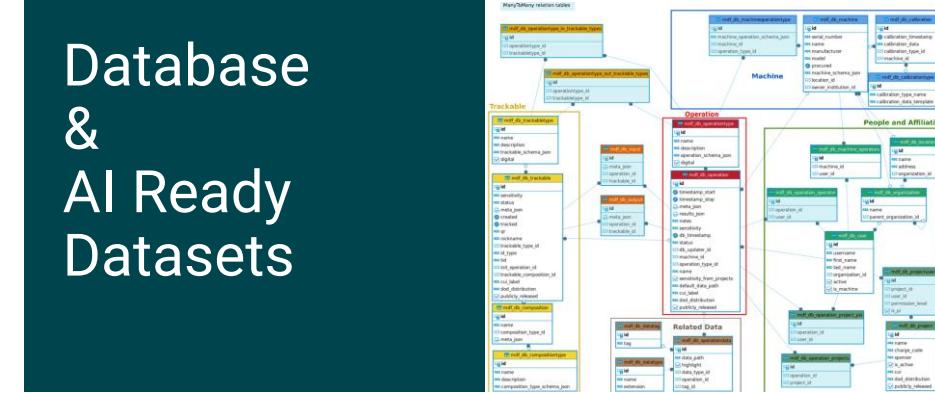
Digital Thread  
&  
Digital Twins  
Standards



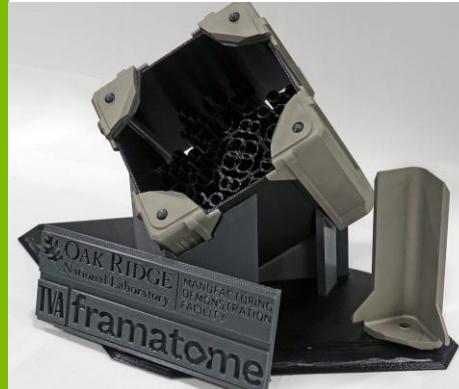
Edge Sensing,  
Analytics,  
Modeling &  
Simulation



Database  
&  
AI Ready  
Datasets



Part  
Certification  
and  
Qualification



# Administration priorities



U.S. DEPARTMENT  
of ENERGY | Office of  
Science

Advanced Scientific Computing Research (ASCR)

THE AMERICAN SCIENCE CLOUD (AmSC)

DOE National Laboratory Program Announcement Number:  
LAB 25-3555

Announcement Type: Initial

Announcement Issue Date:	August 22, 2025
Submission Deadline for Proposals:	September 15, 2025, at 5 PM ET



U.S. DEPARTMENT  
of ENERGY | Office of  
Science

Advanced Scientific Computing Research (ASCR)

THE TRANSFORMATIONAL AI MODELS  
CONSORTIUM

DOE National Laboratory Program Announcement Number:  
LAB 25-3560

Announcement Type: Amendment 000001

Amendment 000001 is issued to ensure that the appendices cited on page 13 are consistent  
with those stated later in the Announcement.

Announcement Issue Date:	August 22, 2025
Submission Deadline for Proposals:	September 15, 2025, at 5 PM ET



The WHITE HOUSE



45 | 47

PRESIDENTIAL ACTIONS

## LAUNCHING THE GENESIS MISSION

Executive Orders | November 24, 2025



By the authority vested in me as President by the Constitution and the laws of  
the United States of America, it is hereby ordered:

Section 1. Purpose. From the founding of our Republic, scientific discovery and  
technological innovation have driven American progress and prosperity. Today,  
America is in a race for global technology dominance in the development of  
artificial intelligence (AI), an important frontier of scientific discovery and  
economic growth. To that end, my Administration has taken a number of  
actions to win that race, including issuing multiple Executive Orders and  
implementing America's AI Action Plan, which recognizes the need to invest in  
AI-enabled science to accelerate scientific advancement. In this pivotal  
*moment the challenges we face require a historic national effort comparable in*

# Qualification Framework

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*Quality assurance and quality control for additive manufacturing systems*

# Additive Manufacturing: Understanding and Controlling A Process of Trillions of Micro-Experiments

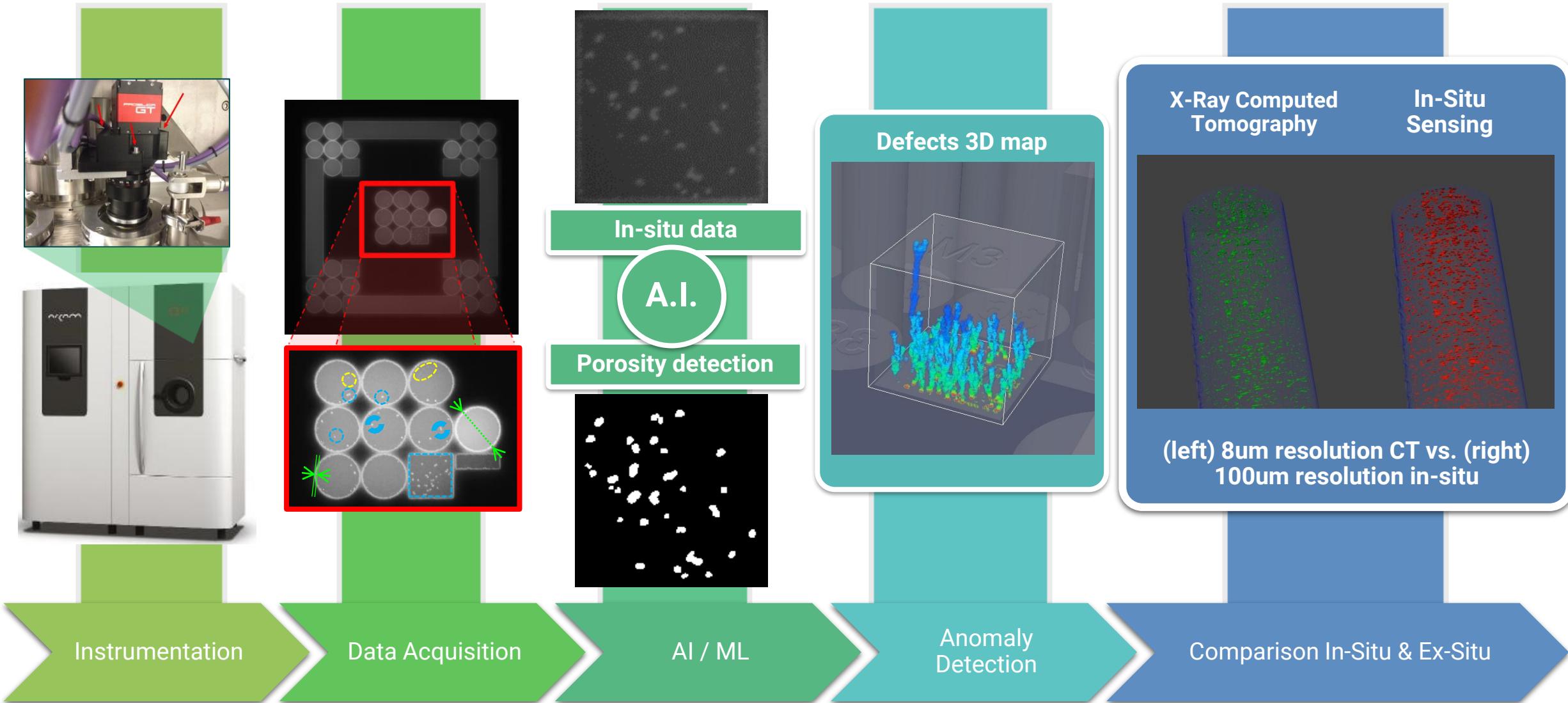
What you want



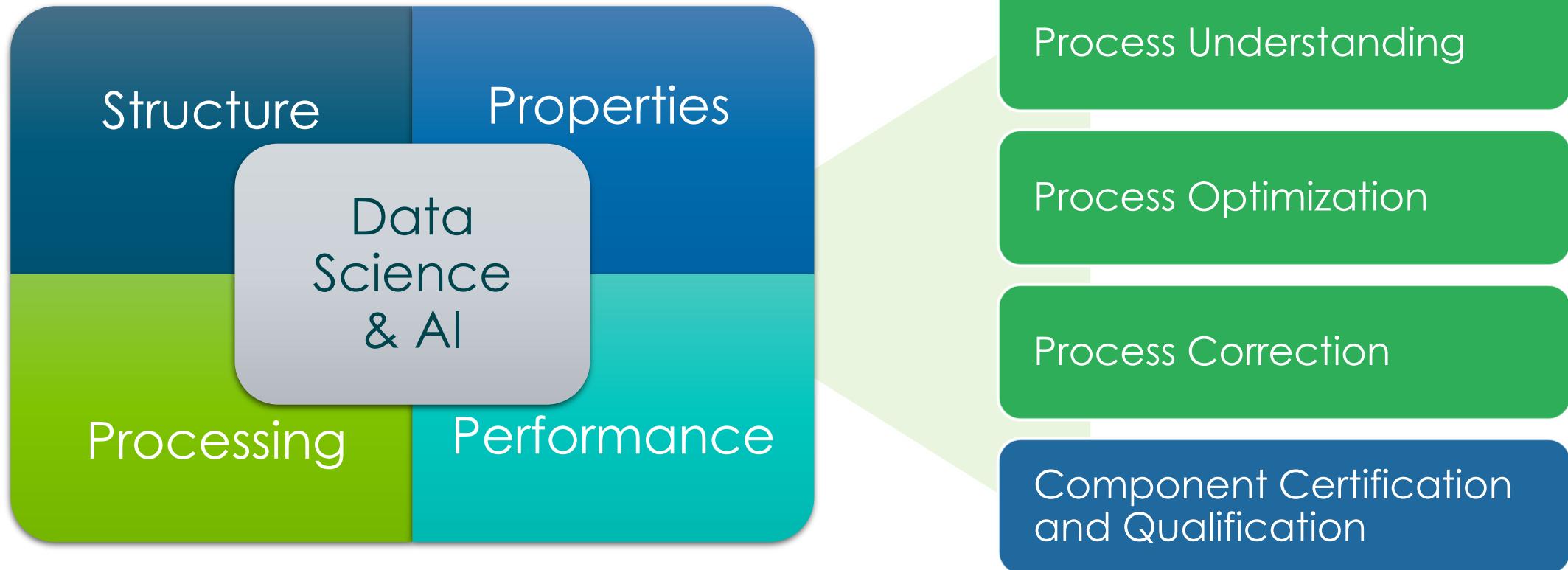
What you get



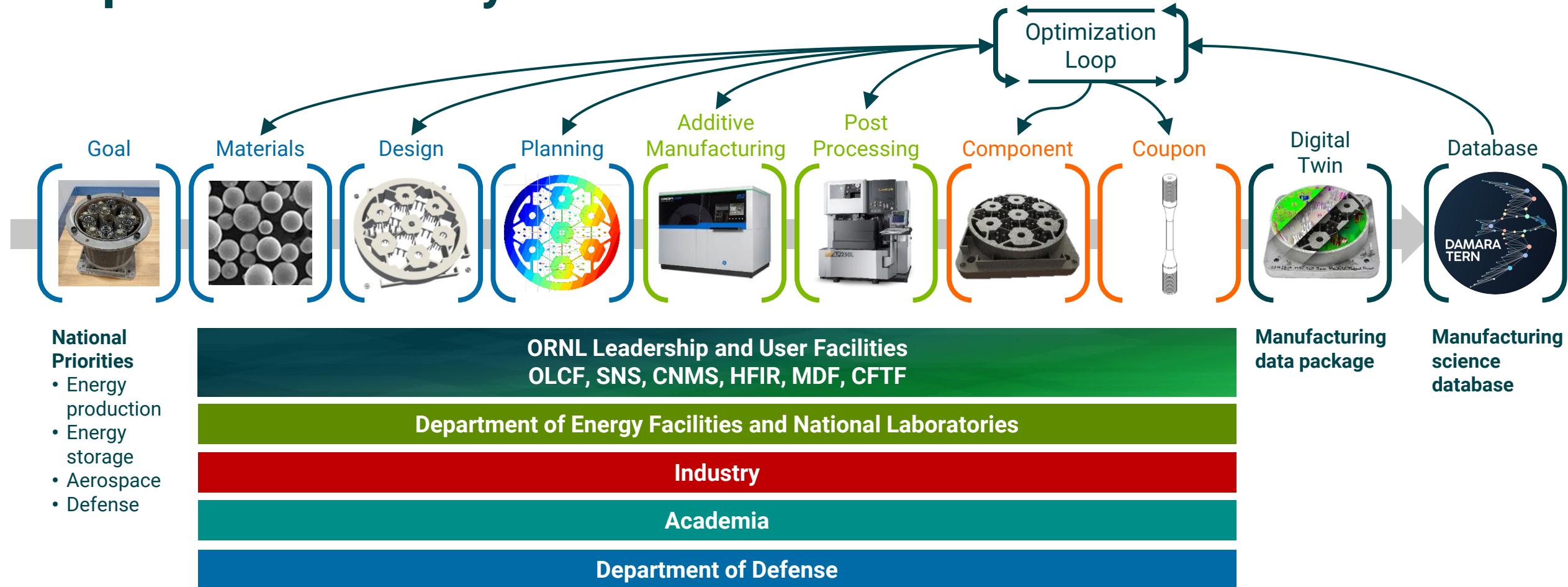
# In-Situ Quality Control of AM Processes using AI



# Certification and Qualification of Additively Manufactured Components: A National Lab Grand Challenge



# A workflow seamlessly integrated with our federated instrument environment, ORNL facilities, US labs, and industry to produce AI ready datasets



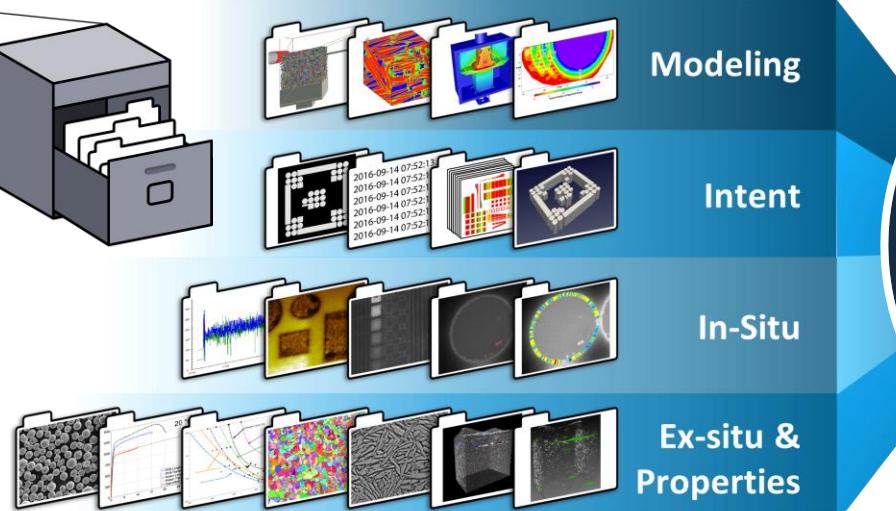
# Capturing component digital threads through voxelized digital twins

Voxelized Parts

Data Producers

Digital Twin

Data Workflow



Data Management & Tracking

Signal Processing

Computer Vision & Image Processing

n-D Data Visualization

Modeling & Simulation

Data Analytics & Machine Learning

Process Optimization

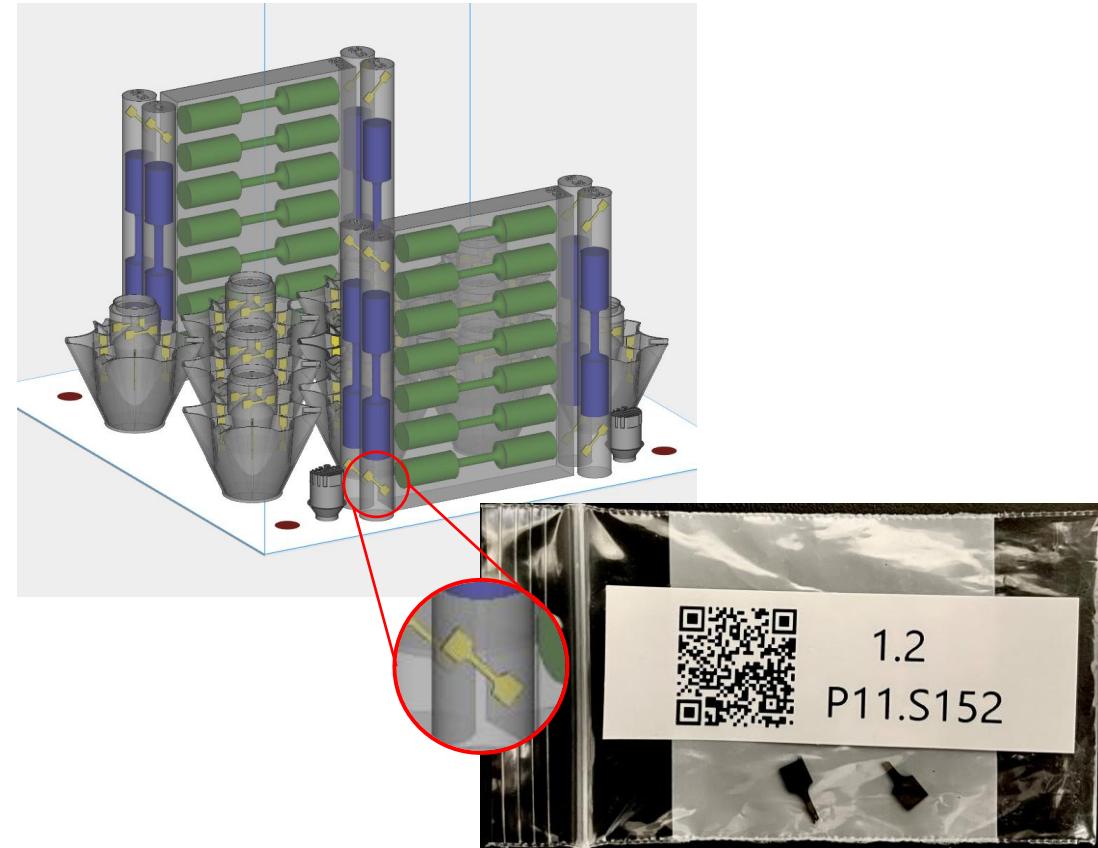
Certification, Verification & Validation

Cybersecurity

Digital Thread

# MDF data management platform (Damara Tern)

The screenshot shows the Damara Tern MDF data management platform. At the top, there is a navigation bar with links for 'admin', 'PROJECTS' (which is underlined in blue), 'feedback', and 'log out'. On the left, there is a circular logo with the text 'DAMARA TERN' and a stylized DNA helix graphic. Below the logo, there are two main categories: 'operations' (in a blue box) and 'trackables' (in an orange box). Under 'operations', there are four options: 'browse', 'create new', 'search', and 'QR scan'. Under 'trackables', there are three options: 'browse', 'register new (procured)', and 'search'. A tagline at the bottom reads 'flying through your data'.



## Platform links operations and trackables:

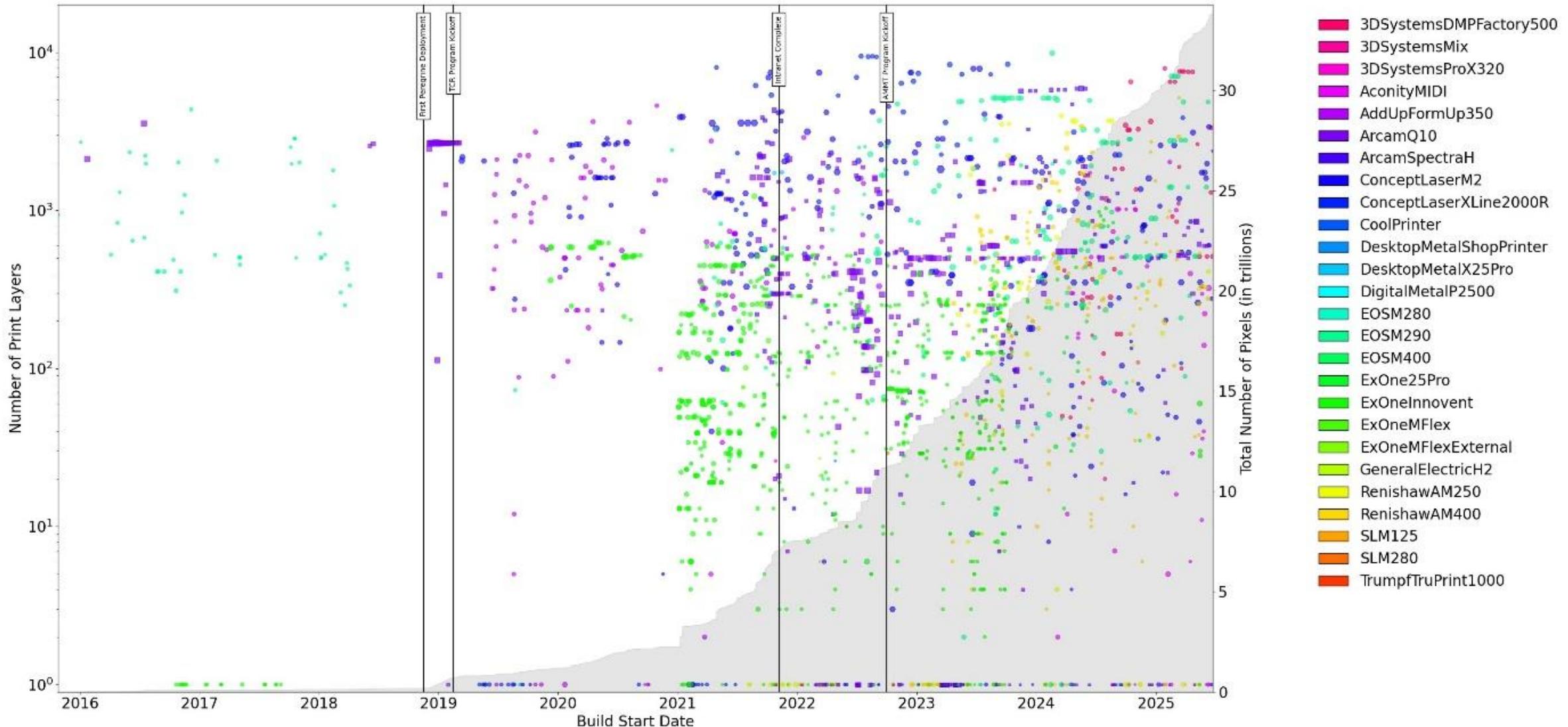
- **Operation:** Any action performed by a machine or a human
- **Trackable:** Anything physical or digital that can be subject to an operation

Scanning the QR code retrieves the tensile specimen's digital thread from the database.

# MDF database

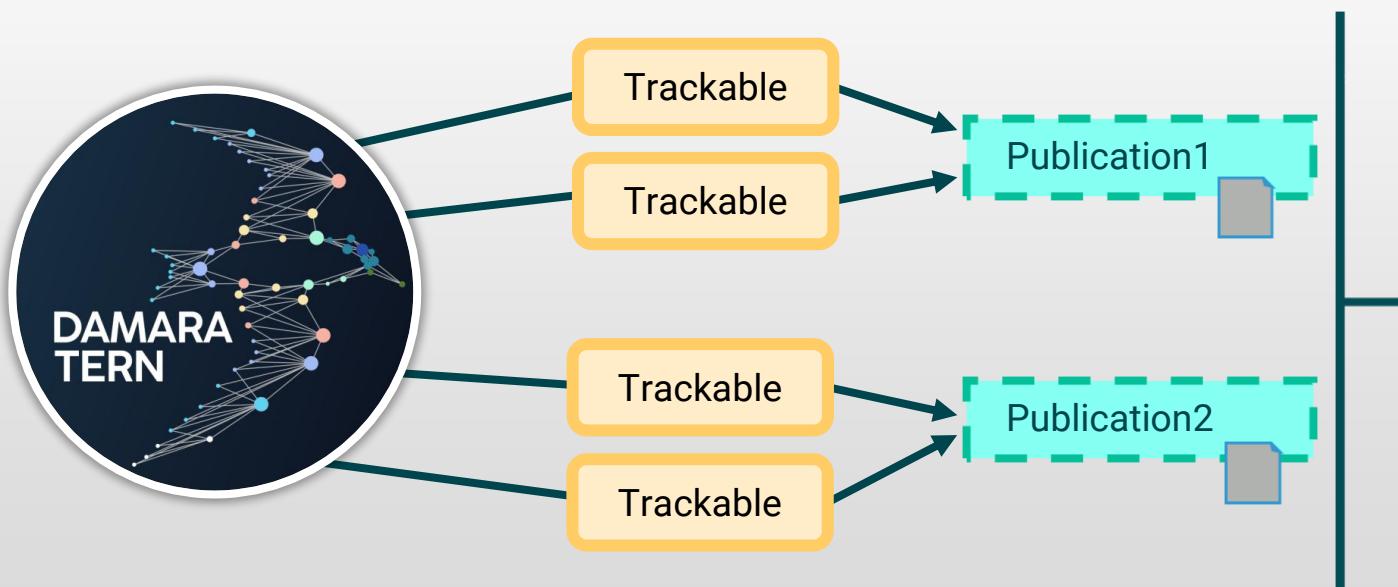
Total number of builds  
Total number of layers  
Total number of pixels

3,162  
1.93 M  
36.5 TP



# Large language models accelerate information access and unlock knowledge discovery in manufacturing data

- Complex experiments (represented by digital threads) culminate in scientific discovery (publications)
- LLMs excel at natural language tasks like asking questions and summarization
- Leverage Damara Tern as knowledge base for an LLM



user: What can you tell me about the Oak Ridge National Laboratory's Manufacturing Demonstration Facility?

llm: The Oak Ridge National Laboratory's (ORNL) Manufacturing Demonstration Facility is a state-of-the-art additive manufacturing facility located at the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory in Tennessee, USA. The facility was established to accelerate the commercialization of advanced materials and manufacturing technologies.

**Facility Overview**

The Manufacturing Demonstration Facility is a multi-purpose facility that offers a variety of AM technologies, including:

1. Directed Energy Deposition (DED): Electron Beam Melting (EBM), Laser Beam Melting (LBM), and Direct Energy Deposition (DED)
2. Selective Laser Sintering (SLS)
3. Solid-State Powder Topic (SSPT) (using a femtosecond laser)

The facility provides concurrent melting, solidification, and inspection, as well as advanced diagnostic instruments for quality control and optimization.

**Facilities Capabilities**

The ORNL Manufacturing Demonstration Facility has a versatile and complementary set of facilities that provide the following capabilities:

1. Materials and Process Development: Research and development of new materials and processes, including alloy development and process optimization.
2. Additive Manufacturing: Design-to-part additive manufacturing services, including consulting, design optimization, and process validation.
3. Technology Transfer: Collaboration with industry and academia to commercialize AM technologies and materials.
4. Radiation Synthesis: Development of advanced materials and technologies, including 3D printing of radiation-resistant materials.
5. Machine Shop and Post-processing: Capabilities to support machining, chemical processing, and other post-processing steps.

# ORNL's open-source modeling software for manufacturing



**AdditiveFOAM**—Heat and mass transfer for AM



**ExaCA**—Grain structure prediction



**3DThesis**—Fast thermal solver for AM



**Adamantine**—DED simulation and data assimilation



**Myna**—Workflow manager for manufacturing data



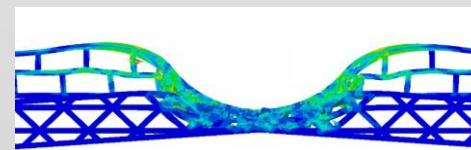
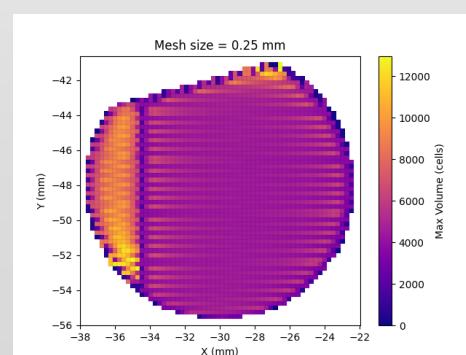
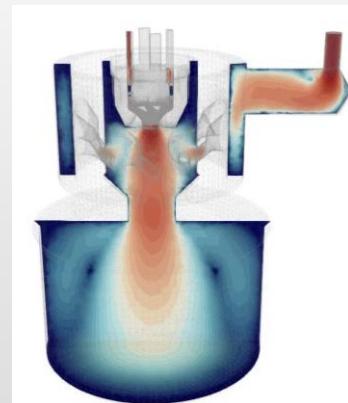
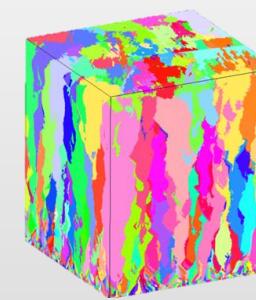
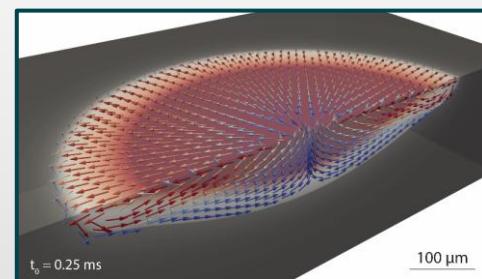
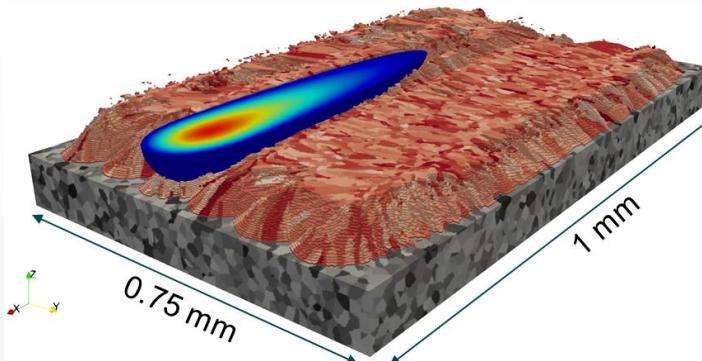
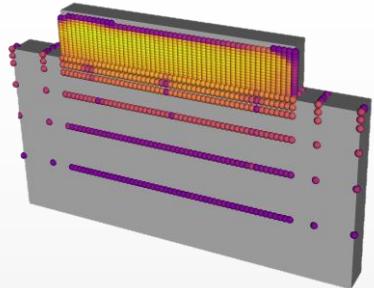
**Mist**—Library for property data



**Raman**—Library for analytical materials models



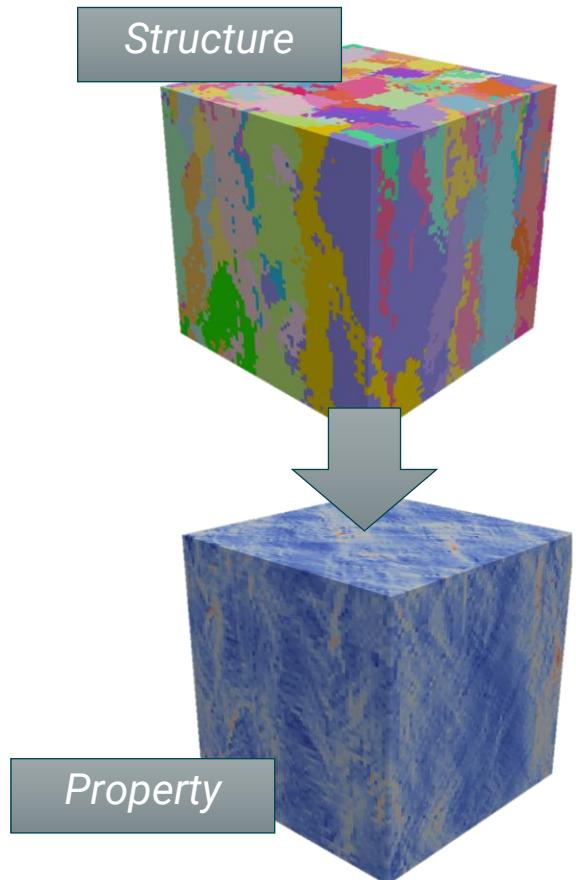
**Equilipy**—Computational thermodynamics



# 3D Microstructure Generation for Qualification

Generate 3D, part-scale material structure representations using generative AI trained on experimental micrographs, enabling accurate input for structure-property models to support qualification and performance prediction

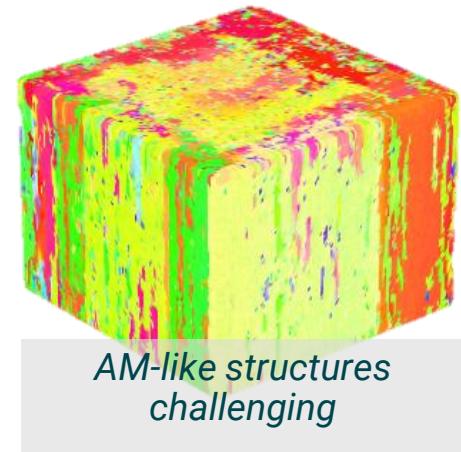
Structure → Property models aid in understanding performance behavior and qualifying processes/materials



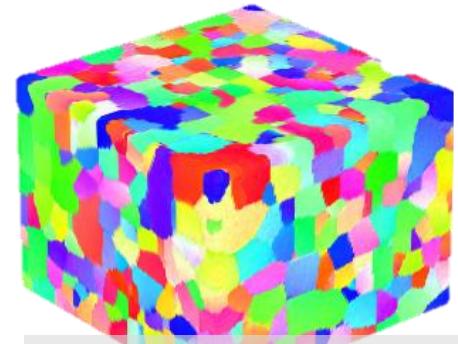
Computational property predictions from input structure

**3D structures can be generated from 2D structures... but extremely morphology-dependent... methods currently do not exist for stable generation...**

Generative AI can synthesize structures when trained directly from experimental micrographs



AM-like structures challenging



Simple morphologies possible

3D structures generated from 2D data

# AI-powered XCT reconstruction increases resolution, speed, and lowers costs

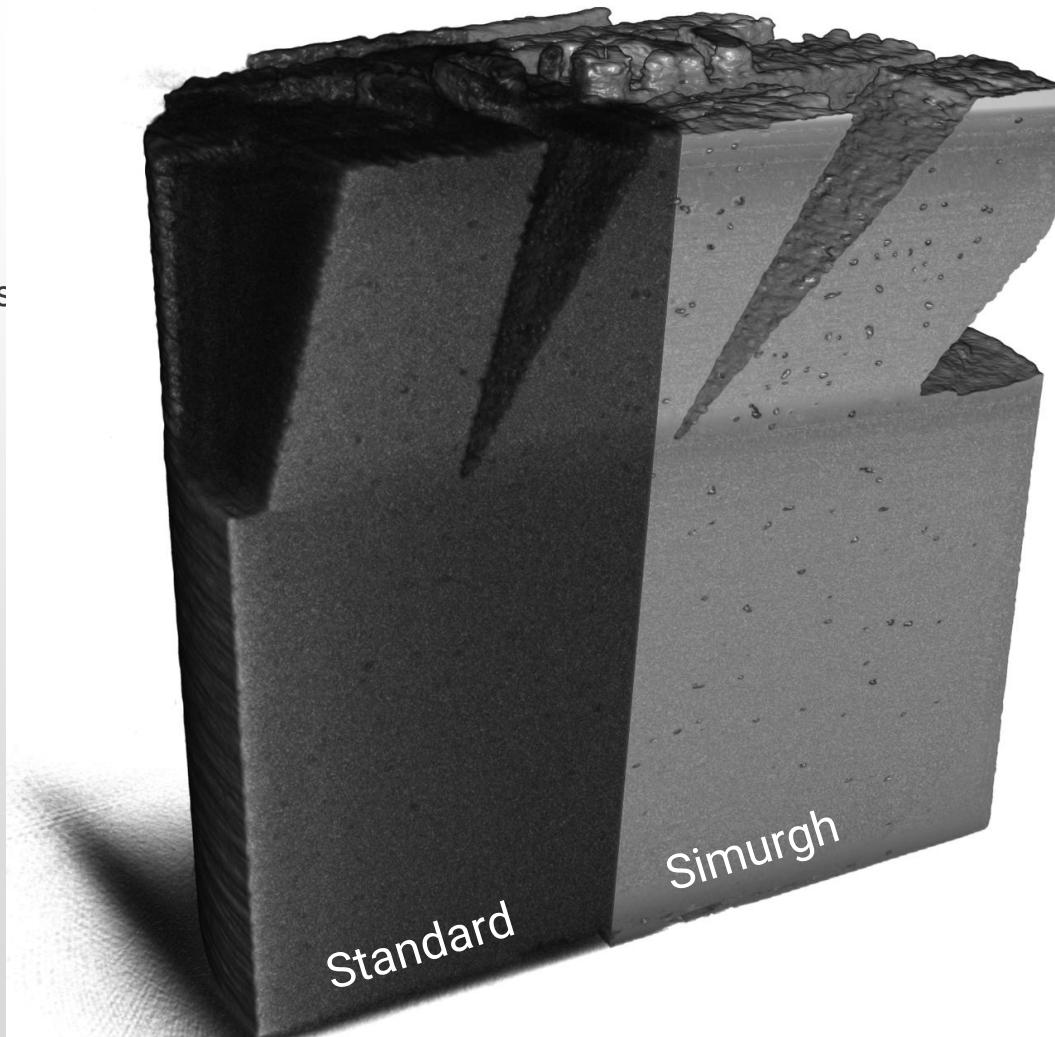


## Innovation

- Simurgh enables rapid materials development, process optimization, and component qualification for improved non-destructive evaluation.
- Relevant across many traditional and additive manufacturing processes for aerospace, nuclear, and other energy applications
- INL is using Simurgh to inspect nuclear fuels and assess irradiation effects on reactor components

## Impact

- >12X faster scan times leading to 2–10X lower cost
- >4X increase in defect detectability
- 4 licenses, with growing interest
- >\$19M commercial impact to date
- ~17,000 commercial scans complete to date
- \$633 est. savings per scan compared to conventional scans
- 80% reduction in process optimization time for AM
- 2–3X increase in productivity through process optimization



## Licensees



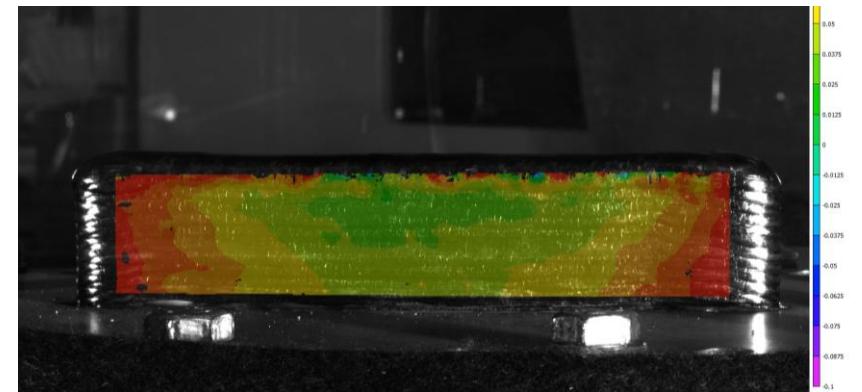
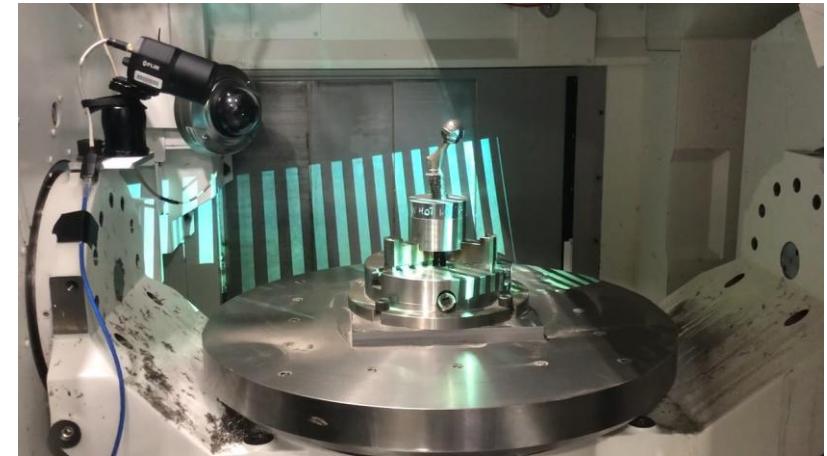
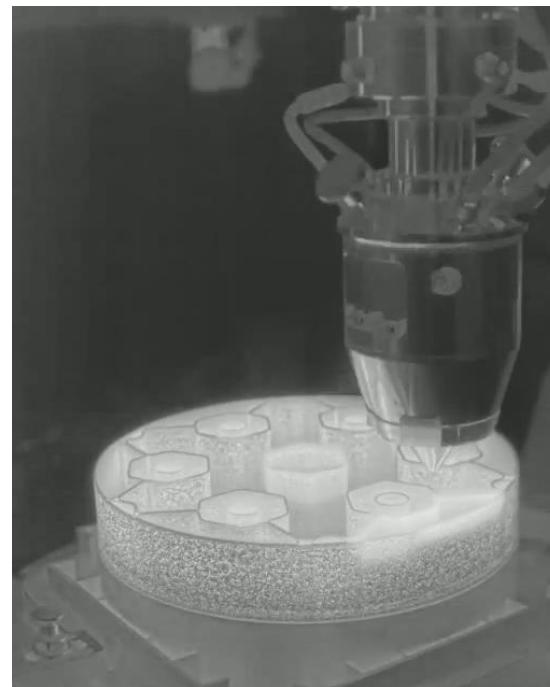
University  
of Dayton  
Research  
Institute



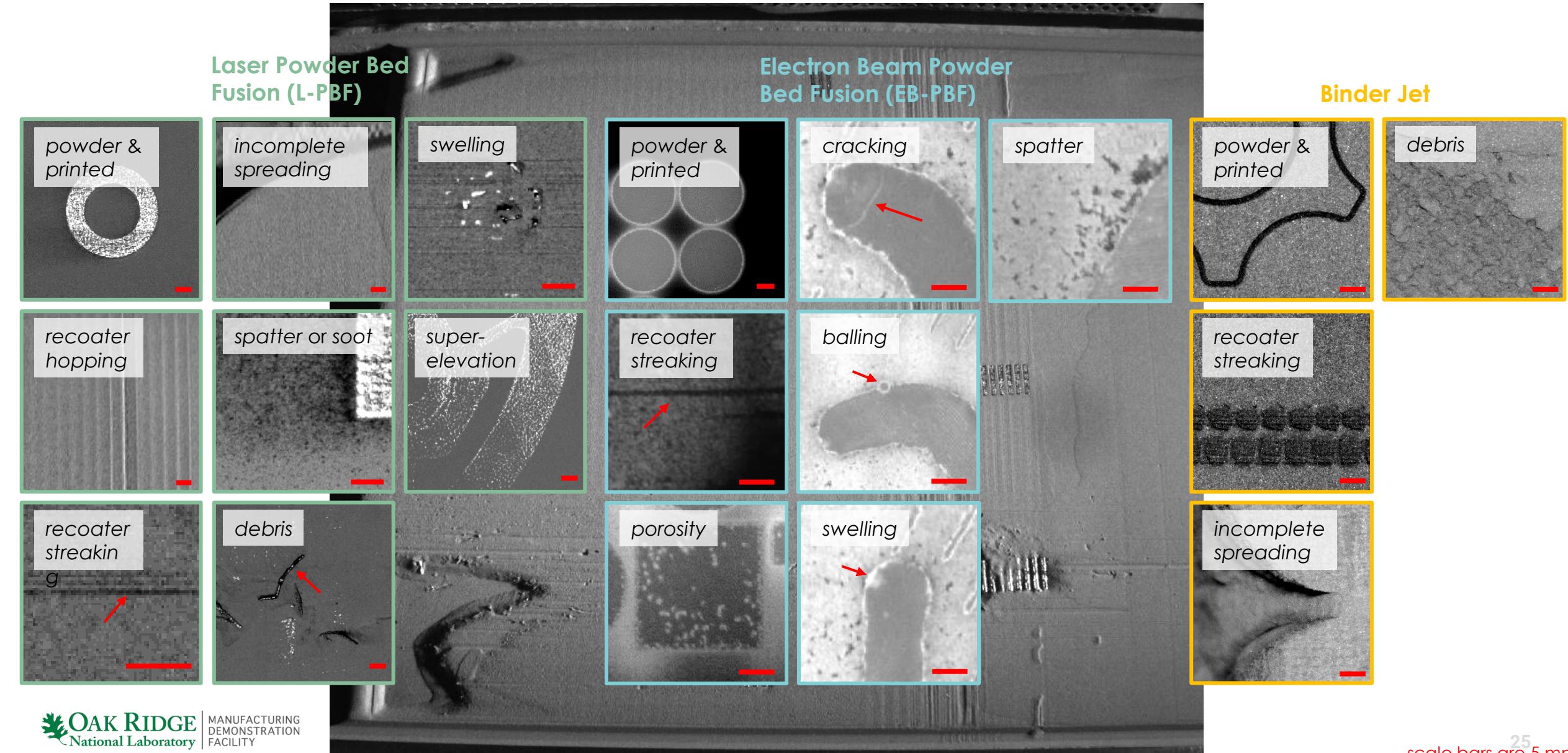
# In situ monitoring, sensor development and integration



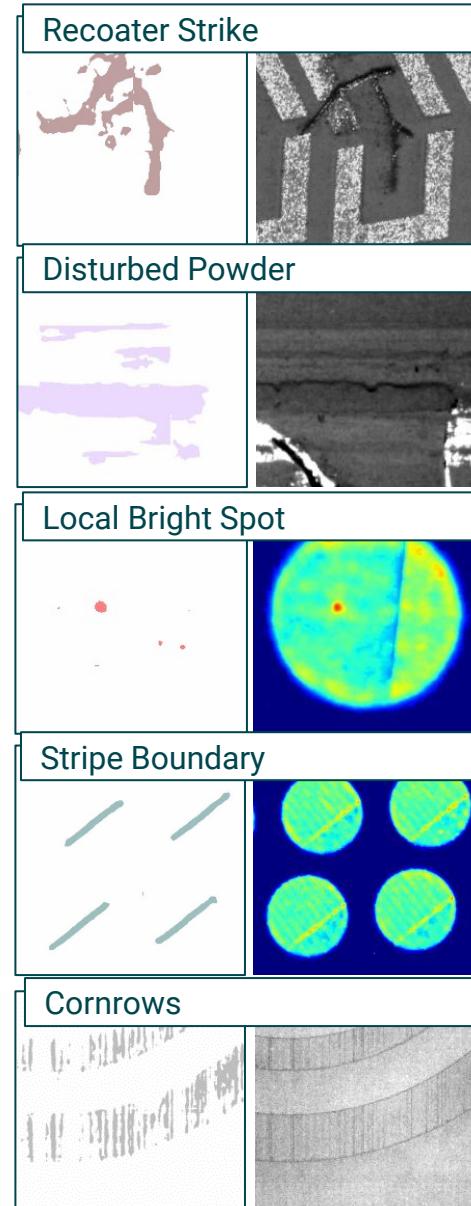
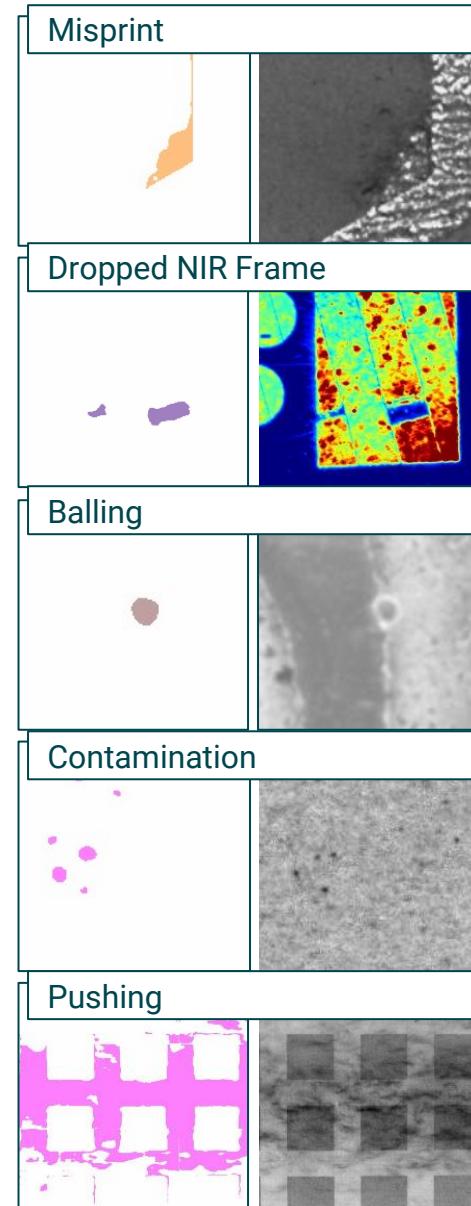
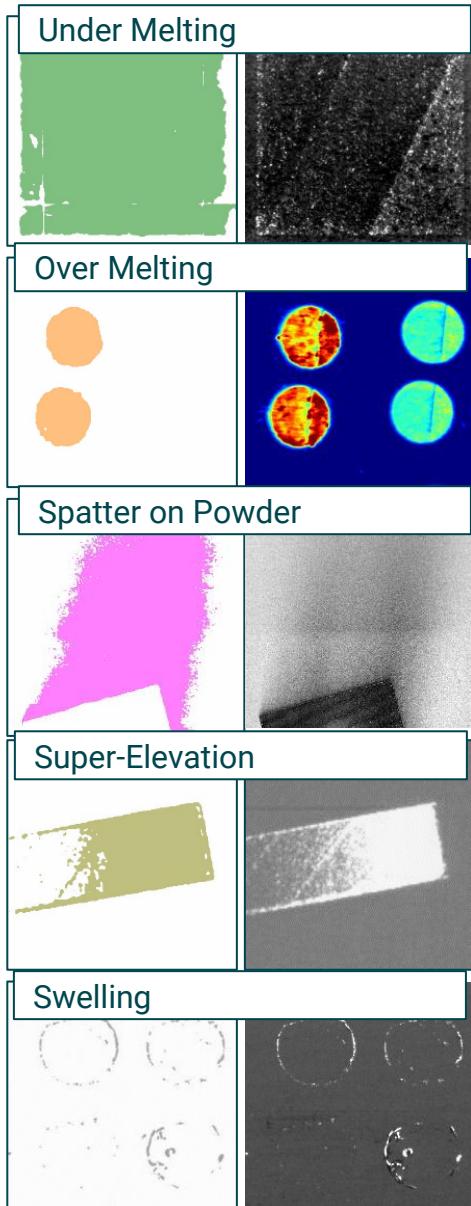
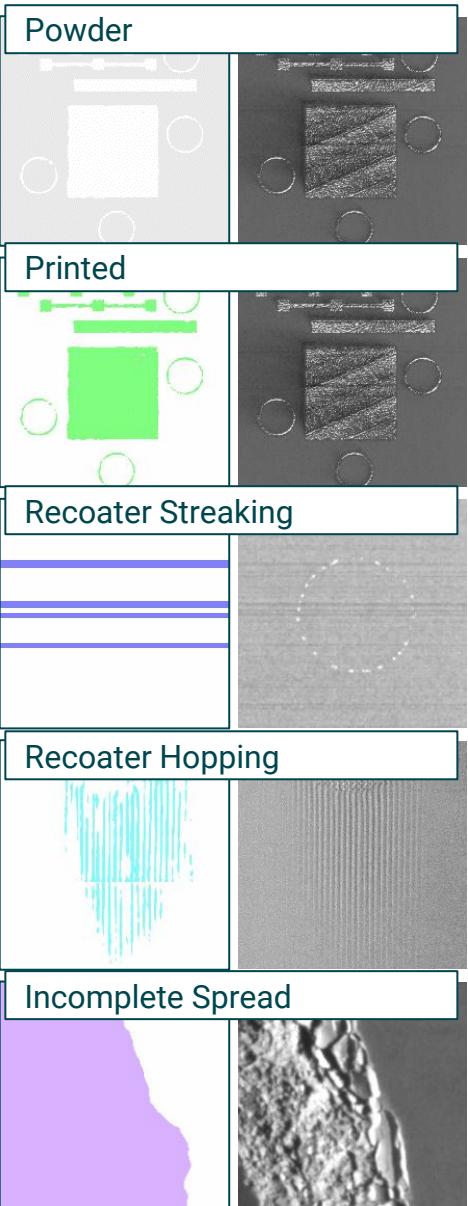
Compact multimodal imaging technology for DED, hybrid, composites, and large-scale manufacturing



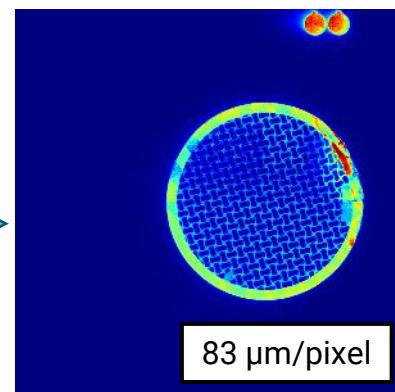
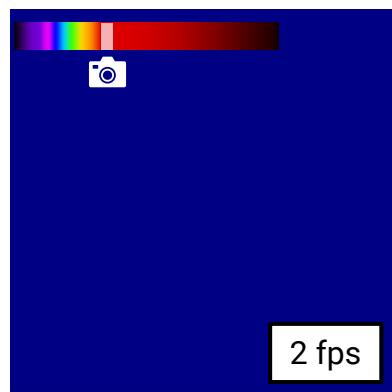
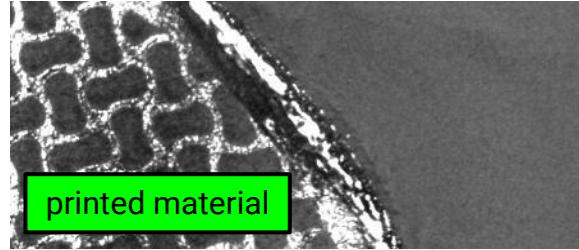
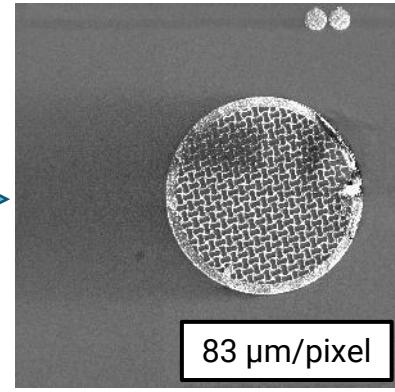
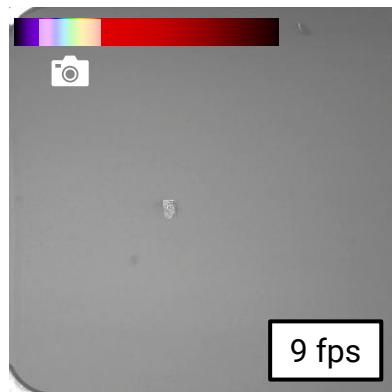
# In-situ monitoring process anomaly detection using AI



# Types of anomalies

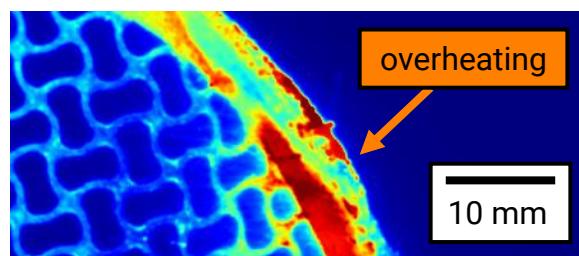
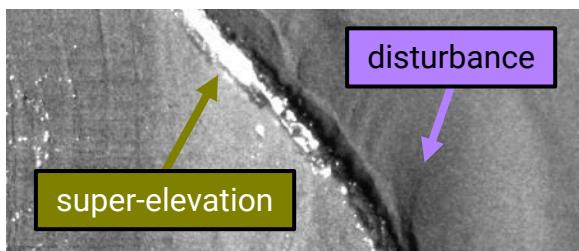


# Real-time multi-modal data collection, processing, and AI based anomaly detection for powder bed AM

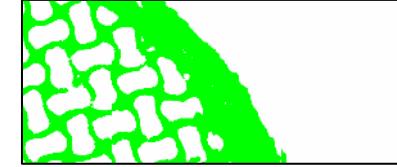


multi-modal  
data collection

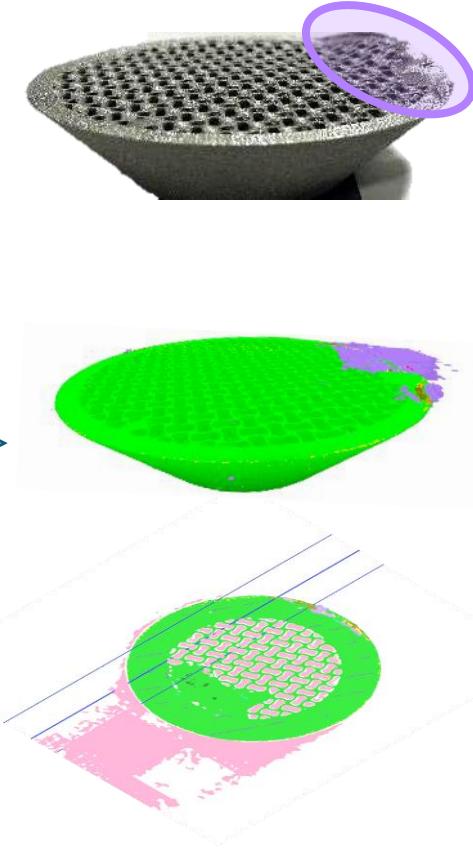
real-time data  
processing



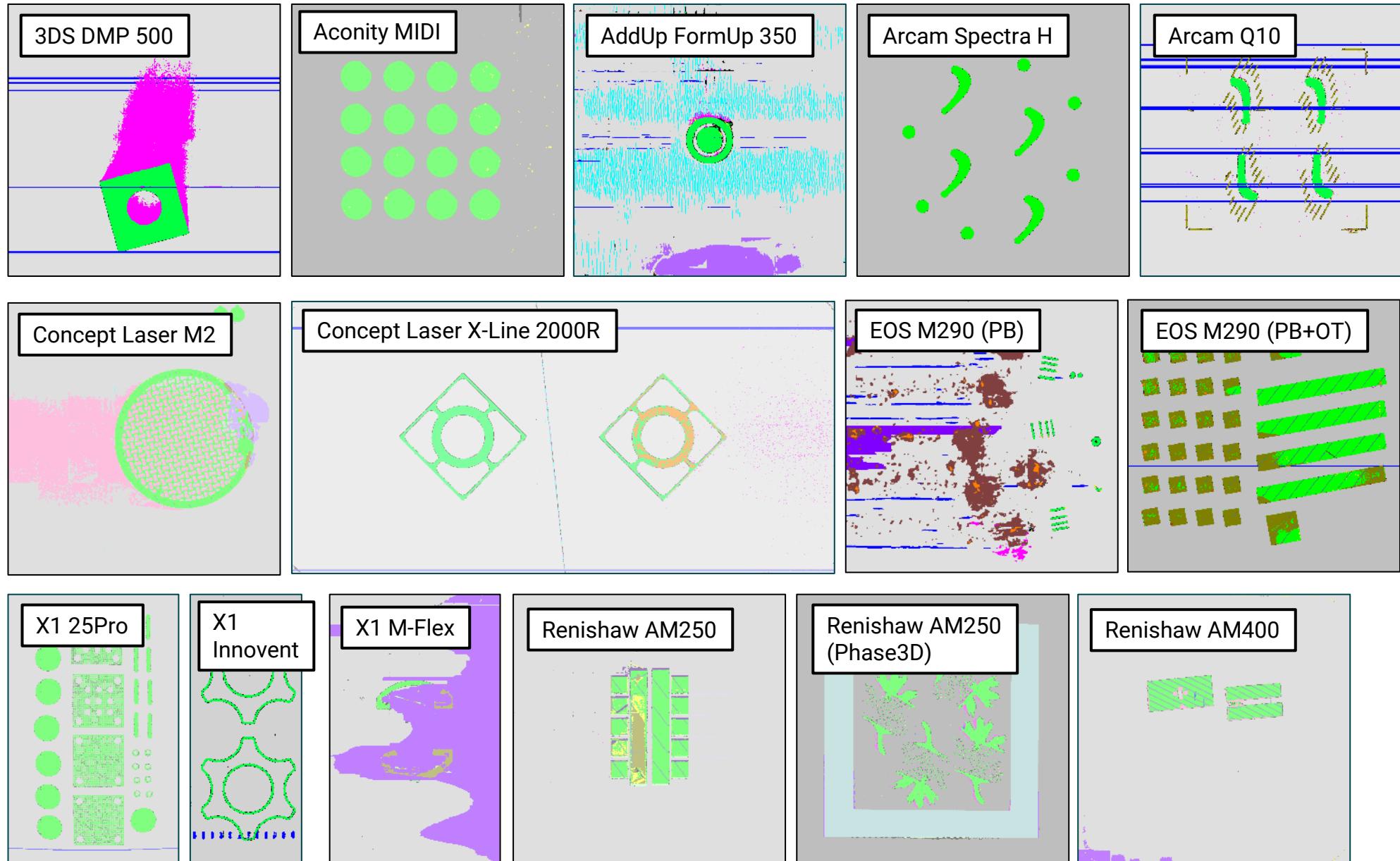
anomalies and flaw indications  
apparent in each sensor stream



AI (DMSCNN)  
anomaly detection

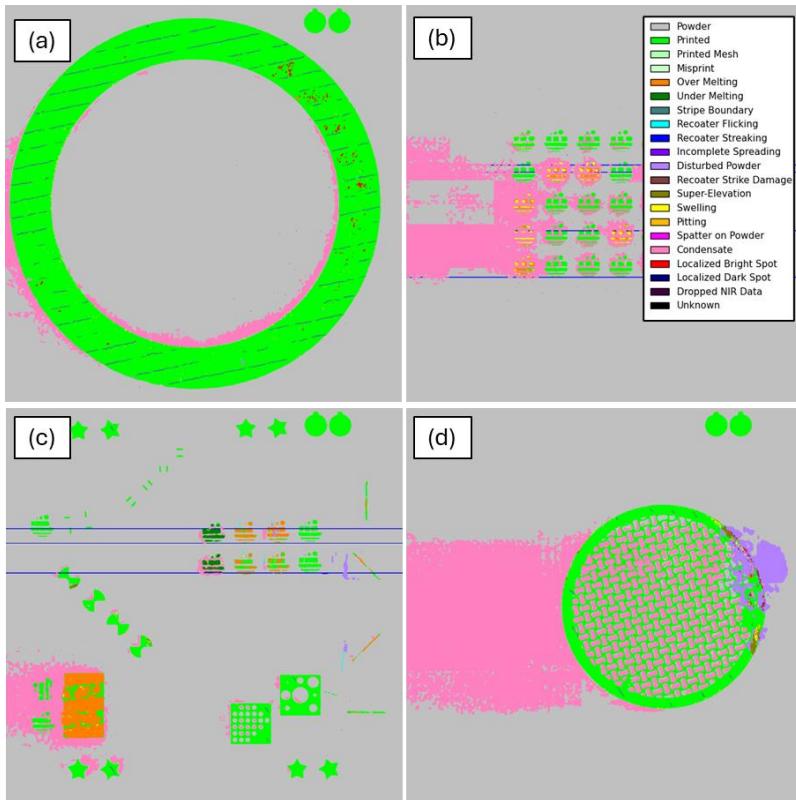


Any sensor input results in the same analyzed data format, this allows data to be leveraged from across ORNL and USG partners for AI

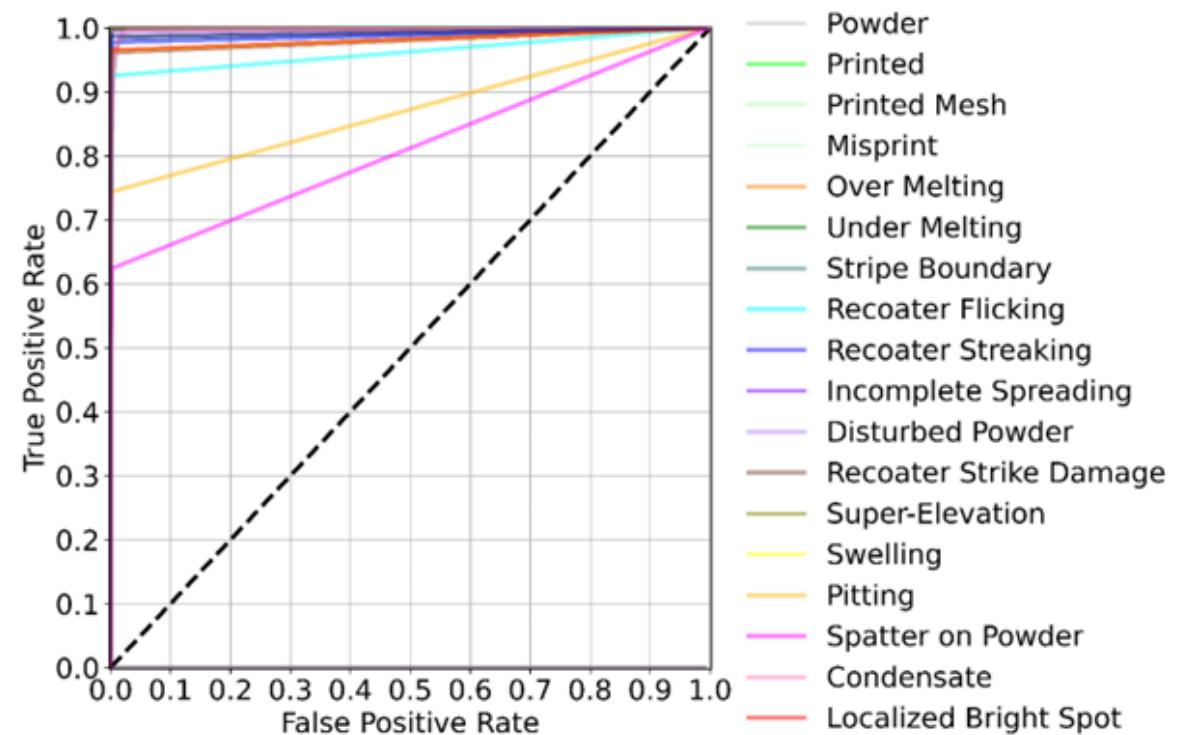


# Enhanced imaging for anomaly detection in L-PBF

## Dynamic multi-label segmentation convolutional neural network (DMSCNN) segmentations



## Receiver operating characteristic (ROC) curves for each anomaly class

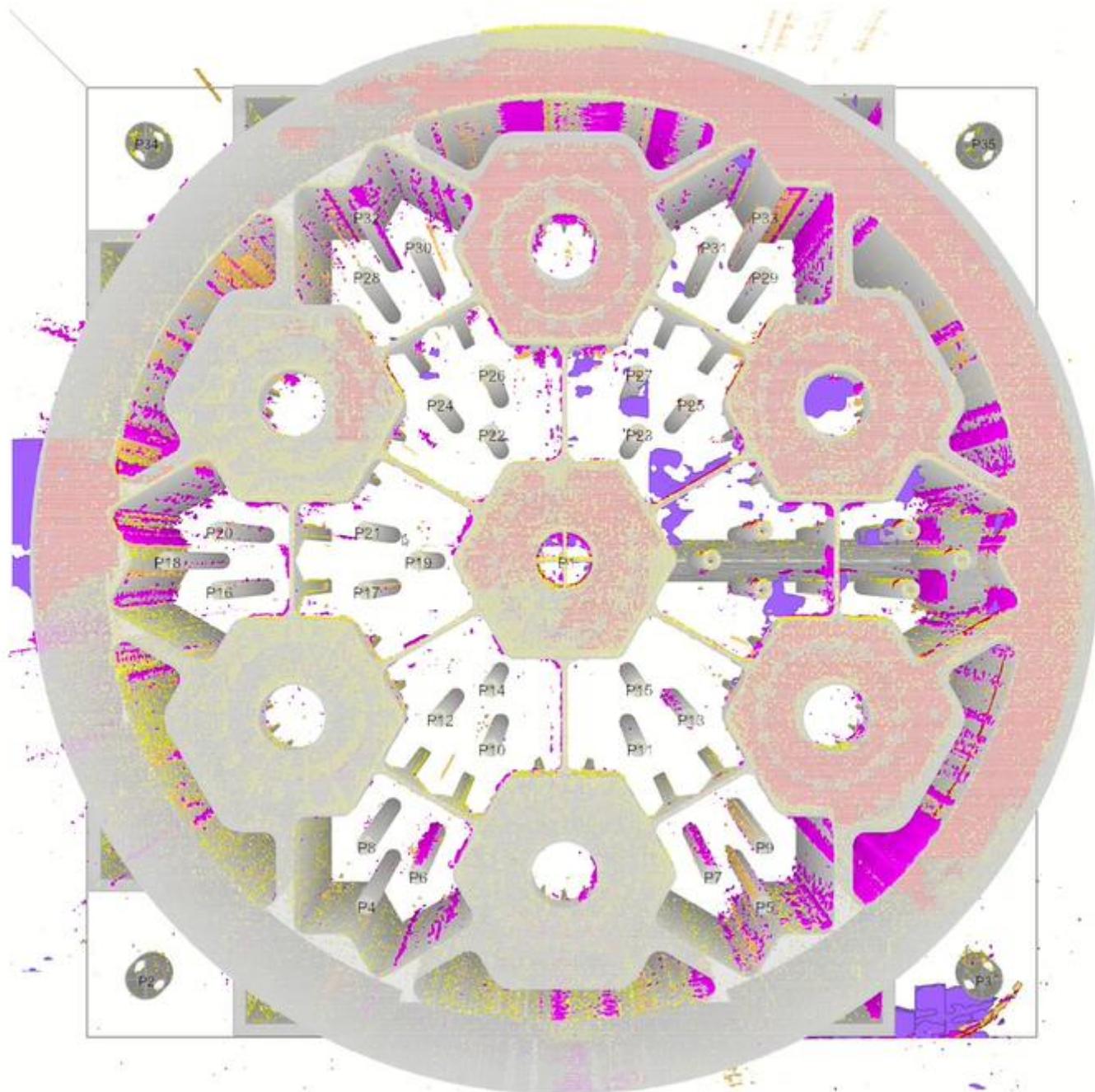




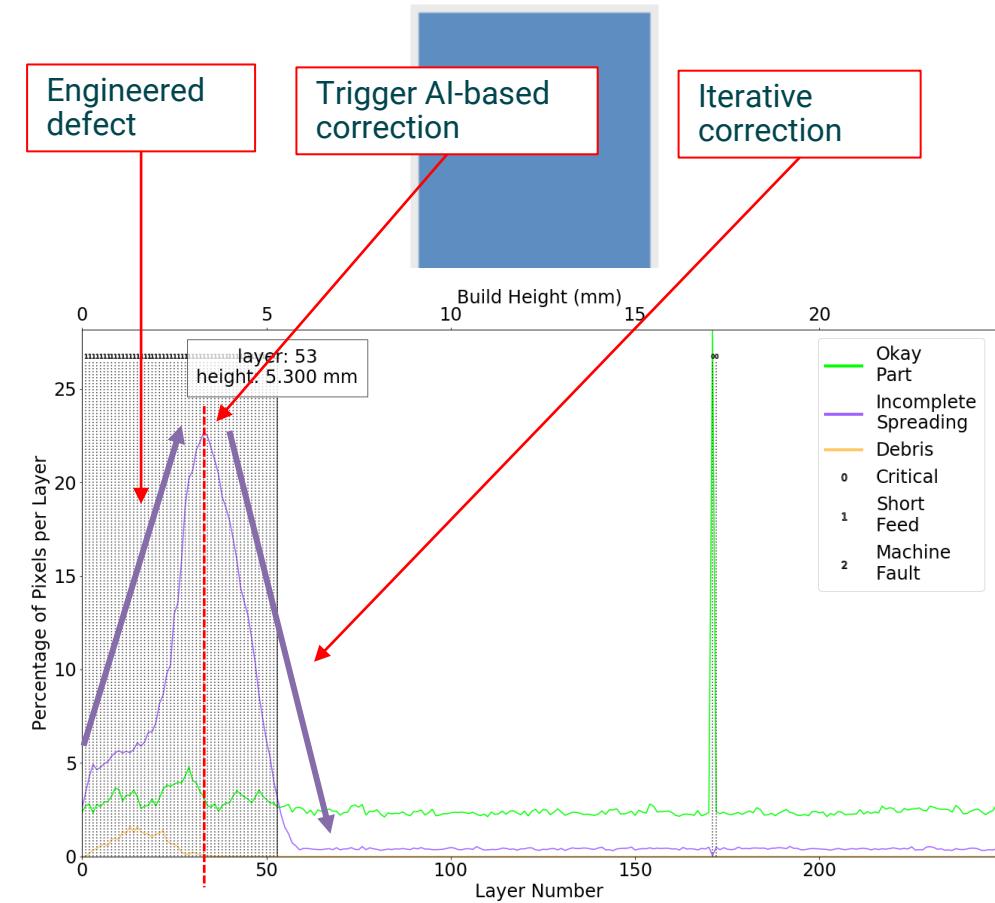
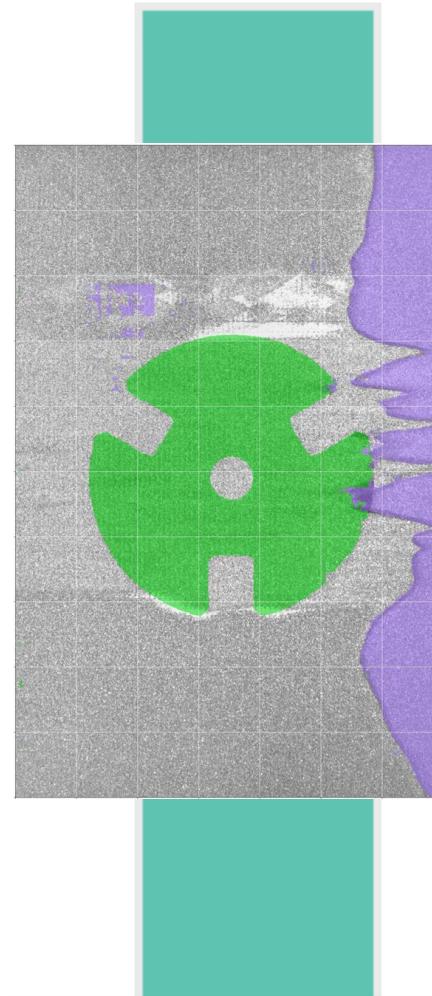
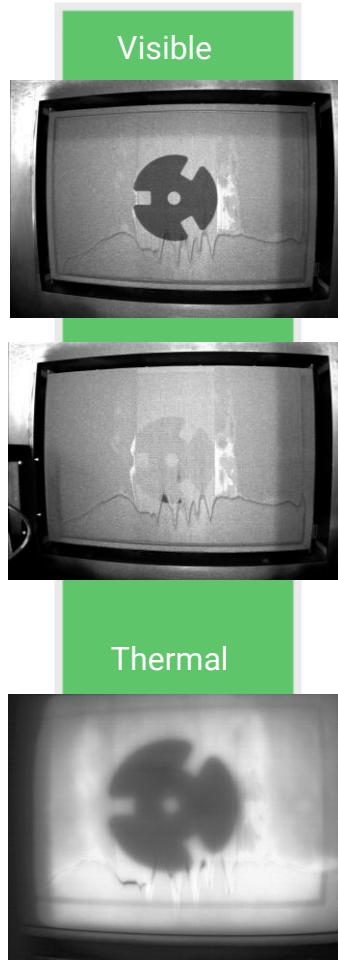
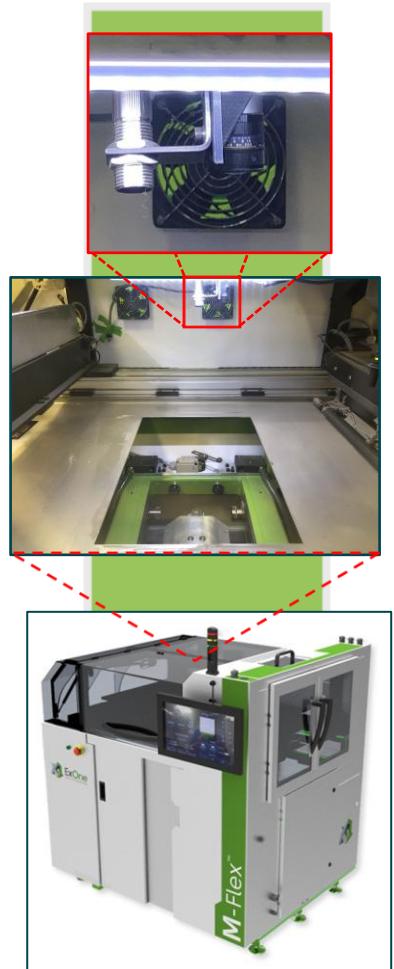
# PEREGRINE



- AI software for real-time 3D print monitoring, and material properties prediction
- **Most Licensed AI tech @ ORNL**
- **2022 FLC Excellence in Technology Transfer Award**
- Deployable at the edge, leveraging HPC platforms for advanced functionalities



# BinderJet: AI based defect detection and correction



ExOne M-Flex equipped with  
in-situ sensing

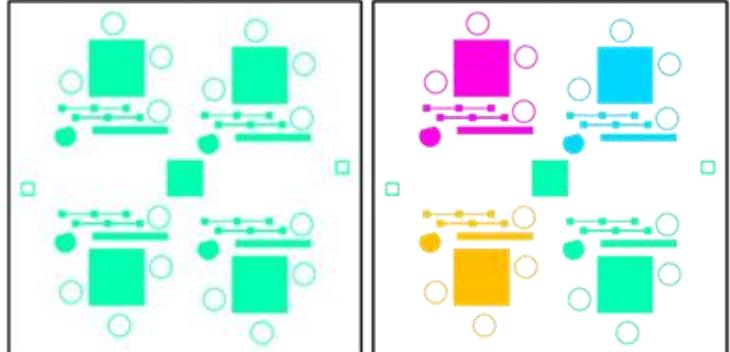
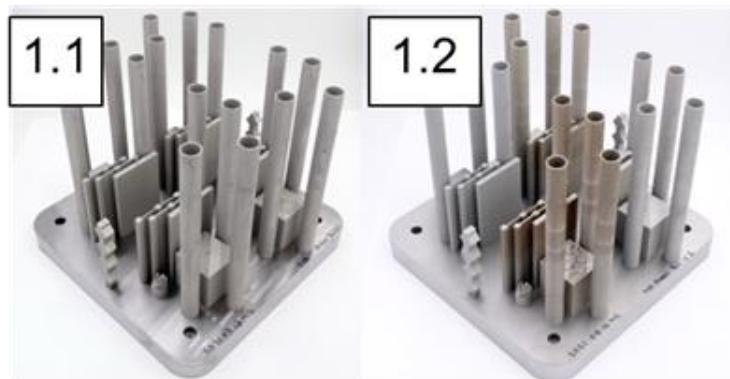
In-situ imaging  
modalities: visible and  
infrared

AI-based defect detection

Implementation of an AI-based feedback loop  
control for defect correction

# Material properties prediction – pedigree datasets

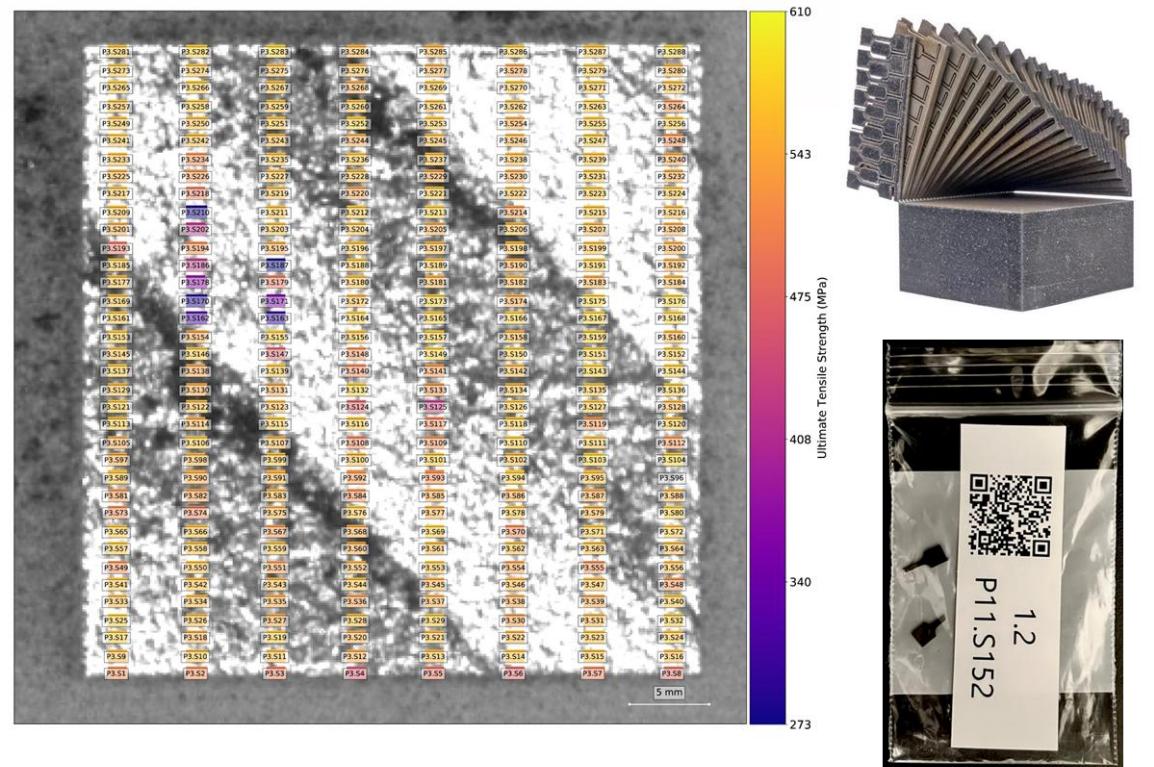
## Design of experiments & data



Each color represents one set of manufacturing process parameters

- Data collected
  - design files
  - machine sensors
  - process parameters
  - in-situ sensors
  - mod/sim
  - destructive testing
  - non-destructive testing
  - ...

## Performing ~10.000 mechanical tests



# Automated mechanical tensile testing

Picking sample and measuring cross-section

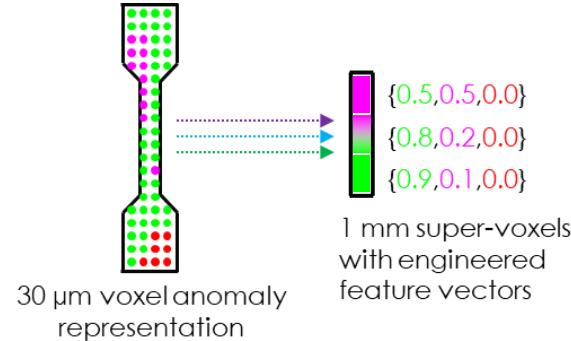


Loading sample in load frame

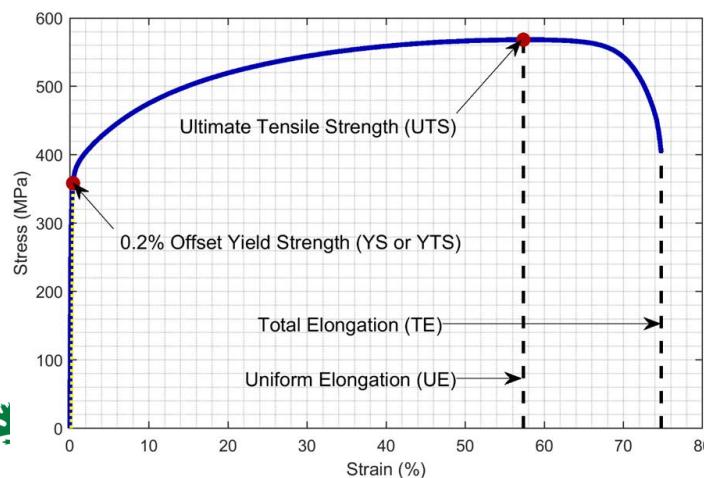
# Material properties prediction- performance

## Input data

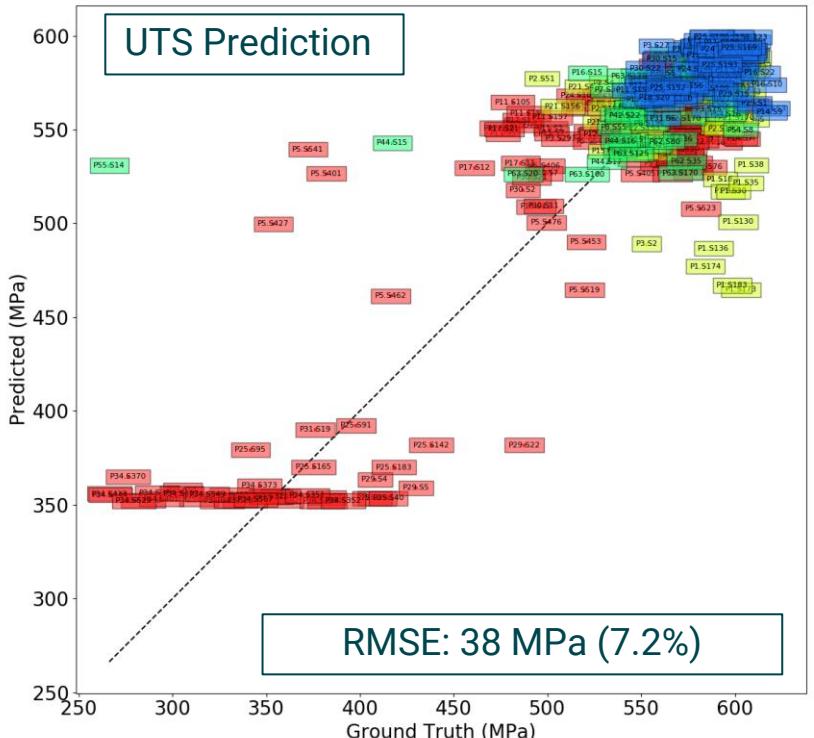
Digital twin data mapped to sample



## Characterization data



## Prediction model results

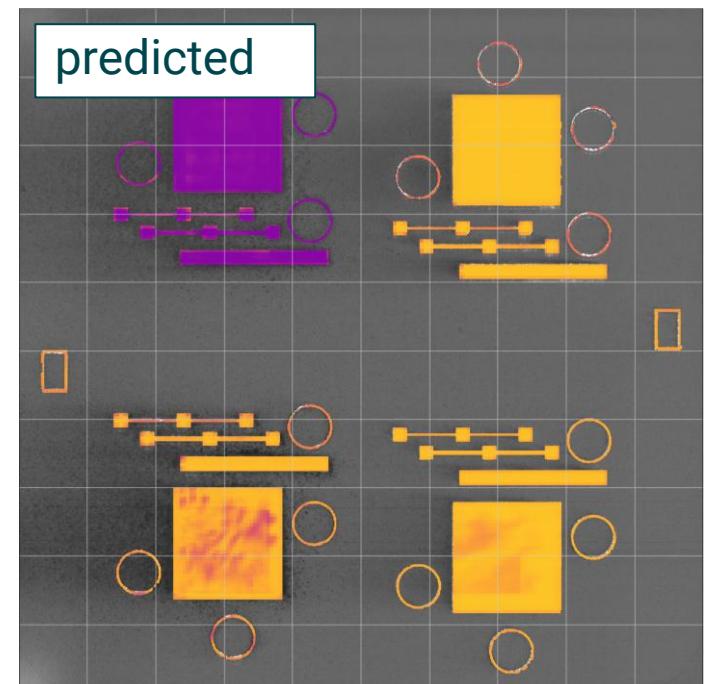


- The UTS RMS error is **38 MPa** over an observed range of 80 MPa – 610 MPa
- This represents a **61% reduction** in the extrinsic RMS error compared to the naïve estimate of the material properties

measured

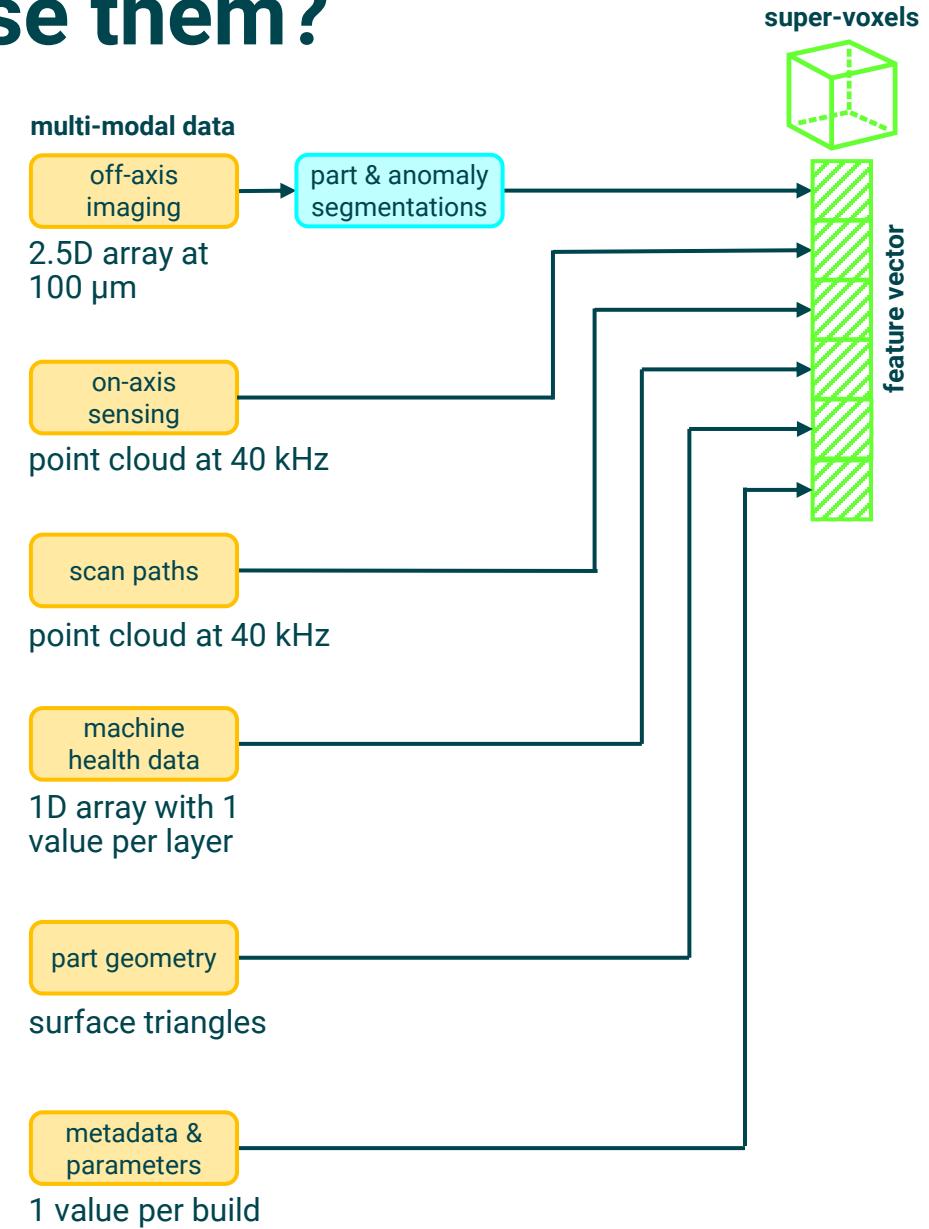
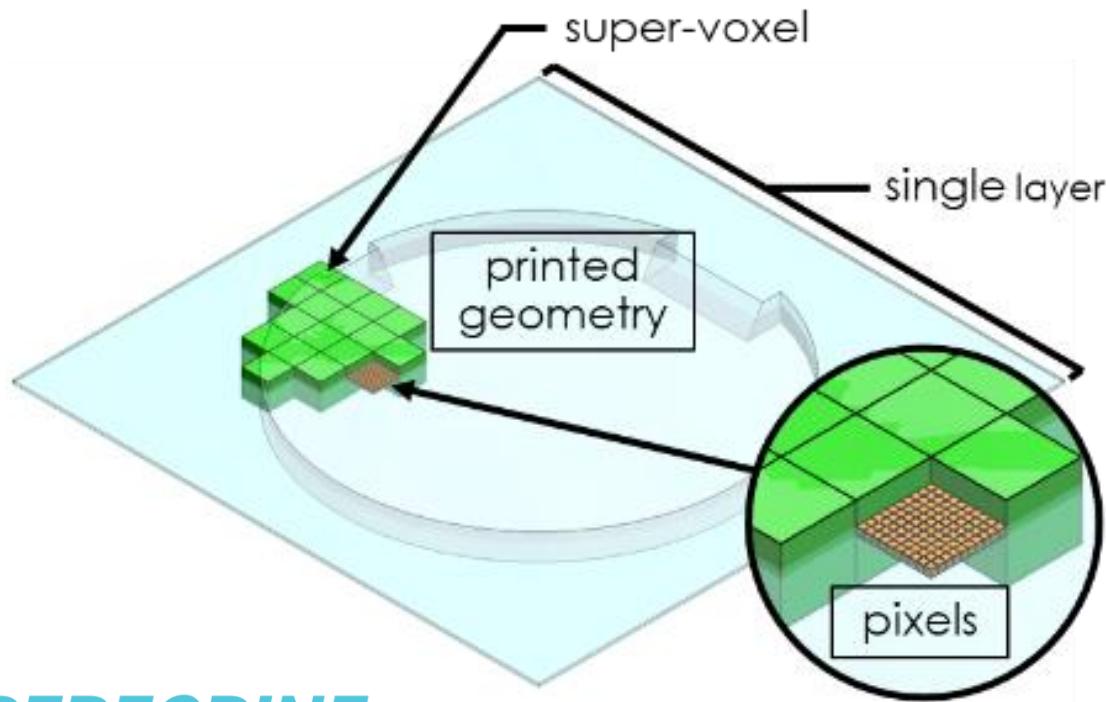


predicted

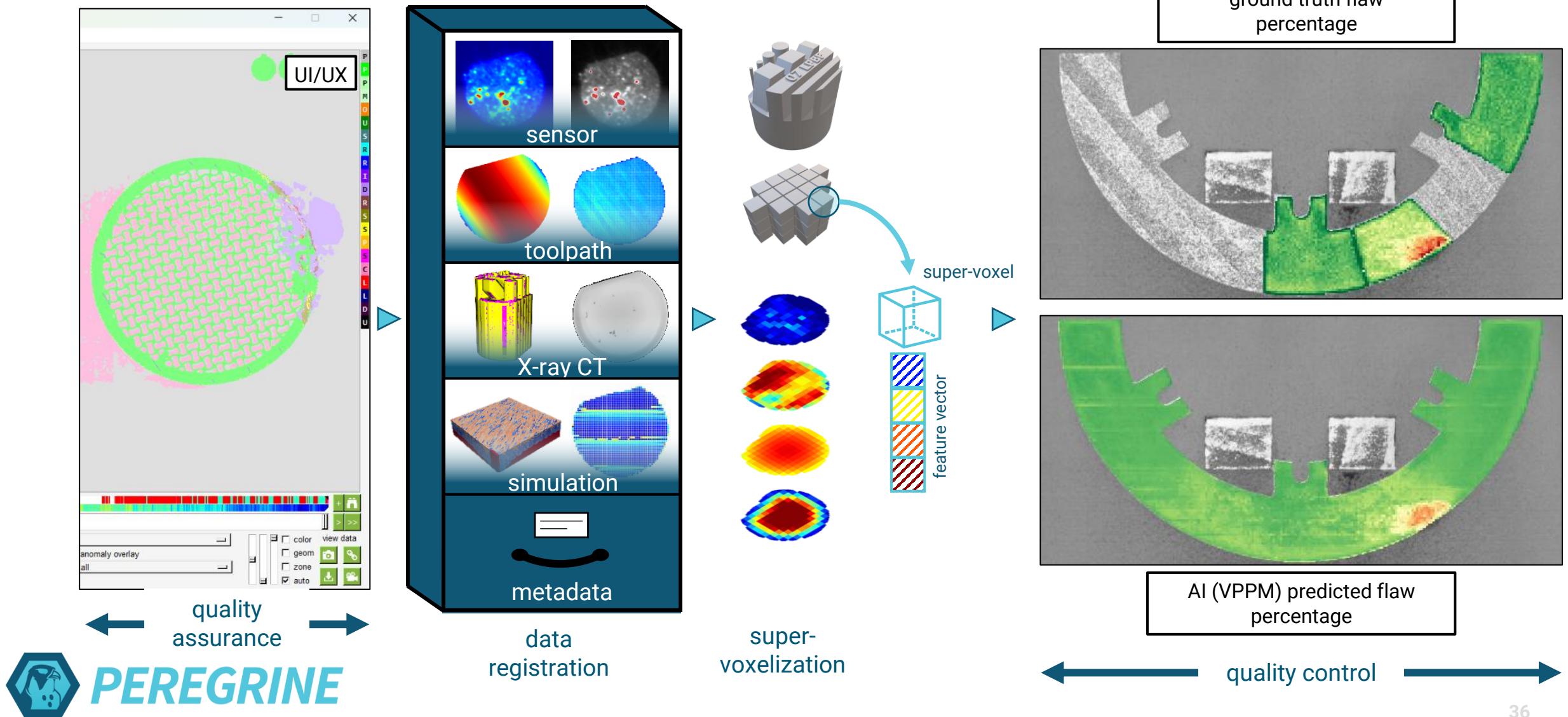


# What is A super-voxel and why do we use them?

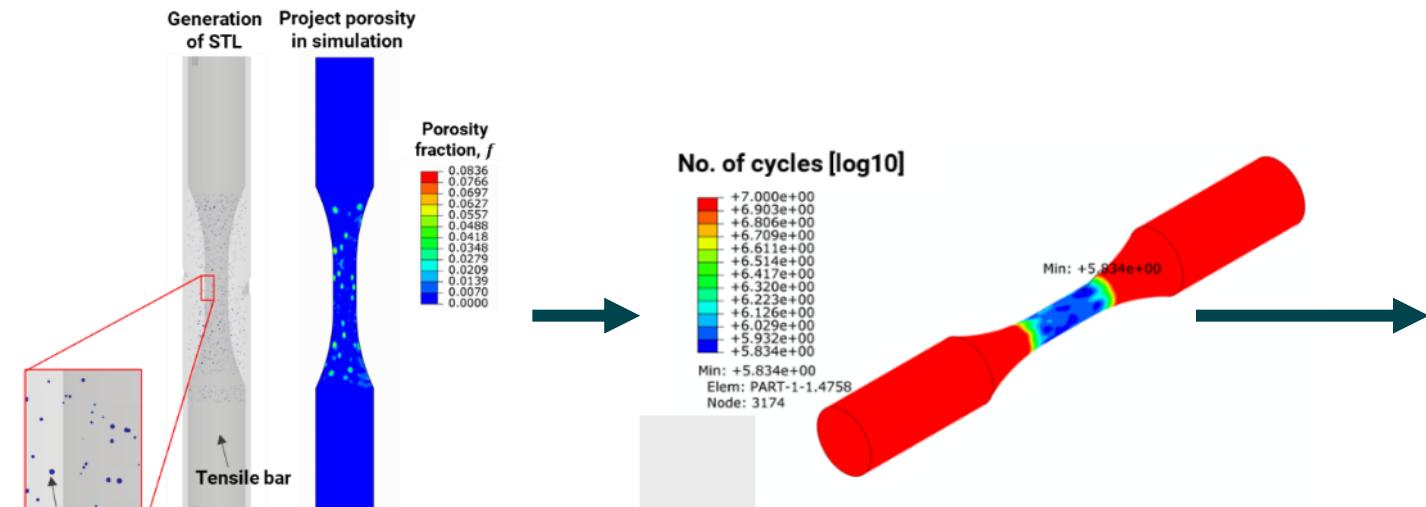
- Achieving property and flaw predictions requires **multi-modal data synthesis** collected at **different spatial/temporal resolutions**
- Predicting properties and flaws is hypothesized to require significant context, e.g., **multi-layer information**
- Humans synthesize using visualizations, but **computers need extremely structured inputs** – this is the goal of the **super-voxel**



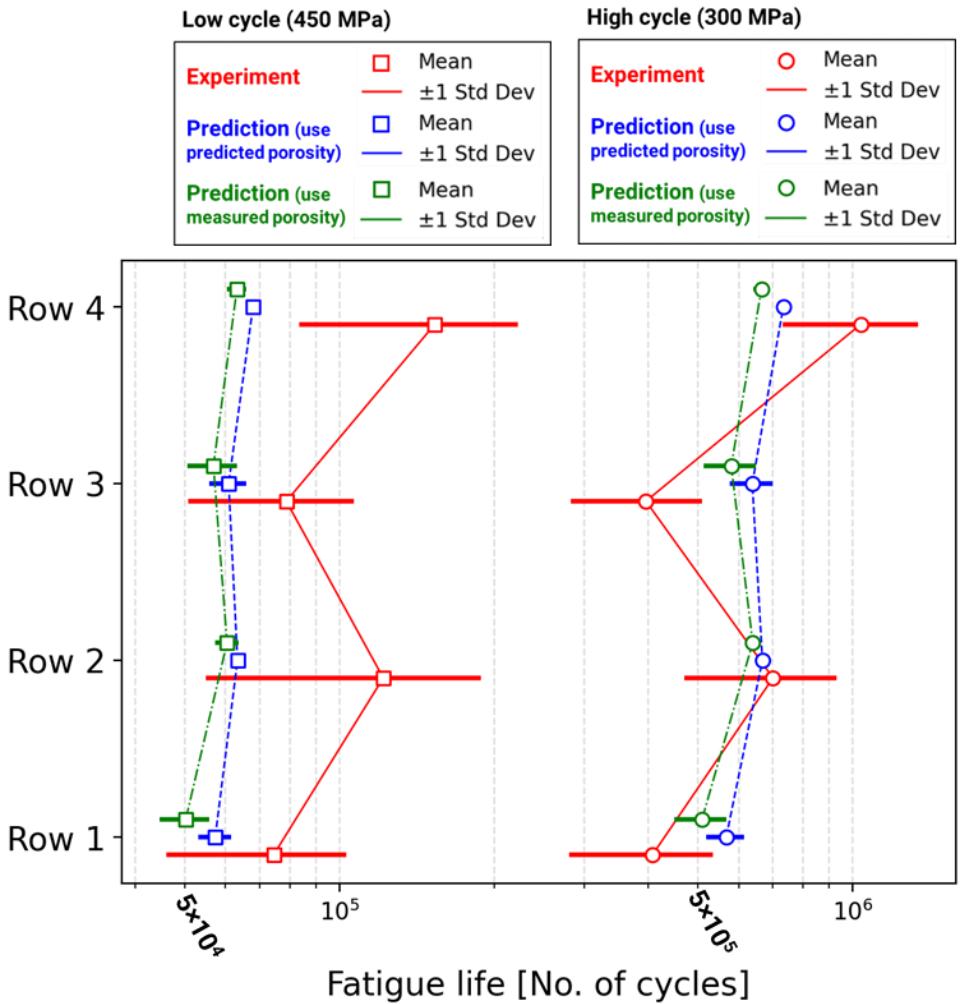
# Predictive Modeling For Manufacturing: Bridging Quality Assurance And Quality Control



# Fatigue life prediction results

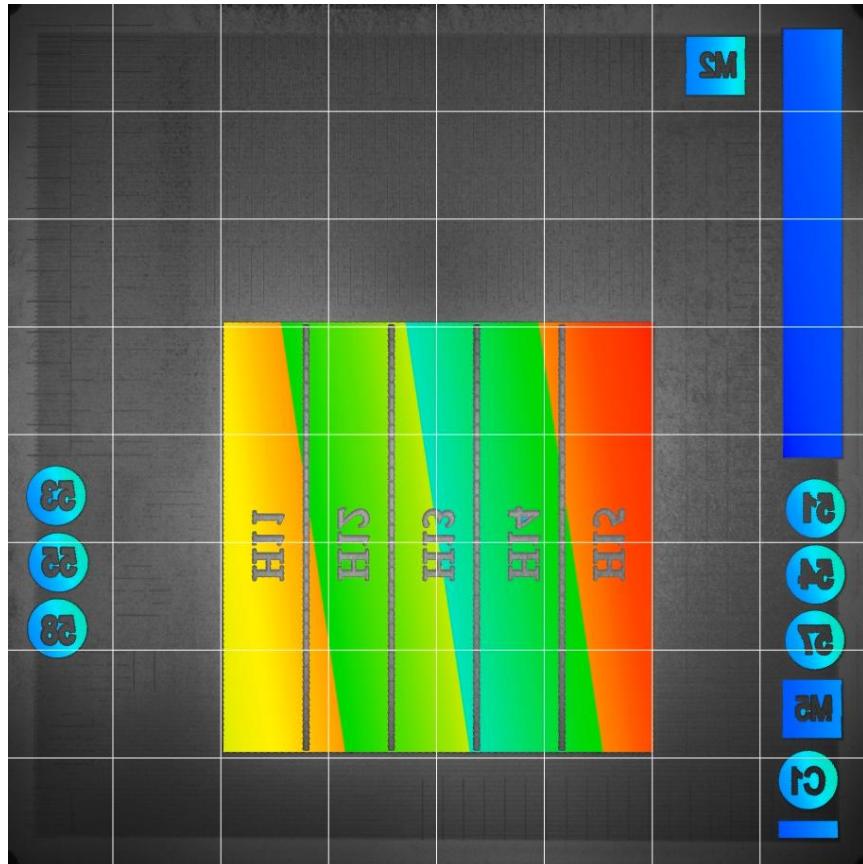


- Construct a virtual part based on the predicted flaw populations
  - Run physics-based models to make performance predictions for each component
  - This is your **digital twin** of your physical component



# Understand Limitations of Current Scan Strategies

## Linear Toolpath



## Point-Based Raster Pattern

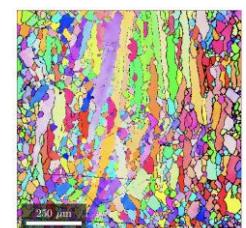
Independent small pools **cool quickly**



**Large slow-moving** pool cool slowly



Rapidly scanned **uniform heat** distribution

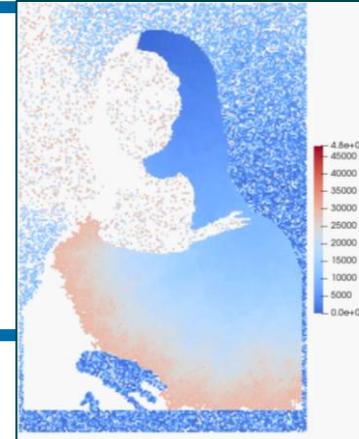


# Scan strategy optimization for microstructure control

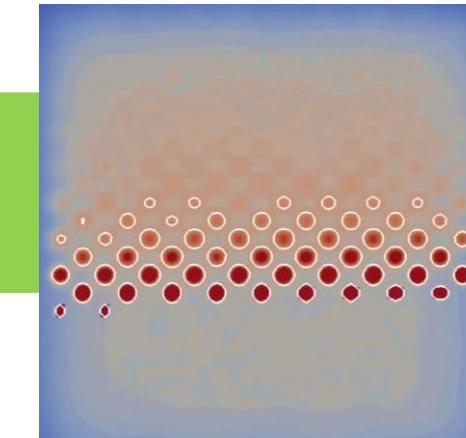
Target:  
Mona Lisa  
portrait



Scan strategy  
using heuristic,  
Genetic  
Algorithm, or  
AI/ML

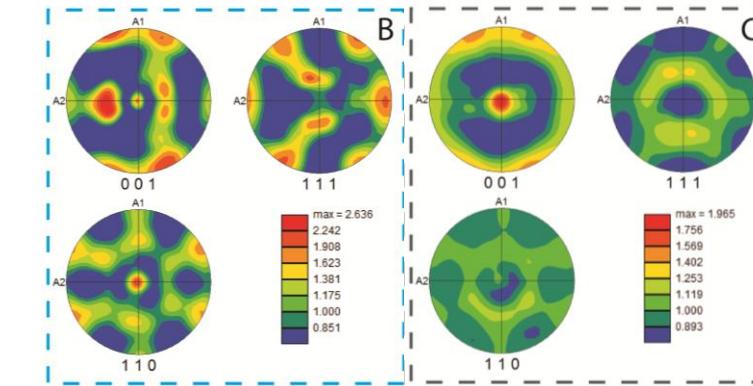
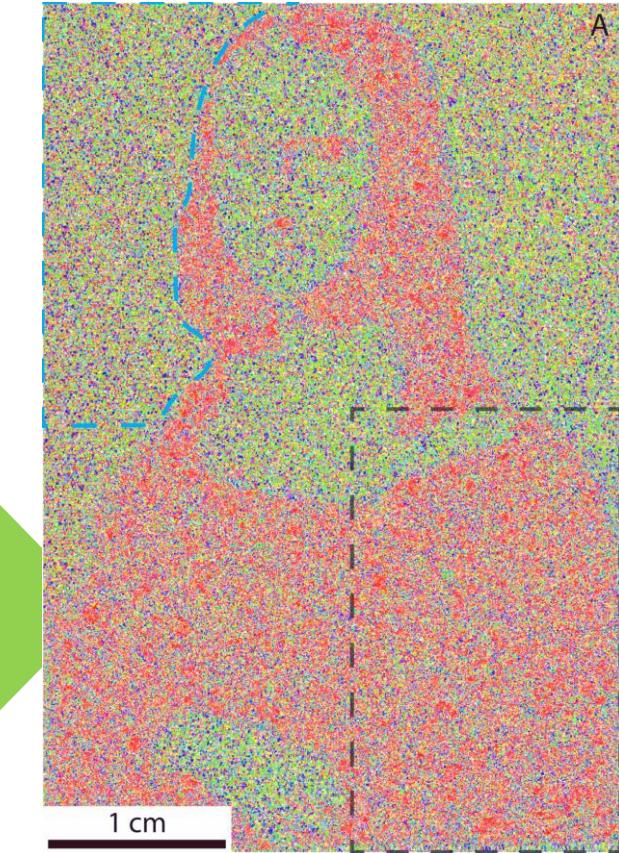
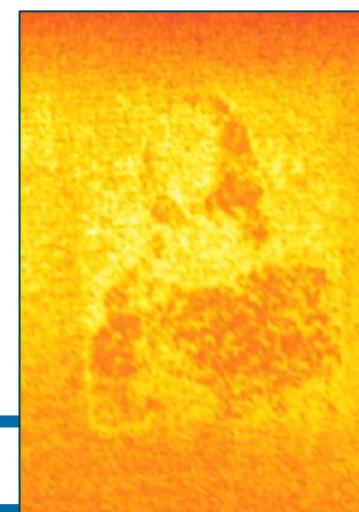


- Material: Inconel 718
- # dots: 60,000
- Machine parameters are constant, only the scan strategy is changing
- Portrait printed every layer
- **Challenge:** solve traveling salesman problem for physics-based thermal model optimization condition



Fluid mechanics  
lower order  
models

Thermal Imaging



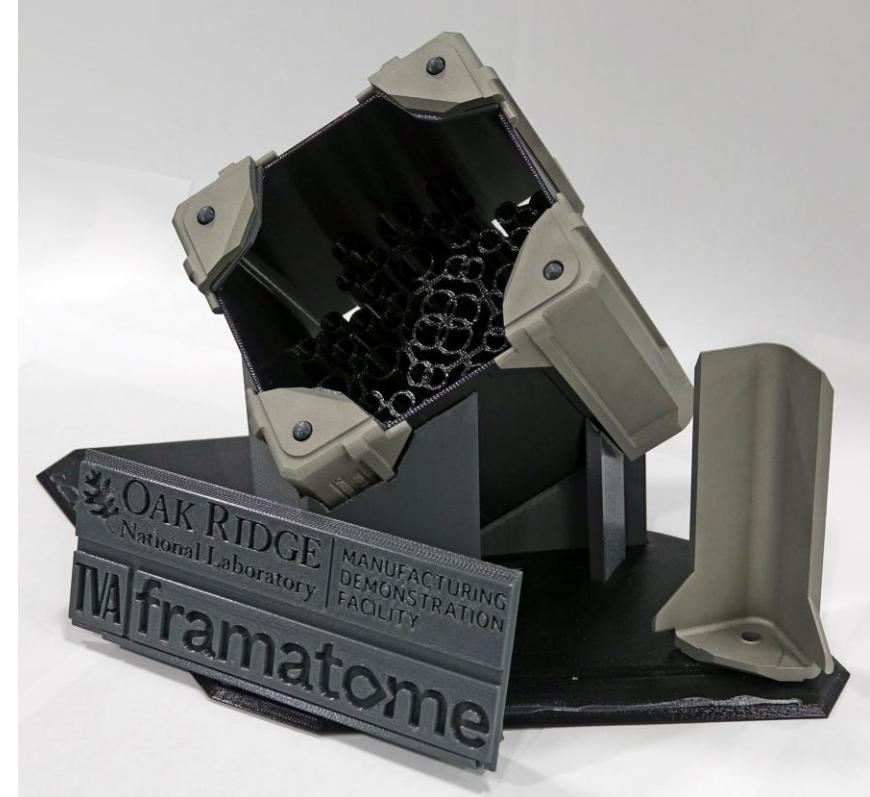
# Demonstrations in Power Generation Technology

## Gas Turbine Engine



Near net-shaped Mercury 50 Stage 2 airfoil set from a high gamma prime Ni-base superalloy. Successfully tested on August 25<sup>th</sup>, 2020

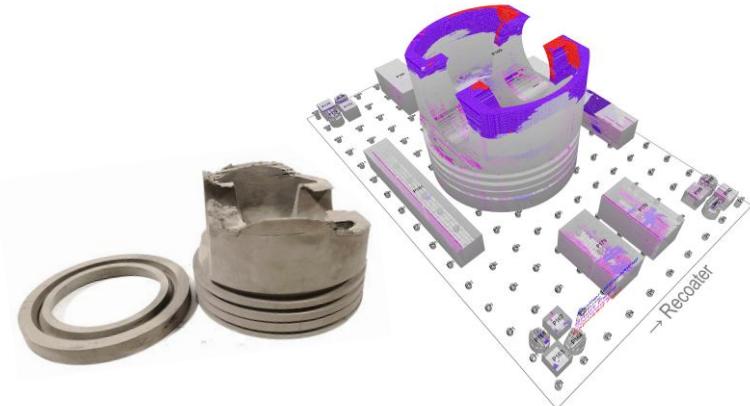
## Nuclear



Framatome Channel Fasteners inserted into TVA's Browns Ferry Unit 2 reactor April 26th, 2021

# Multiple Opportunities for Scientific Discovery Using AI

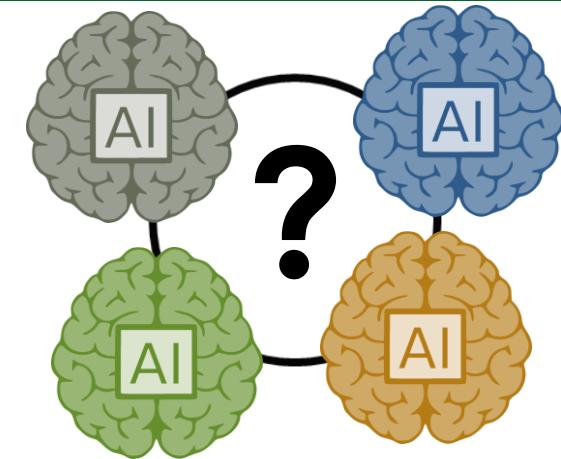
Standards for Component Digital Twins



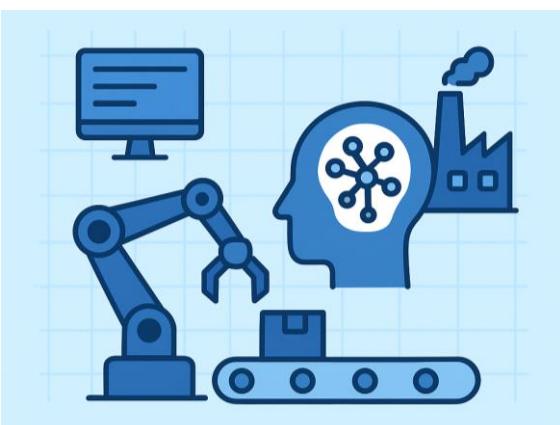
Data Engineering



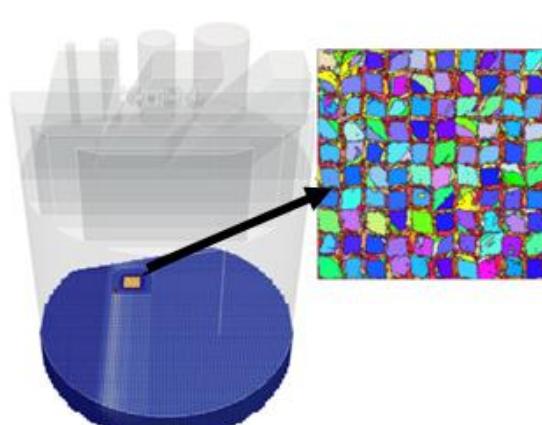
AI/ML Model Interpretability and Explainability



Agentic AI



Mod/Sim/AI for Materials and Process Prediction



LLM and AR/VR for User Assistance



# Questions?

Contact:  
[paquitvc@ornl.gov](mailto:paquitvc@ornl.gov)

