# The Use of AI in Welding

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Process Monitoring Session

Adaptive Feedback Welding: Problem Definition

- Operator-driven, "mechanized" arc welding is used for many safety-related welds in the nuclear industry

- Availability of skilled certified welding operators has become increasingly scarce since the turn of the century

- Weld quality/productivity will become a significant issue in the future as the industry struggles to maintain skilled welders
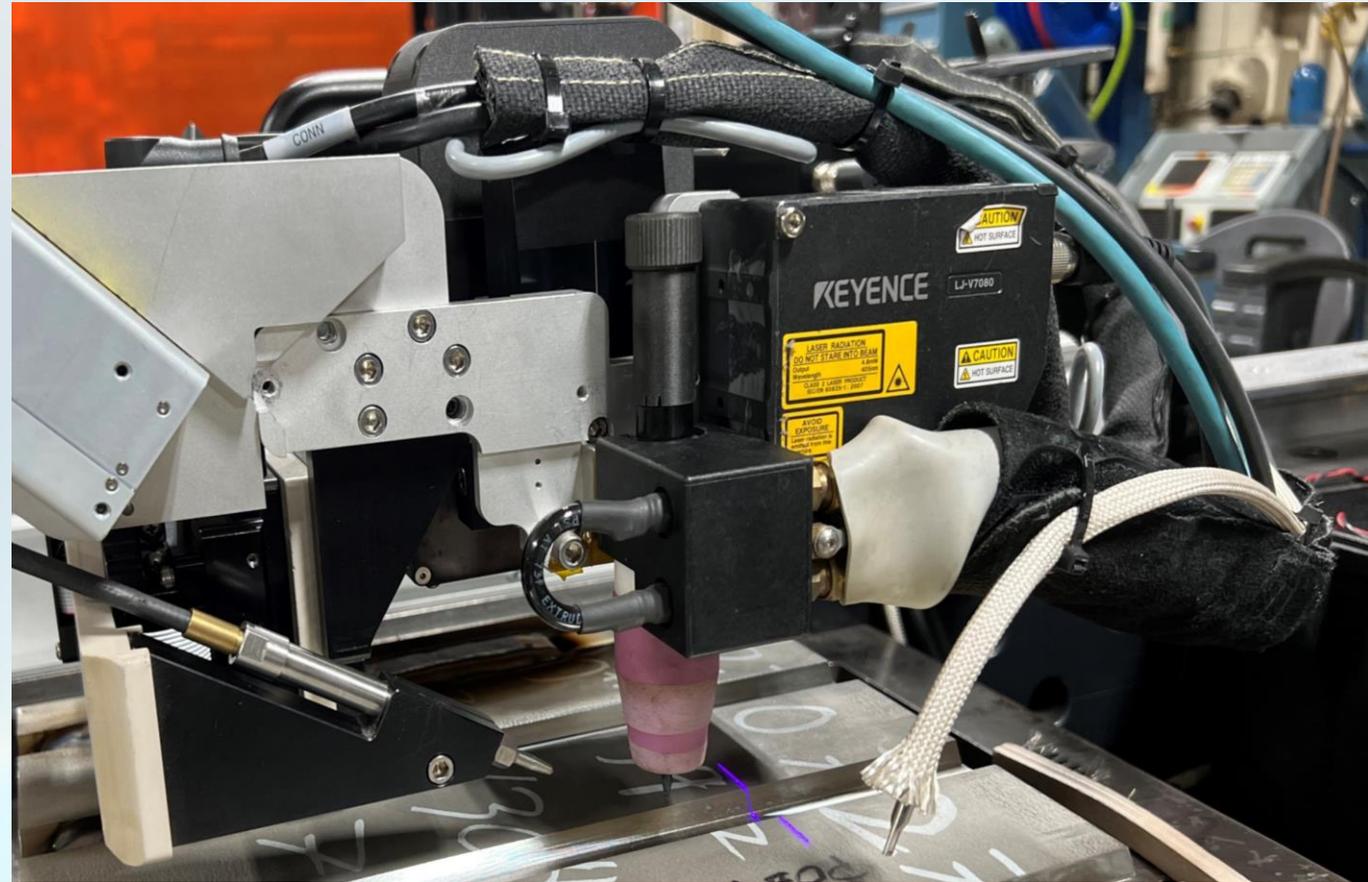
EPRI Adaptive Feedback Welding System

Problem Definition

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Solution: Artificially Intelligent Autonomous Welding

Real-time data to support adaptive control ("eyes and ears")

- Real-time image data processing from vision system
- Real-time weld, groove, and joint profile data from laser profiler
- Weld parameter data acquisition
- Acoustics (microphone) data

Solution to address reduced welding workforce ("brain")

- The next evolution for the welding process is to drive it towards autonomous operation, accomplished through real-time data processing / feedback and incorporation of artificial intelligence algorithms

Optimal Profile & Parameter Prediction
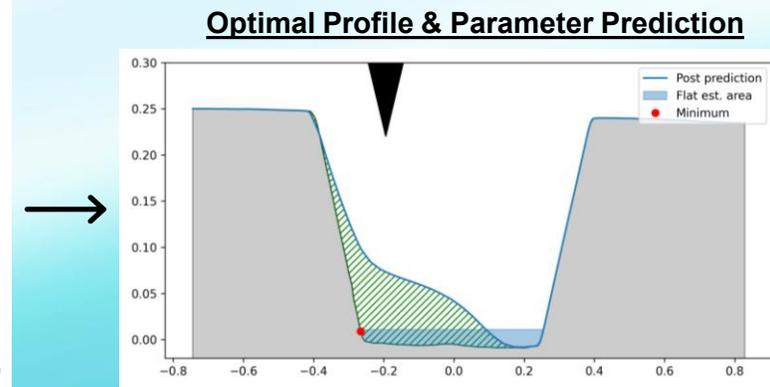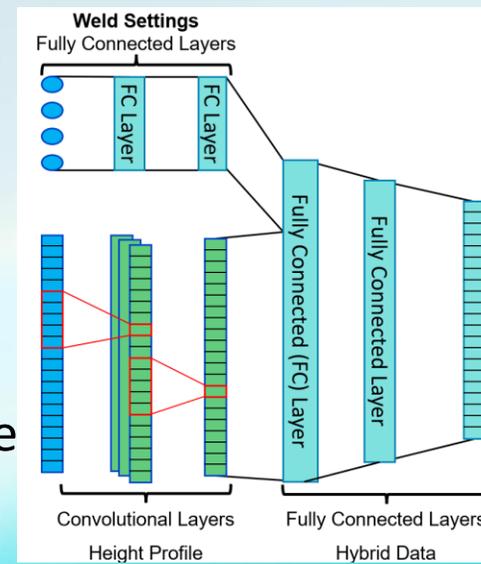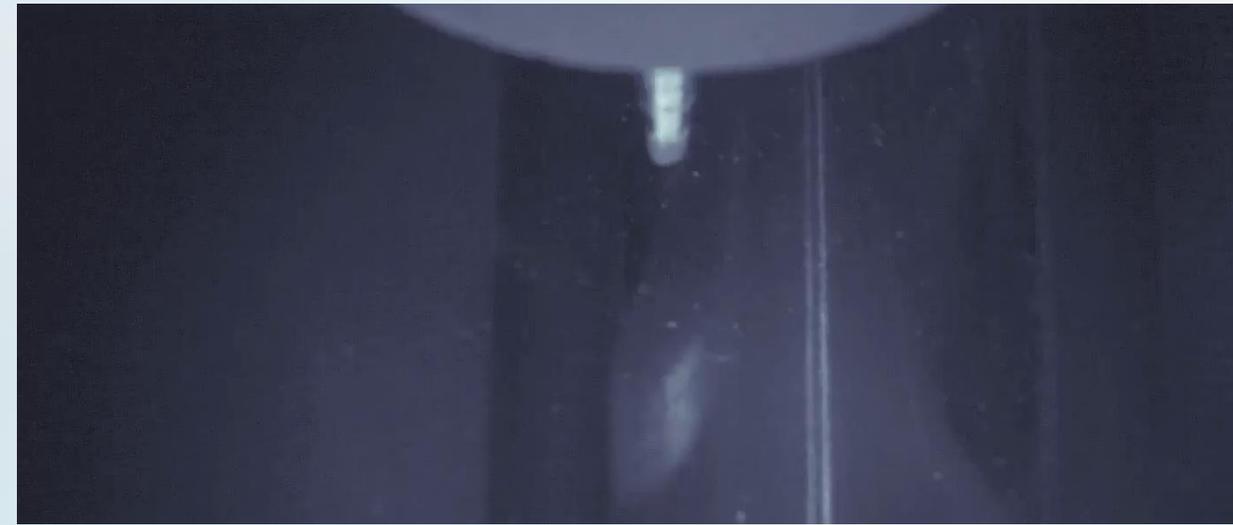
Key Project Research Needs

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Collaborative Model for Commercial Implementation

Welding Equipment Sensor Data Collection Test Algorithms

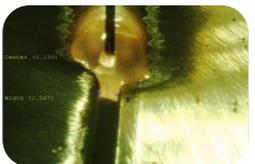**Data Processing** — **Algorithm & Neural Network Development**

Iterative Data Collection & Algorithm Development

AI MODEL

Commercial Implementation — Adaptive Weld System for Industry Integration

Application-Specific Model Training

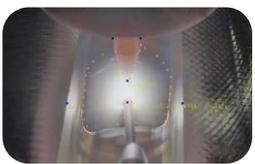**Different Equipment** — Liburdi Equipment

Multiple Processes — GMAW, GTAW

Weaving — Oscillating Electrode

Multiple Applications — Orbital Welding

Convolutional Neural Network
Semantic Segmentation:
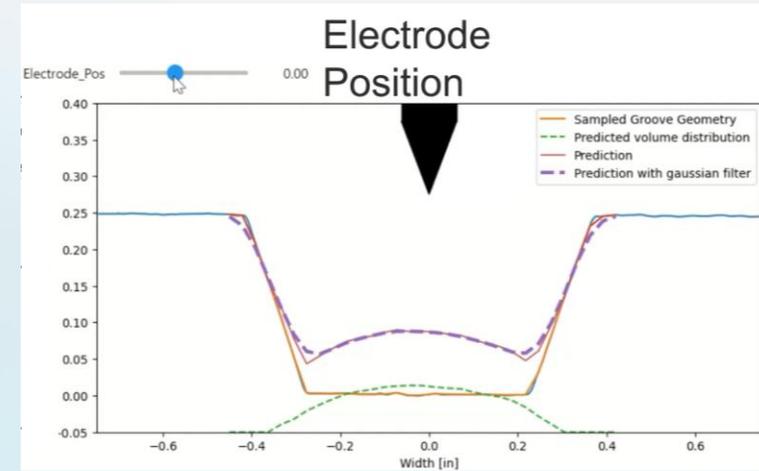Real-time Image Processing (3X speed)

Wire Position Control

Weld Pool Shape Monitoring

Different Cameras

EPRI
ELECTRIC POWER
RESEARCH INSTITUTE

LIBURDI
DIMETRICS

Optimal Parameter Selection Tool

Electrode Position

Operator Defines:

- *WFS & TS*
- *Current & Voltage*
- *Cap (height, width)*
- *Parameter Limits*

For *all* parameter combinations

Calculate Score

Load Profile Data → **Calculate Cross-Section** → **Define Parameter Combinations**
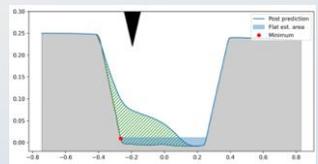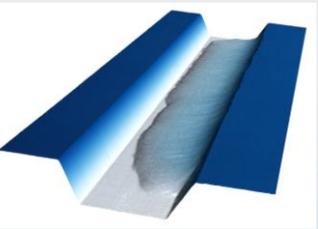
Predict weld bead shape

Compare Score with best weld found so far

Get new parameter combination
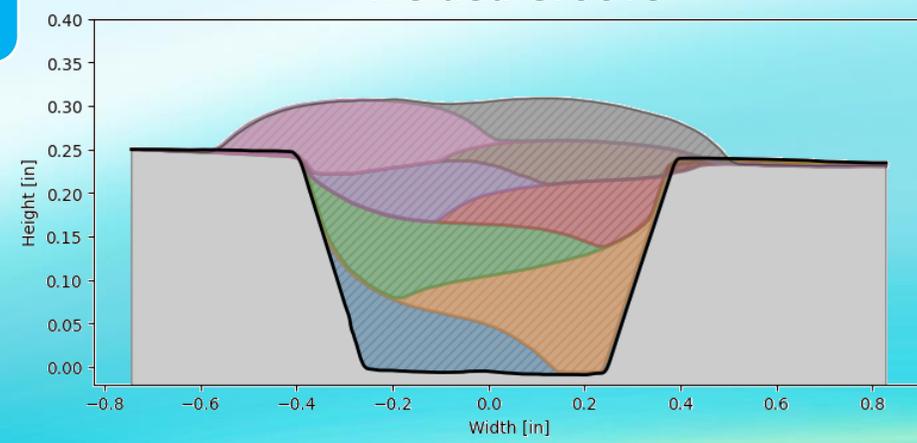
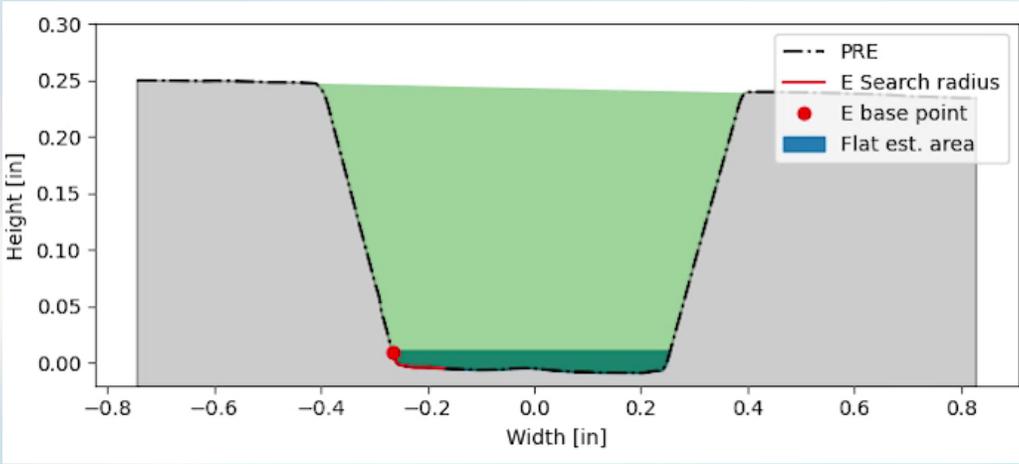**Return & Upload Best Combination**

Begin Welding & Repeat
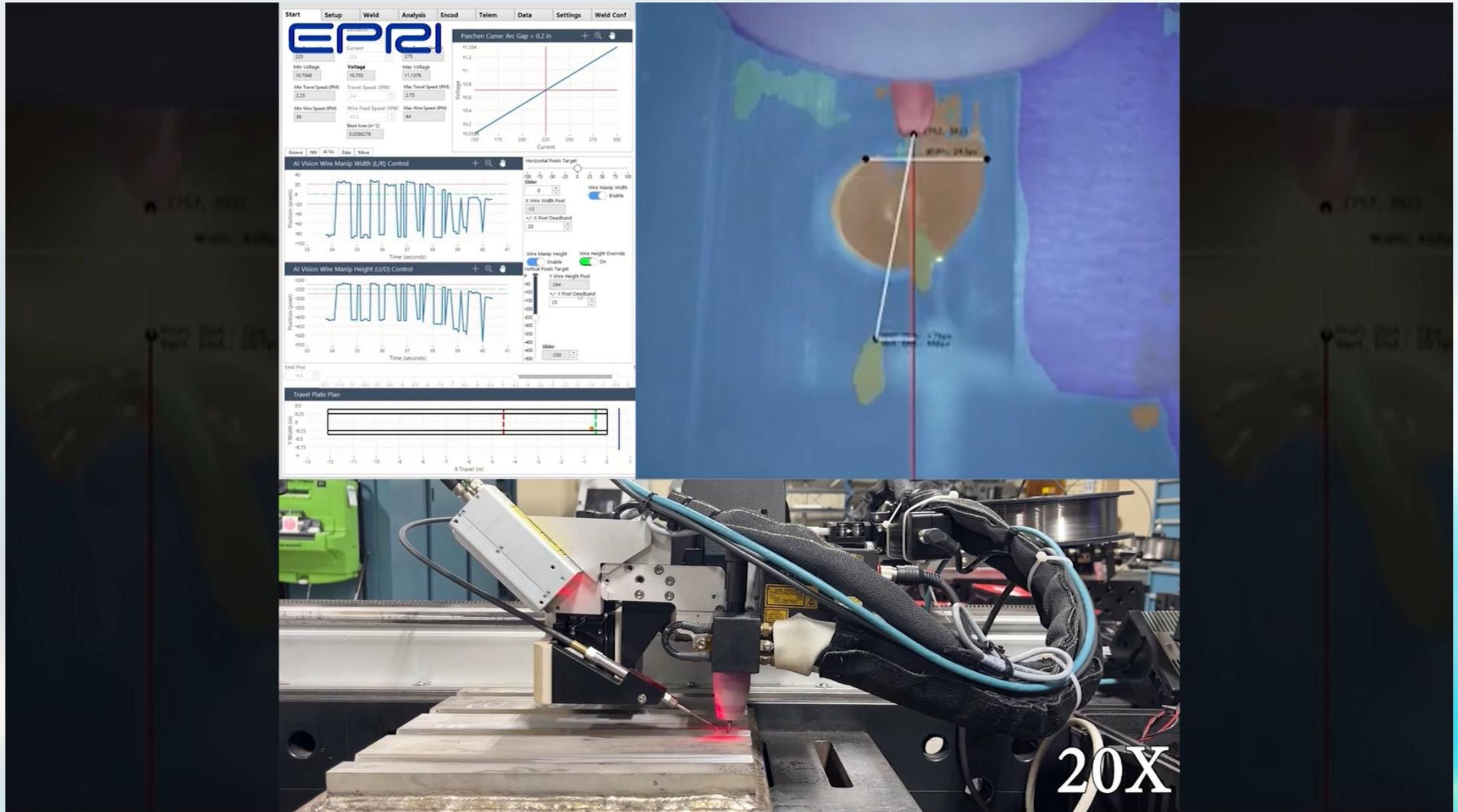

Actual Profile of Autonomously Welded Groove
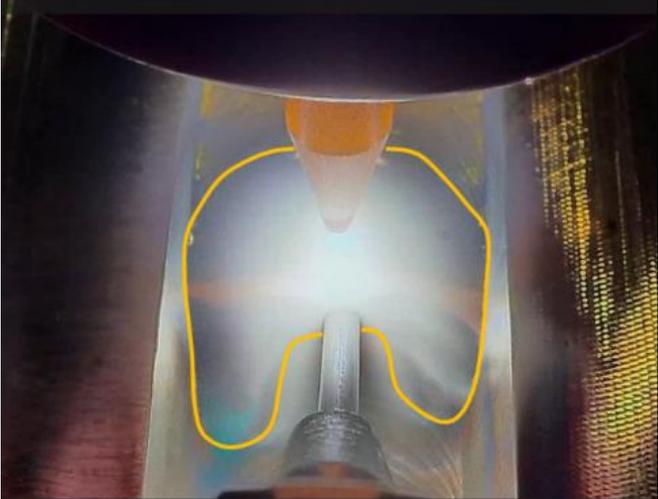
Fraunhofer   EPRI

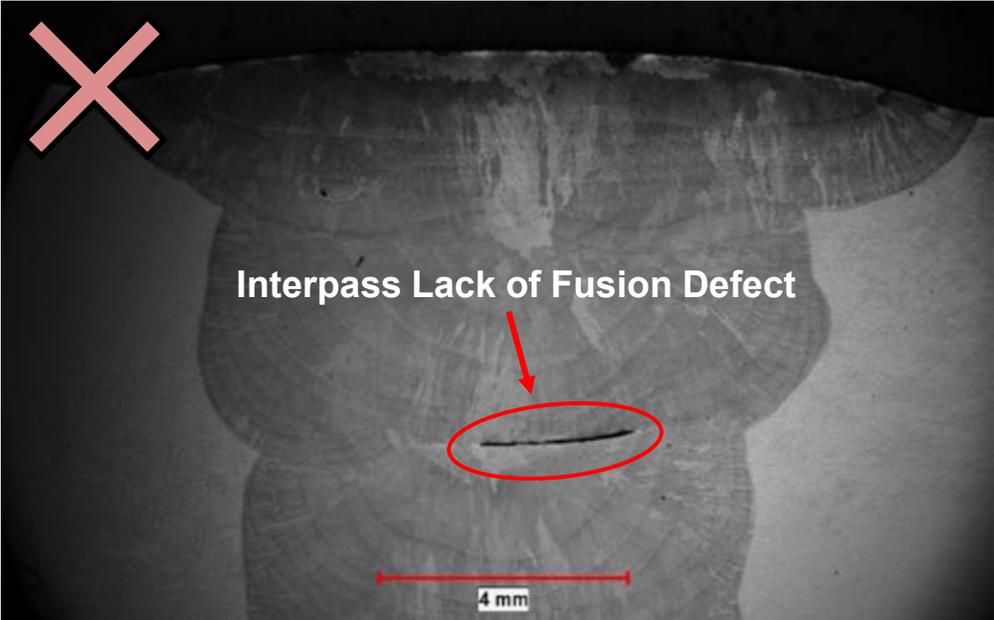# Adaptive Welding Demo – EPRI System

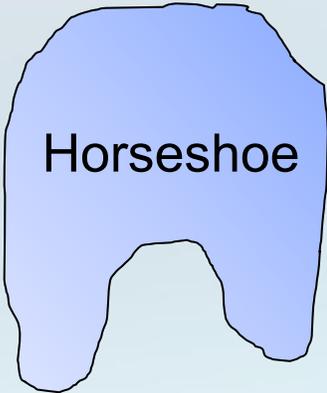# Real Time Detection of Weld Defects

- Weld Pool Shape -> Presence of Defects

Do Nothing
- Traveling Too Fast
- Excessive Wire Feed Speed

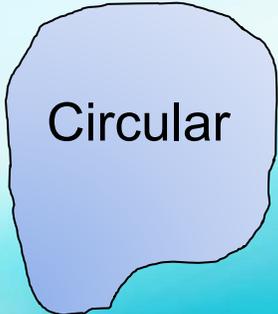Horseshoe

Interpass Lack of Fusion Defect

4 mm

Adaptive Correction
- Decrease Travel Speed
- Decrease Wire Feed Speed

Circular
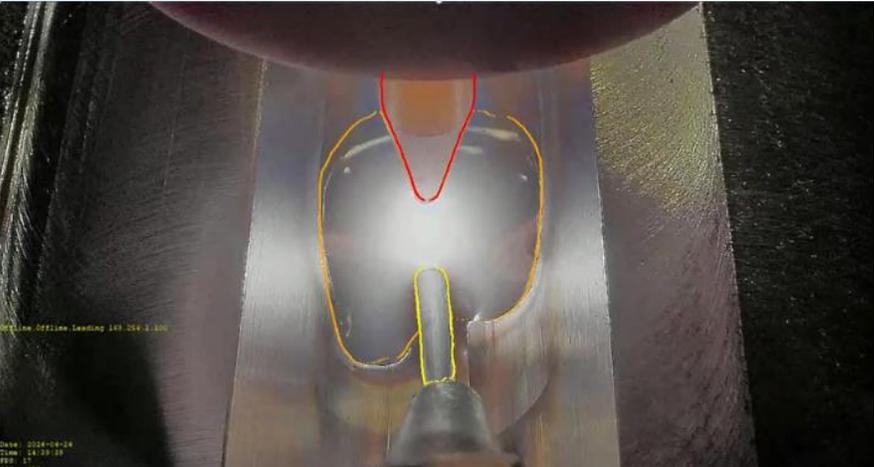
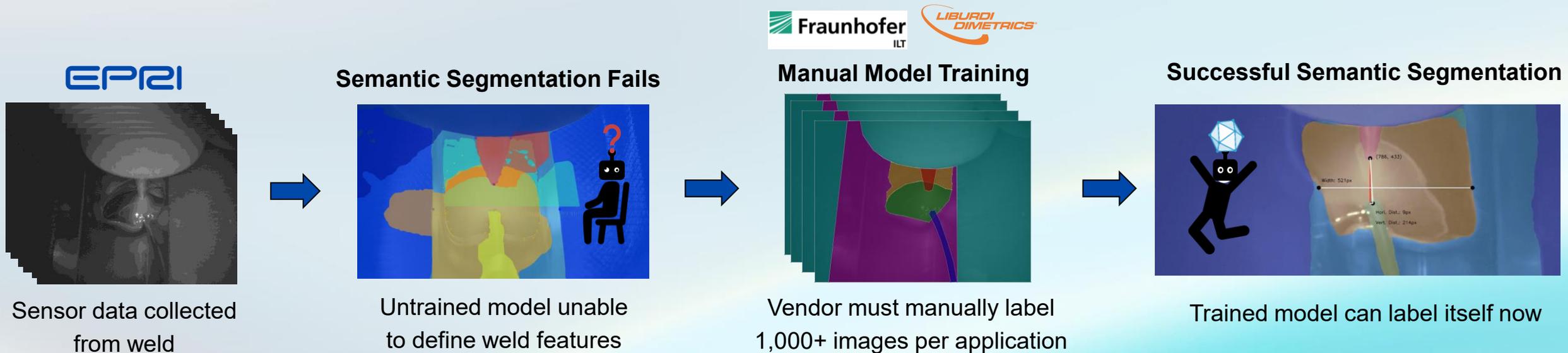# Technology Transfer: Canister Closure Welding at Hanford Site

- Adaptive feedback welding system to be deployed in 2025 to autonomously perform high radiation cesium-strontium canister closure welds at the U.S. Department of Energy Hanford Site

    - Collaboration with U.S. DOE, Fluor, Liburdi Dimetrics, and Central Plateau Cleanup Company
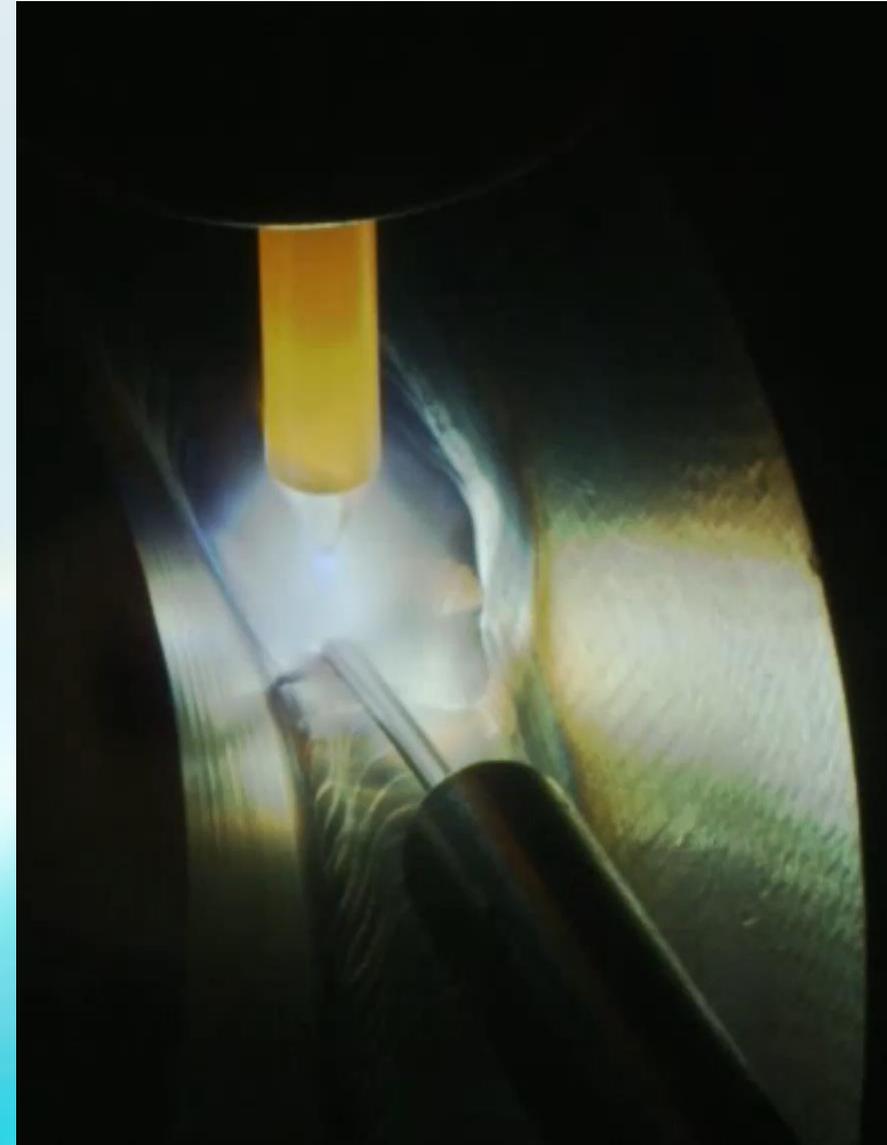
Next Steps to Improve AI Algorithms: Semi-Supervised Learning

- **Supervised Learning:**
  - Developed AI algorithms currently require manual labeling of 1000+ images per application to train model
  - Tedious manual labeling presents bottleneck for commercial implementation

Semantic Segmentation Fails **Manual Model Training** **Successful Semantic Segmentation**

Sensor data collected from weld

Untrained model unable to define weld features

Vendor must manually label 1,000+ images per application

Trained model can label itself now

- **Phase 2: Development of Semi-supervised Learning Approach**
  - Develop improved labeling methods to potentially reduce required number of manually labeled images to between 10 and 50 per application

Next Steps to Improve AI Algorithms: Penetration Monitoring

*Collaboration with Oak Ridge National Laboratory*

OAK RIDGE
National Laboratory

Partial penetration

Full penetration

Testing	Thickness, mm	Speed, mm/s	BKG Current, A	PK Current, A	Pulse Duration, %	Comment
1	2.5	4.3	100	200	5	Partial
2	2.5	4.3	120	240	5	Partial
3	2.5	4.3	140	280	5	Partial
4	2.5	4.3	150	300	5	Full
5	2.5	3.7	150	300	5	Full
6	2.5	3.7	120	240	5	Full
8-wire	2.5	3.7	150	300	5	Full-wire
9	1.5	4.3	80	160	5	Full
10	1.5	4.3	60	120	5	Full

Weld pool dynamics (x34 slow motion)

Weld pool vibration
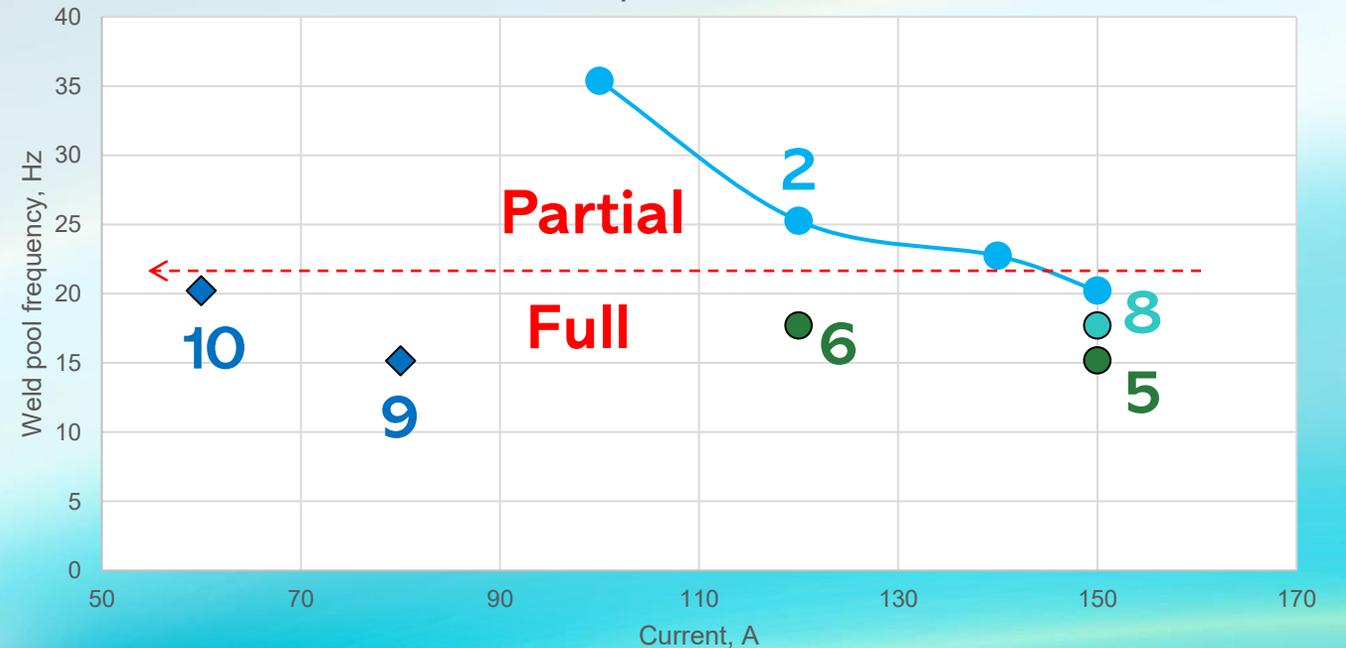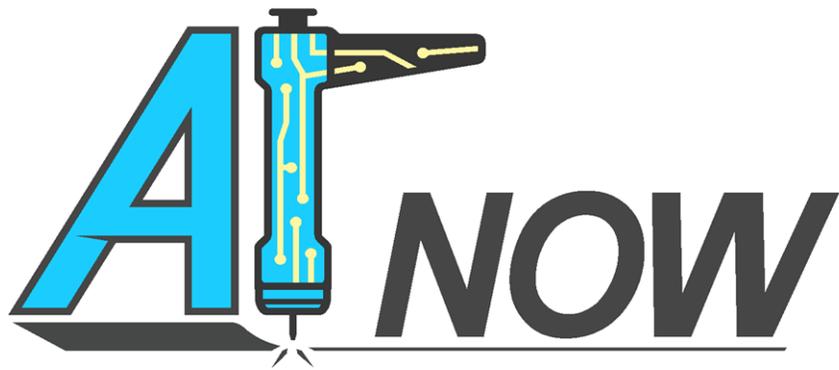
Artificially Intelligent, Next-Gen Optimized Welding Implementation Program

New EPRI Supplemental Program to accelerate industry implementation of intelligent AI-driven welding

Goals
- Accelerate transfer and deployment of EPRI adaptive welding technology
- Develop modular, platform-agnostic control system supporting diverse sensors & welding equipment configurations
- Create R&D consortium to enable cross-sector collaboration

Benefits
- Opportunity for application-specific algorithm training, demonstrations, & tailored implementation support (Tier 1)
- License rights to EPRI-developed, field-validated adaptive control algorithms & version updates (Tier 2)
- Significant cost savings (reduced oversight, repairs, inspections)

EPRI Roles
- Provide members early influence over acceptance standards, training, system architecture & priorities to meet member needs.
- Promote an industry-supported approach to qualification, validation, & field demonstrations, reducing time, cost, & risk of transitioning autonomous welding from concept to deployment

Connecting Members
- Initial outreach underway. Webinars and scoping calls to be held with interested organizations
- Tiered membership model based on desired level of engagement
- Anticipated launch: Q4 2026 with initial demonstrations & prototyping in Q2 2027

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Applications Currently Being Explored for Adaptive Welding

- Nuclear:
  - Primary loop construction (narrow groove welding)
  - Spent nuclear fuel canister fabrication
  - Fabrication of advanced reactor piping system & pressure-retaining structures
  - Main Steam Line Replacements
  - Additive manufacturing (GMAW, laser DED)
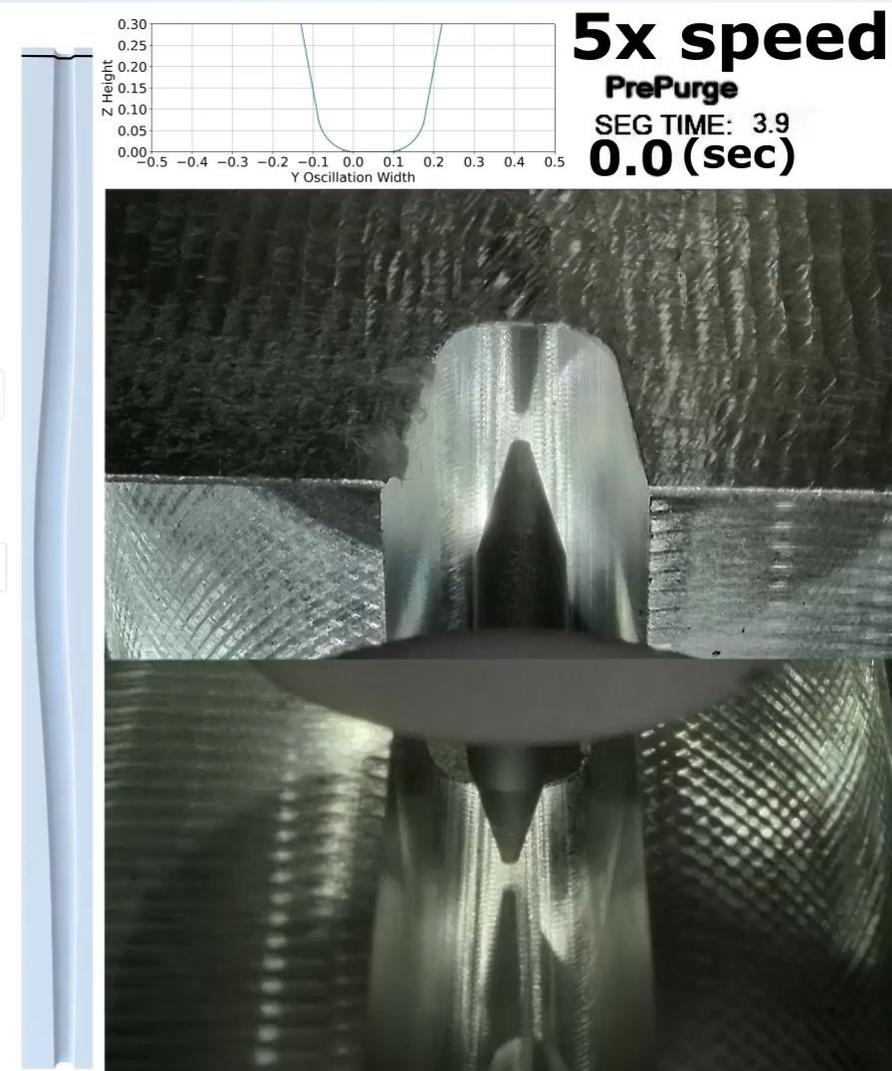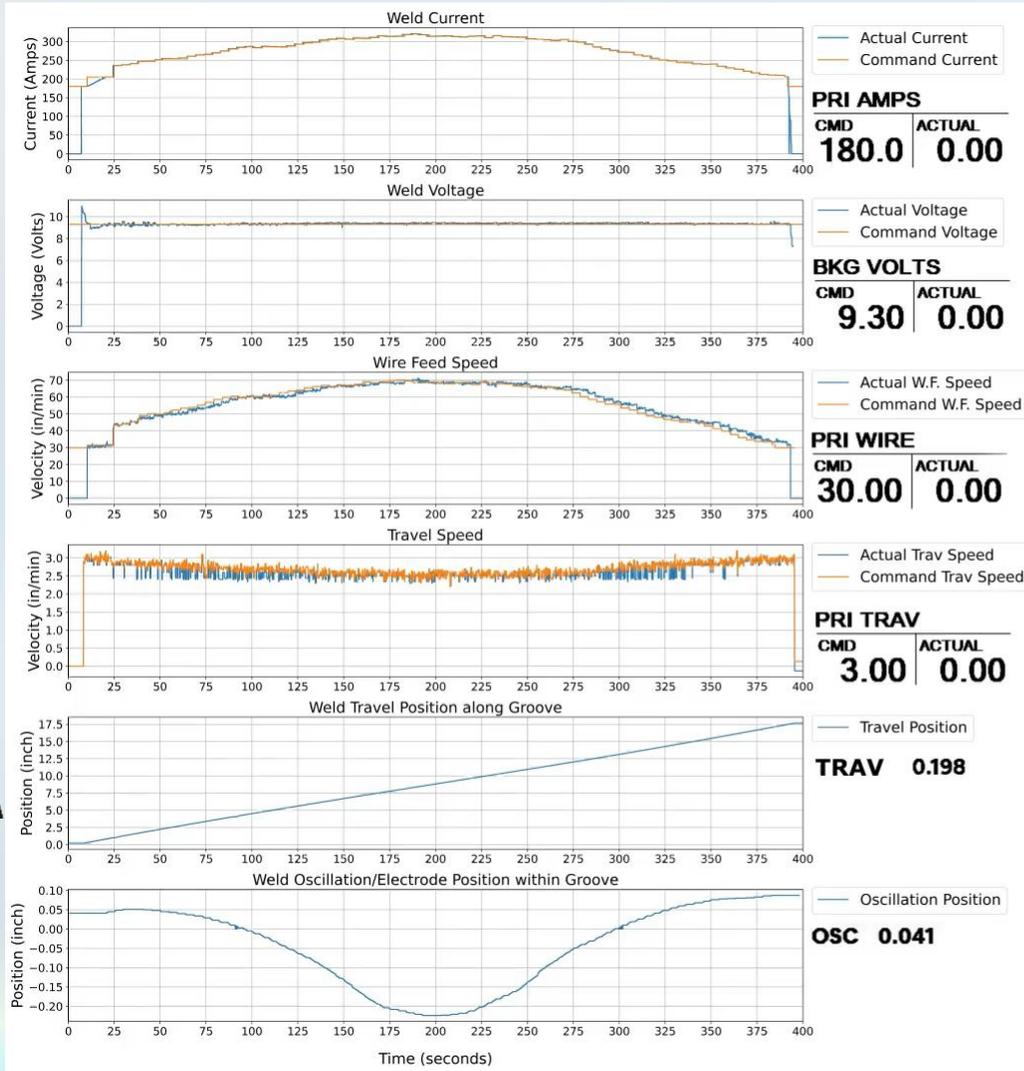 - Structural module fabrication
  - Others?
- Non-Nuclear:
  - Thin-wall orbital piping (Blue Origin – Rocket Engines)
  - Piping and hull joining (Shipbuilding)
  - Off-shore wind turbine fabrication

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ADAPTIVE WELDING DEMO EXAMPLES (LIBURDI)

This product was developed and licensed using research

Adaptive Welding – 2" Schedule 40 Pipe, 37.5 Bevel, Open Root Stainless Steel

Adaptive Welding – 6" Schedule 10 Pipe, No Backing Gas Stainless Steel

Center (0.150)

Width (1.567)

MINIMIZE FIREVIEWSA
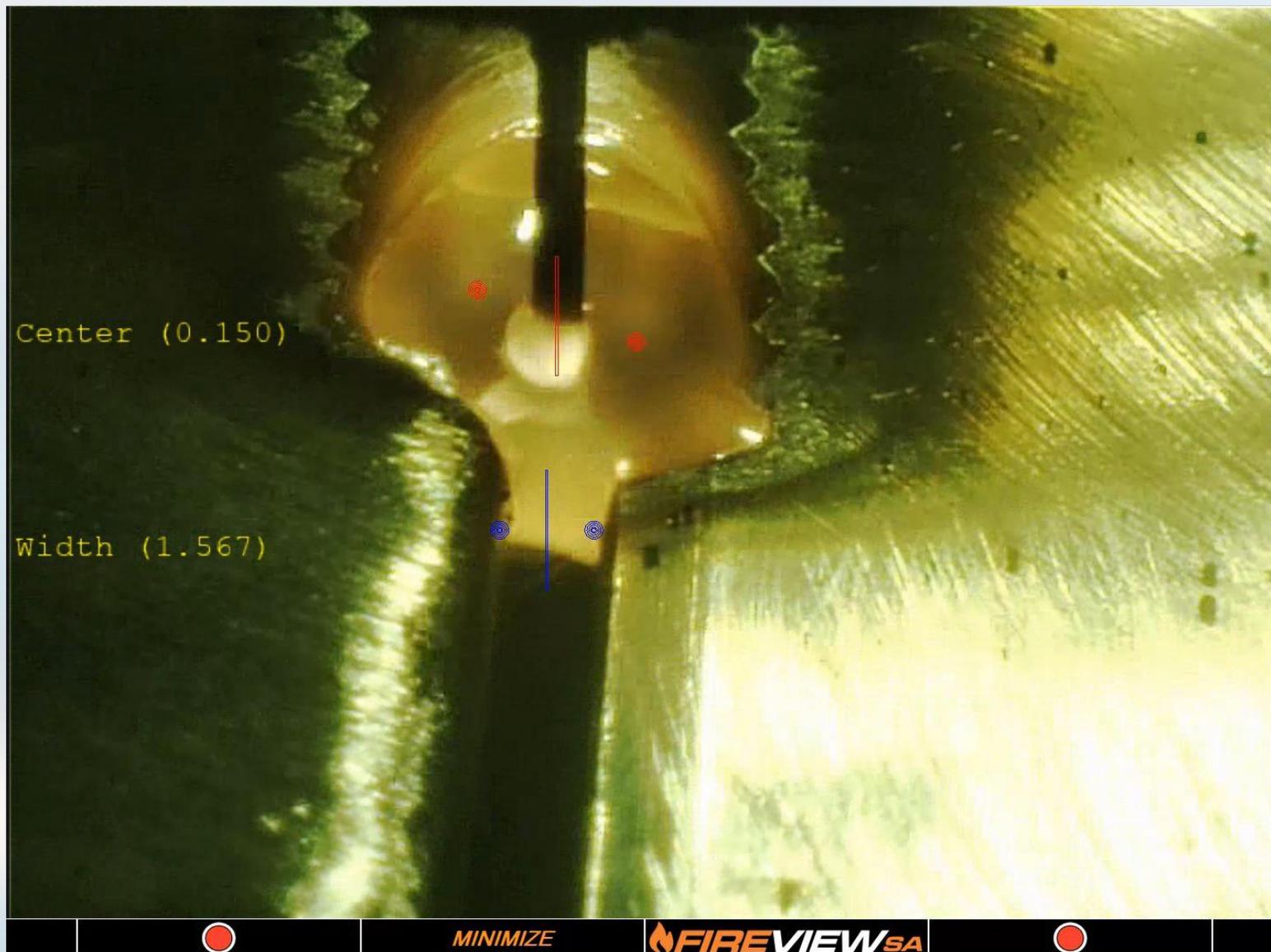
1. Joint Tracking
2. Root Opening Measurement
3. Adaptive Response:

   - Steering
   - Oscillation Width
   - Travel Speed

4. Process limit monitoring (i.e. mismatch)
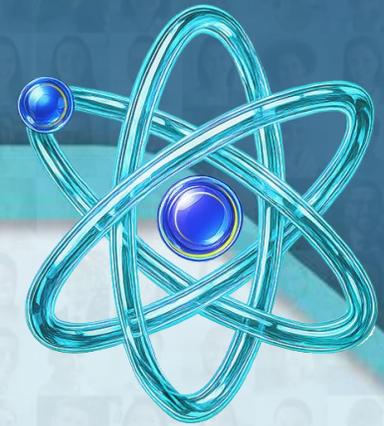5. Weld Pool Monitoring

Adaptive Welding – GMAW Fillet Welding
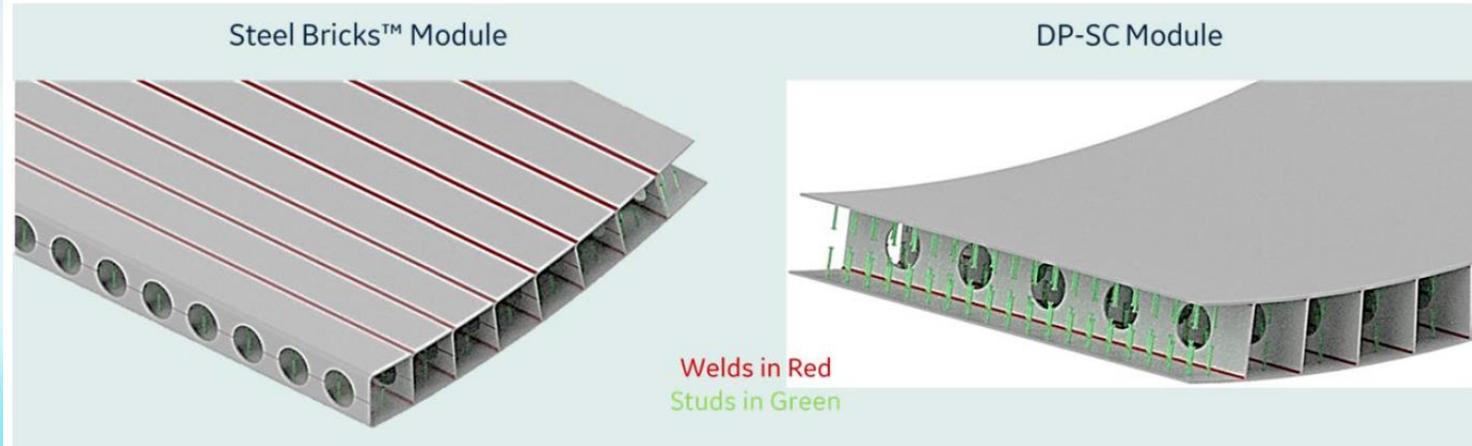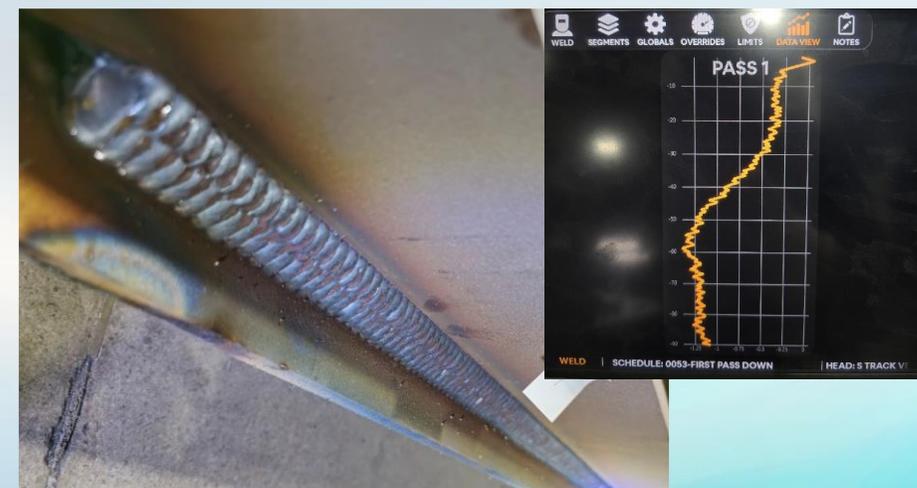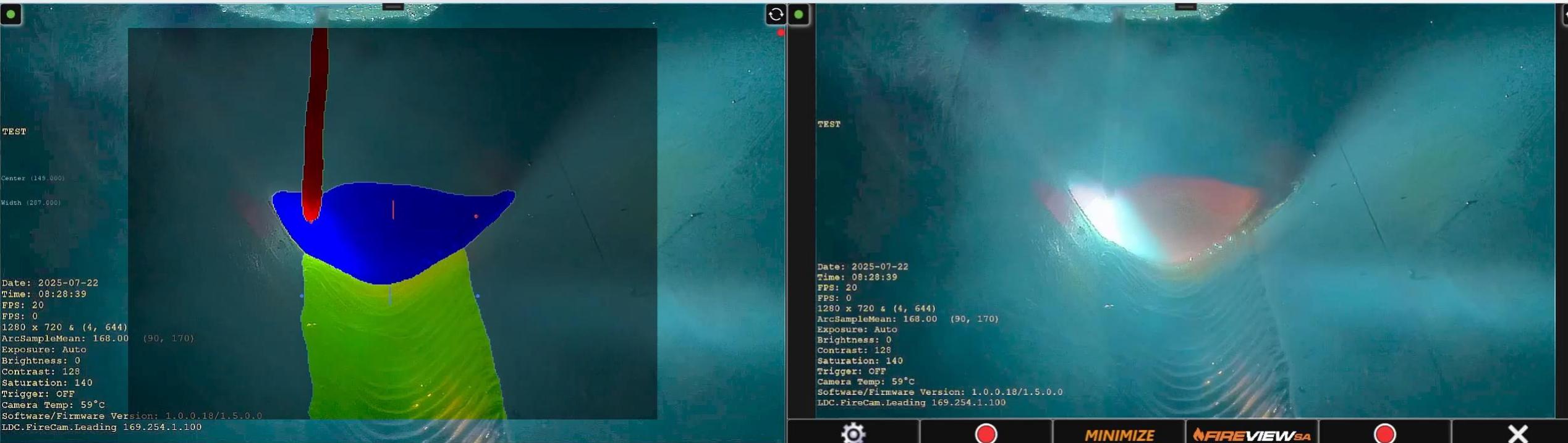
Source: National Reactor Innovation Center, Advanced Construction Technology Initiative Program

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