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Integrated Virtual Blast Furnace for Real-Time Energy Efficiency Improvement| IEDO

Tyamo Okosun, Research Associate Professor

Purdue University Northwest, Steel Manufacturing Simulation & Visualization Consortium (SMSVC)

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Project Overview

- **Objective**: To develop the **Integrated Virtual Blast Furnace (IVBF),** a next-generation, physics-based & data driven industrial operational guidance tool, by combining:
  - Computational fluid dynamics (CFD) with High-Performance Computing (HPC)
  - Machine Learning (ML) & Reduced Order Models (ROMs)
  - Visualization & novel sensor technology
- **Issue:** Challenging to understand how changes to operating conditions impact Blast Furnace performance
  - Operators often must rely on generic rules of thumb and on-the-job experience (lost with turnover)
- **Impact:** The IVBF will provide key new guidance for managing blast furnace **energy consumption, improving stability**, **reducing emissions**, and **enhancing product quality**:
  1) A physics-based and data-driven BF operation prediction system to guide operators & engineers
  2) Rapid 3D visualization of the BF internal state under a wide range of conditions
  3) New operational indices to better quantify furnace health and stability and make decisions accordingly
  4) New sensor data to provide instantaneous non-invasive measurement of BF hot metal production rate

Energy, Emissions, & Environment: 4.5-10% reduction in energy (coke) consumption, enabling roughly 10% reduction in CO_2 emissions	**Cost & Competitiveness:** $93M-$221M in cost savings for U.S. blast furnaces through improved iron quality and reduced coke rate
Technical & Scientific: Enable use of new, low-carbon injected fuels (Syngas, H_2) through better understanding of chemical reactions	**Other Impacts:** Directly aid steel workforce development with training and education to ensure industry stability

Project Outline

Innovation: An Integrated Virtual Blast Furnace for rapid process guidance, internal-state visualization, performance and stability improvement, and workforce training

Project Lead: Purdue University Northwest, SMSVC

Project Partners: Cleveland-Cliffs, Linde, Oak Ridge Nat'l Lab, Purdue University, U. S. Steel

Timeline: 06/14/2021 – 03/31/2025, **Progress:** 33%

Budget:

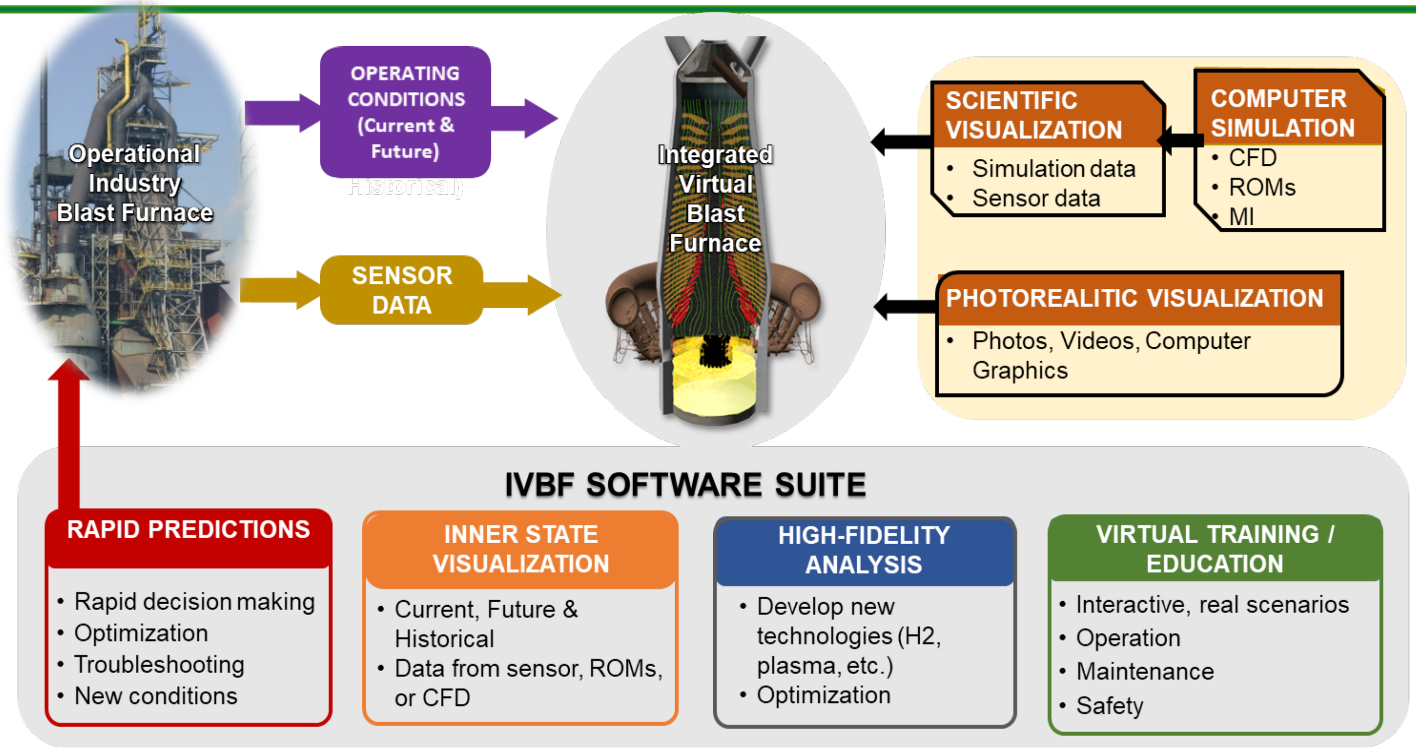
	FY21 Costs (BP1)	FY22 Costs (BP1)	FY23 Costs (BP1)	Total Planned Funding (BP1, BP2, BP3)
DOE Funded	$16,707.07	$1,325,972.82	$340,332.08	$7,048,122
Project Cost Share	$3,376.69	$315,674.05	$327,337.60	$1,864,972

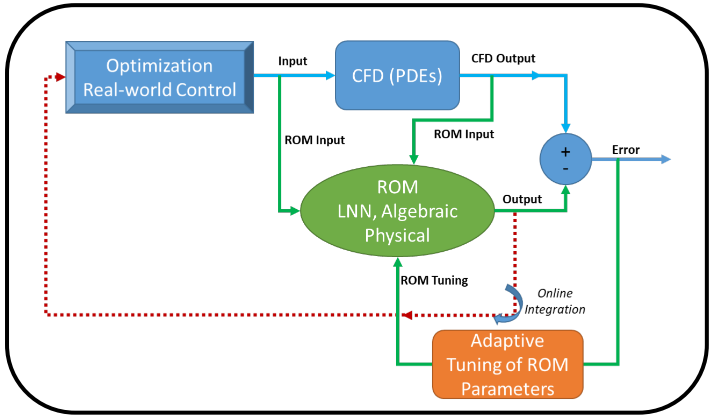
End Project Goal:

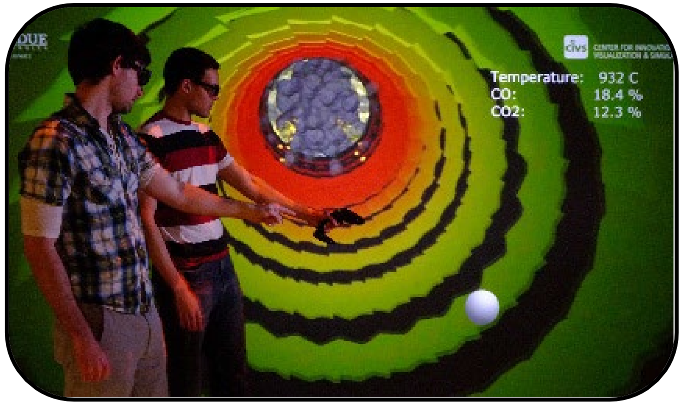
1. Develop physics-based and data-driven ROMs for rapid prediction of blast furnace performance. Validate against industry data and CFD to within 10% of industrial values.
2. Design, build, and install a prototype casting-rate imaging sensor at a site blast furnace. Integrate the system with existing network and control room, accounting for on-site restrictions and limitations.
3. Validate use of IVBF implementation at an industry blast furnace site for a target of ~450 kBtu/nthm in energy savings through identification of new operating conditions and stability/product quality improvement.

Background & Strategic Approach

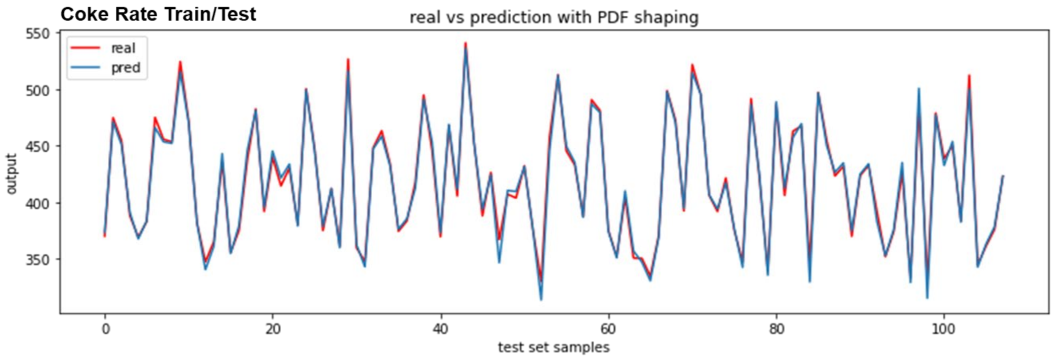
- **+26M tons of pig iron** from U.S. BFs annually
  - Needed for high purity ironmaking!
- 65% of energy consumed in an integrated mill
- Extremely difficult to take measurements inside the furnace (>1500°C)
- State-of-the-art smart manufacturing approach used to enable higher performance and lower CO_2 emissions with BF ironmaking process
- **Uniqueness:** Integration of world-class ironmaking CFD modeling, novel non-invasive imaging sensors, ML-based ROMs, and AI data analytics to provide guidance for BF operation
- **Team Members:**
  - **U.S. Blast Furnace Operators**: Cleveland-Cliffs, U. S. Steel
  - **CFD Modeling Expertise:** PNW
  - **Reduced Order Model Expertise**: ORNL
  - **Flow Imaging Expertise:** Purdue University
  - **Gas Combustion Expertise**: Linde





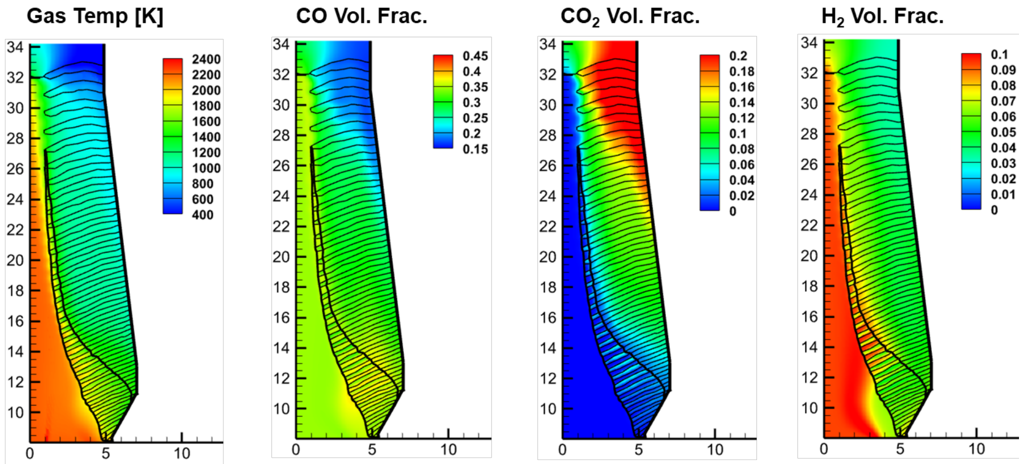


Results and Achievements



ML & CFD-based ROM

- Based on ~900 CFD simulation scenarios
- Current model predicts BF operation to **within 2%** of CFD models
- CFD runtime: **~2 weeks**; ROM runtime: **<1 second**

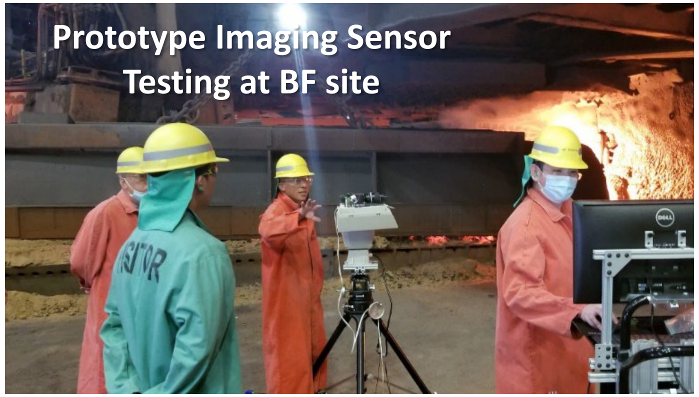


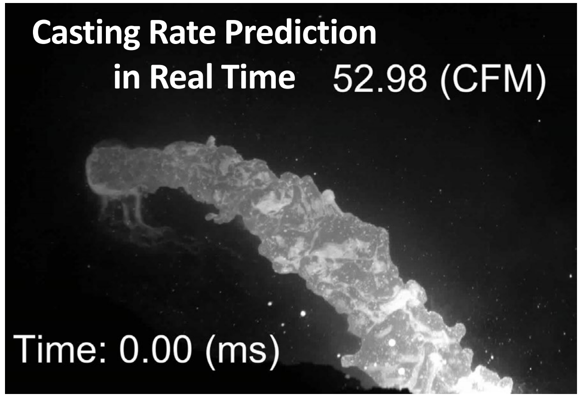
Validated CFD Model of Industrial Blast Furnace

Approach	Coke Rt. [lbs/thm]	Top gas T [K]	ΔP [KPa]	η_{CO}	HM Temp. [K]
CFD	462.7	391.9	108.6	47.2	1,797
Industry data	~463	~370	~115	46.8	1,786
% Difference	**0.06%**	**~6%**	**~5%**	**0.85%**	**0.62%**

IVBF IMPACTS TO OPERATION

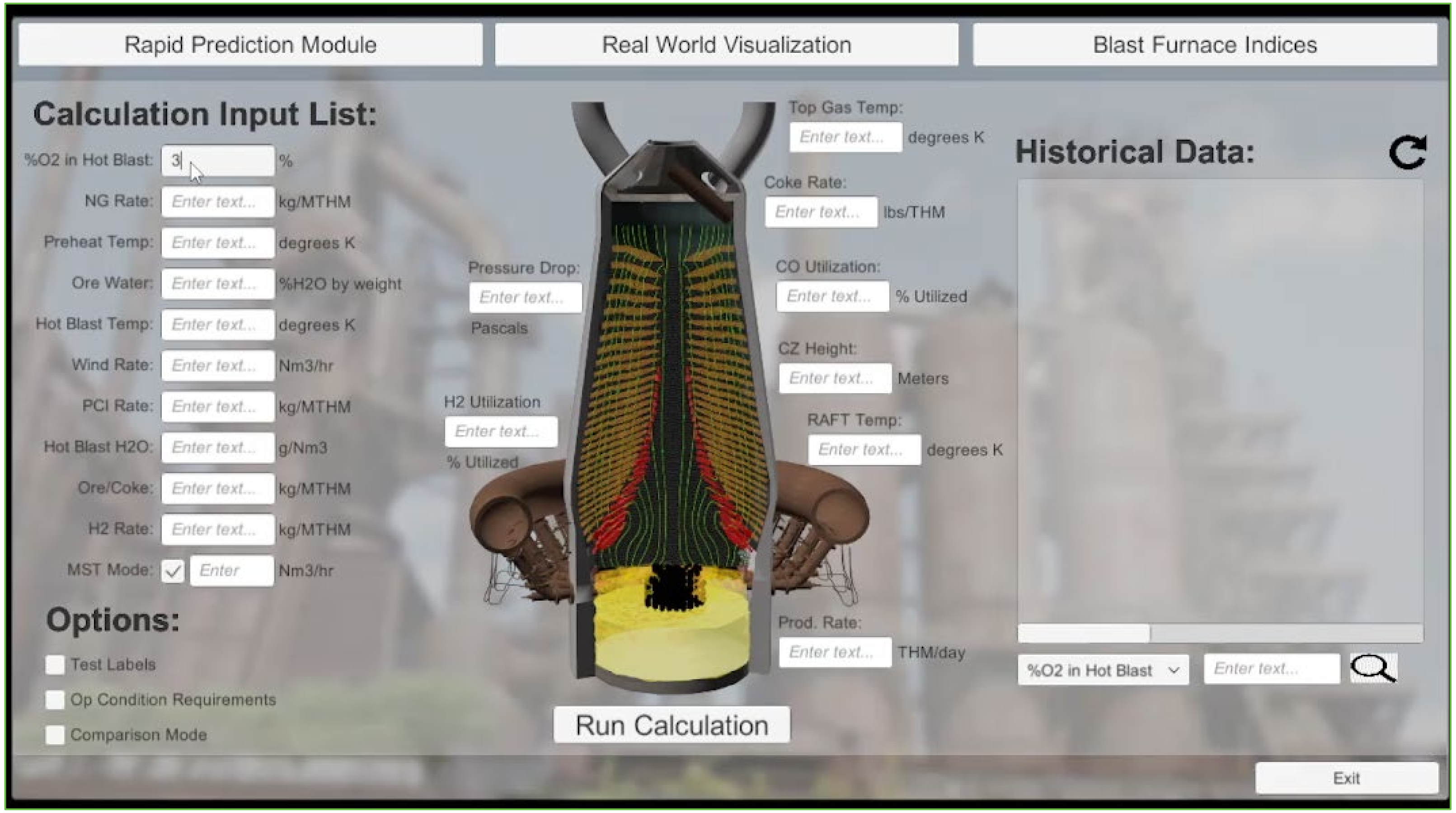
- Understanding and enabling new (low carbon) operation
  - Auxiliary fuel injection (H_2, Syngas, Waste Plastic)
  - Reduced coke rate & CO_2 emissions
- Improving furnace performance
  - Identify methods to maintain furnace stability
  - Maximize energy efficiency & productivity
  - Quick response to changes in raw materials
- Visualizing BF internal state with CFD modeling & sensor data
- Process troubleshooting: slips/hangs, channeling, etc.

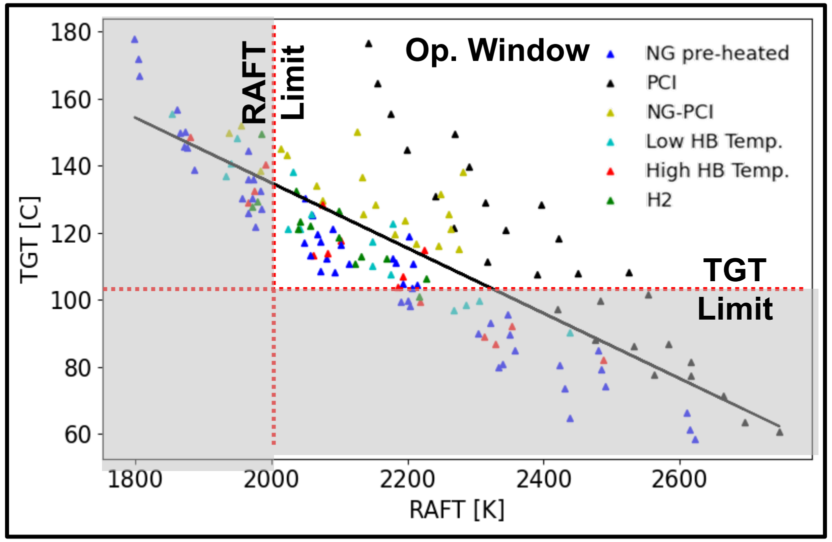


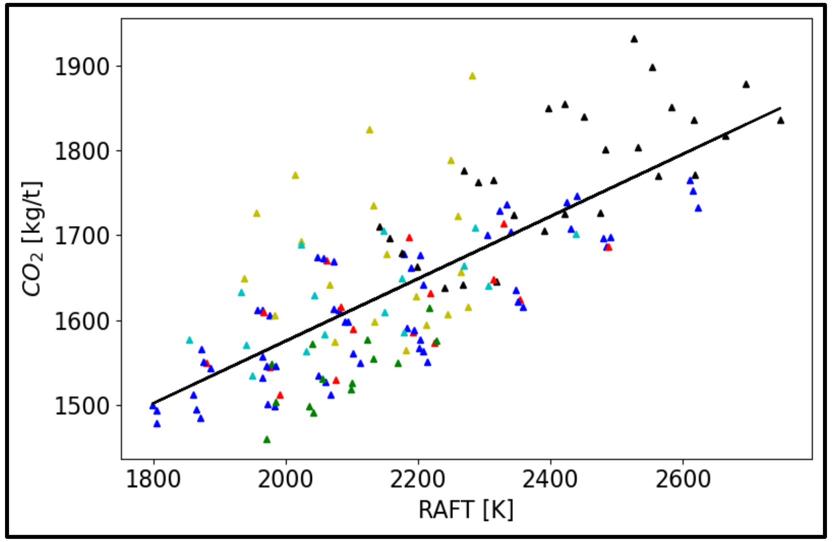


Results and Achievements pg. 2

- ROMs used to identify **stable scenarios** with **low CO_2** emissions
- Competing impacts of fuel injection, O_2 enrichment, production, & more
- Interactive UI for operators and engineers to input and extract data quickly and efficiently – Answer questions faster!







Future Work, Technology Transfer, & Impact

Future Work:

- Several tasks ahead of schedule: **CFD model validation**, **ROM development**, and the **prototype casting rate imaging sensor**
- Expansion of ROM training database for to include additional CO_2 mitigating technologies
  - Syngas injection, waste plastics injection, hot blast superheating
- Further ROM validation against industrial conditions, followed by optimization trials utilizing these ROMs
- Development of indices quantifying blast furnace stability, thermal state, and deadman conditions
- Calibration of casting rate imaging sensor and implement at a site furnace, integrated with their control room
- Integration of IVBF component modules into a single UI, solicit feedback from industry, and deploy on-site for trials and evaluation

Technology Transfer:

- The completed and validated IVBF will be deployed at SMSVC member blast furnaces (all U.S. BF operators are current members) through the work of the Ironmaking Project Technical Committee
- The SMSVC will support the IVBF with CFD models for ROM training, site-specific health indices, and design and installation of casting rate imaging sensors for viable locations

Impact:

- Blast Furnaces remain a critical piece of America's steelmaking infrastructure
- The operational guidance provided by the IVBF will be key to minimizing BF energy consumption and reducing CO_2 emissions, while maintaining productivity and strengthening a critical portion of the U.S. steel industry

Questions?

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Tyamo Okosun, Research Associate Professor

Purdue University Northwest

tokosun@pnw.edu