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

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EE0009390 | 6/14/2021 – 3/31/2025

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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 CO₂ 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, H₂) 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:

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<th>FY21 Costs (BP1)</th>
<th>FY22 Costs (BP1)</th>
<th>FY23 Costs (BP1)</th>
<th>Total Planned Funding (BP1, BP2, BP3)</th>
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<td>DOE Funded</td>
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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. BF 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 CO₂ 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

IVBF IMPACTS TO OPERATION
- Understanding and enabling new (low carbon) operation
  - Auxiliary fuel injection (H₂, Syngas, Waste Plastic)
  - Reduced coke rate & CO₂ 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.
• ROMs used to identify **stable scenarios** with **low CO₂ emissions**
• Competing impacts of fuel injection, O₂ 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 CO₂ 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 CO₂ emissions, while maintaining productivity and strengthening a critical portion of the U.S. steel industry
Questions?

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