IDEAS: Intelligent Dynamic EAF Advisory System

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Team

- Missouri University of Science & Technology (MS&T)

- Arizona State University (ASU)

- Continuous Improvement Experts, Inc. (CIX)

- Linde, Inc.

- **Multiple Industrial Partners**

- **United States Department of Energy's Advanced Manufacturing Office (AMO-Part of the office of Energy Efficiency and Renewable Energy)**

Background

- AMO Issued a Funding Opportunity Announcement in mid-2020 to "accelerate the development of novel technology innovations for iron and steelmaking." Applicants were to "develop and demonstrate new advances in manufacturing processes to improve energy efficiency in iron and steelmaking."

- Over the previous several decades, few major changes in EAF process technology have been adopted. Great advances have been made in automation, safety, reliability, data collection, and consistency of operation.

- Further optimization of the EAF process faces a number of hurdles:
  - The destructive environment in the EAF means that when available, sensors for direct measurement are high-cost, single-use disposable units, or both. These sensors frequently make point measurements that may or may not be applicable to the entire batch.
  - Some data like tapped steel chemistry, steelmaking slag analysis, and even the types or amount of scrap charged might not even be available until after the heat is complete.
  - The nature of EAF raw materials is also a challenge. Scrap, by its nature, is a commodity with significant variability in sizing, chemistry, contamination, and availability.
  - Many operations collect a huge amount of data but lack the tools to turn this into actionable information for the **operator and process engineer**.

- All of these factors combine to make the EAF an extraordinarily difficult process optimization challenge.
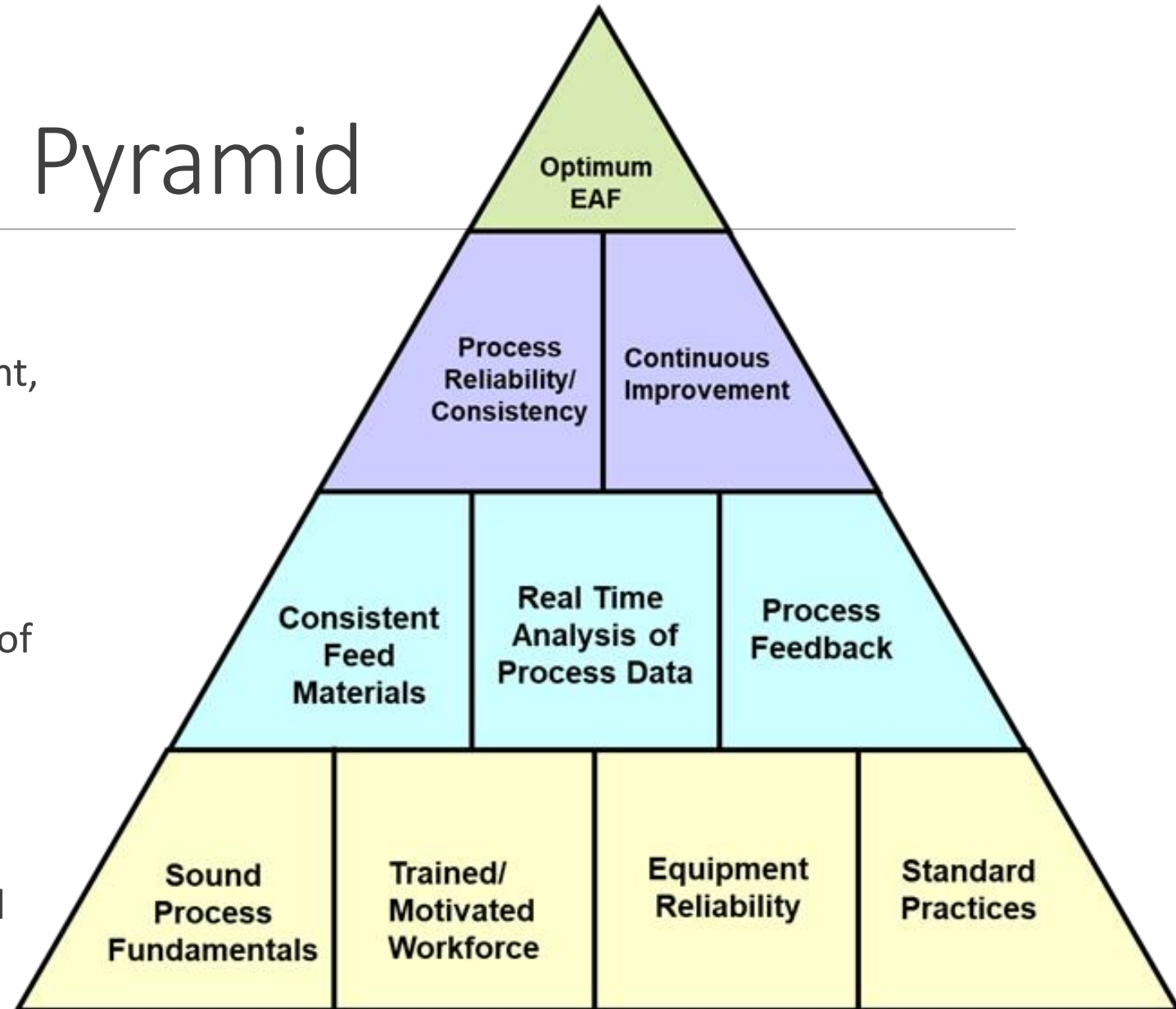
Background

- In conjunction with the real difficultly involved in EAF process optimization, the pool of trained process engineers is shrinking, and the extensive knowledge built up over the previous generation of EAF development is being lost as highly trained and talented personnel retire from the industry.

- Many University metallurgy programs have evolved into Material Science programs or as part of a Chemical Engineering or Mechanical Engineering Department. Whereas 30 years ago an undergraduate student in Metallurgical Engineering might have taken multiple courses on steelmaking and ferrous metallurgy, students may only take one steelmaking course today.

- When graduates enter the industry, they commonly change positions frequently, rarely developing a deep, detailed understanding of the process. And many of the most successful engineers move into management, creating a constant drain of talent out of front-line process engineering positions.

Background

- In response to these challenges, many steel plants have implemented automation solutions to the EAF and many are investigating applications of AI and machine learning.

- There are some weaknesses with this approach, namely:
  - Implementation of extensive automation has sometimes come at the expense of EAF operator training and experience. While automation systems are better able to make some adjustments (power regulation, for example) the operator is the individual with the most direct experience with running the EAF and experiences many of the process challenges first-hand.
  - AI and machine learning solutions that rely primarily on extensive statistical analysis of process data experience problems with false correlations due to the large amount of confounded data and limited knowledge of raw materials quality.

EAF Optimization Pyramid

- EAF Optimization must be built on a sound foundation-of which a well-trained and motivated workforce is key. Reliable equipment, standardized practices, and a good understanding of process fundamentals comprise the remainder of the base.

- An improved understanding of raw materials compositions coupled with real-time analysis of process data will allow for greatly enhanced feedback to both operators and process engineers.

- All of this, coupled with a focus on reliability, consistency, and continuous improvement will lead to an optimized EAF.

Pyramid levels (top to bottom):
- Optimum EAF
- Process Reliability/Consistency | Continuous Improvement
- Consistent Feed Materials | Real Time Analysis of Process Data | Process Feedback
- Sound Process Fundamentals | Trained/Motivated Workforce | Equipment Reliability | Standard Practices

Project Objectives

- Arriving at an optimized EAF will involve the integration of several comprehensive solutions across a broad range of engineering fields.

- Novel Instrumentation-The project will explore the use of optical fibers in novel ways to measure real-time process data that was either unobtainable, unreliable, or only available after the conclusion of a heat.

- Fundamentals-Based Process Models-A set of interlinked process models to collect and interpret process data, transforming raw data into actionable information for both the EAF operator and process engineer. These models, based on work performed by CIX at many steelmaking operations, will be installed as a complete suite so that data can be shared between each component.

- Improved understanding of raw materials, slag chemistries, and their impact on EAF efficiency will be achieved through fundamental research into slag properties at various points in the heat and various conditions.

Traditional EAF Control

-Delayed Feedback Loop to Operator (up to 2-3 days)
-Response dependent on operator skill and motivation

Residuals checked post-production with chem analysis

Post-production slag samples taken (infrequently) to check basicity and FeO%

Temperature/Oxygen probe sampled at the end of the process

Liquid steel height checked by eye and used to adjust scrap weight/account for yield changes

Advisory System Real-Time Data Inputs

- Electricity Input
- Burners/Oxygen Lances
- Raw Materials Additions
- Measured Heat Losses
- Offgas flow rate
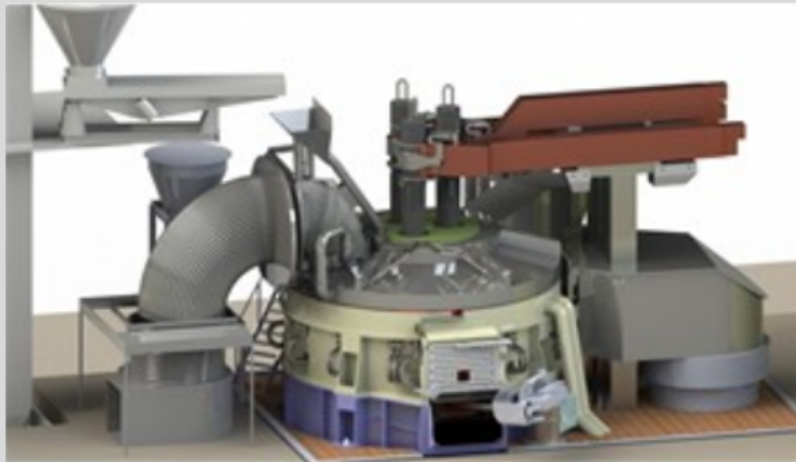
Future EAF Control

Real-time process feedback using:
- Enhanced sensor networks
- Digital twin production models
- Dynamic models coverage of full heat cycle
- Recommendations to operator for out-of-bound conditions and corrective actions

Enhanced raw materials tracking via analysis and regressions. Slag chemistry optimization-higher material recovery, flame steering, maximized carbon utilization, and higher energy efficiency

Novel sensors (fiber optics) for precise, real-time temperature and EAF weight monitoring of:
- Water-cooled components
- Refractory condition
- EMI-immune replacement for load cells/strain gauges
- Real-time slag chemistry analysis

ASU

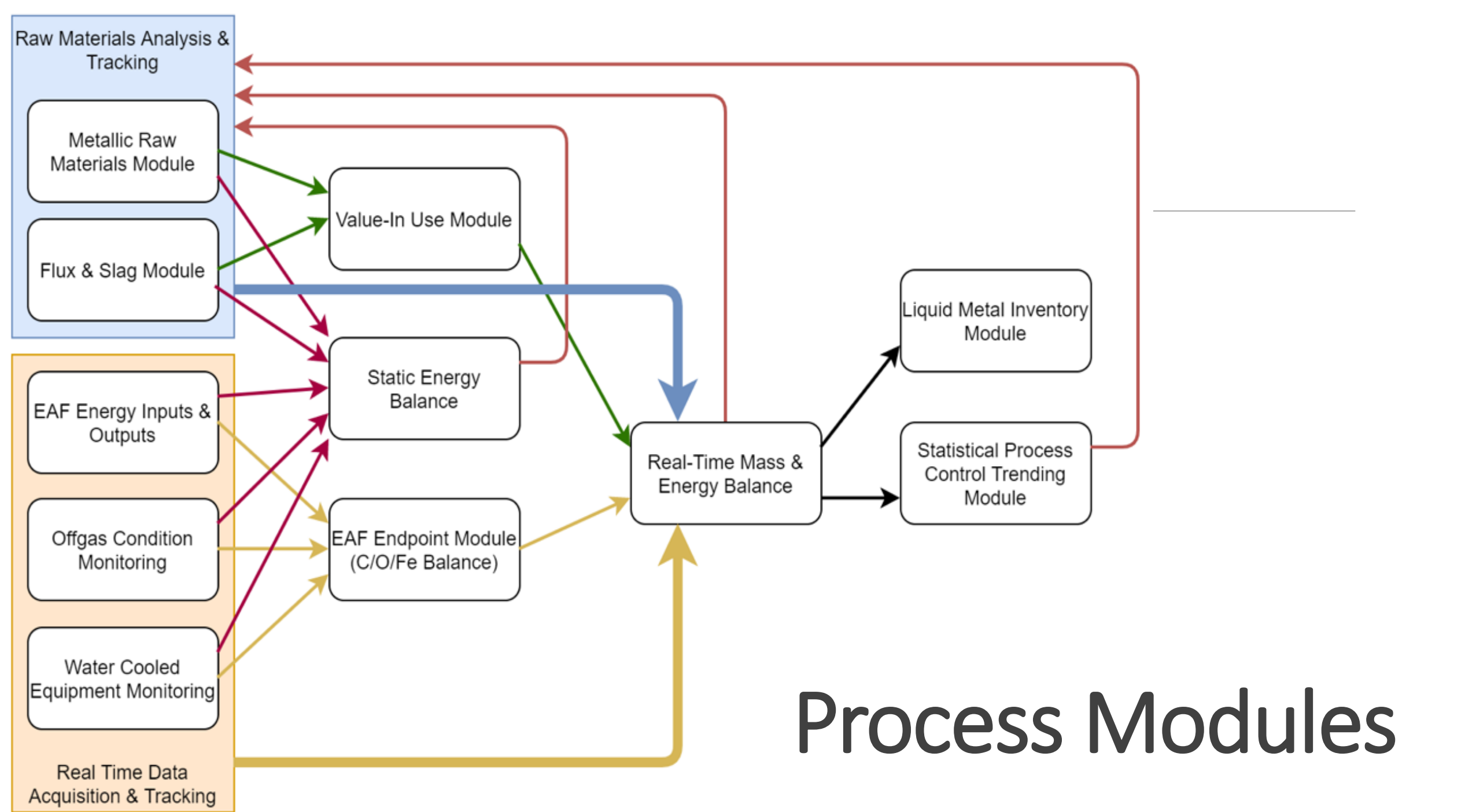CiX inc.
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Process Modules

IDEAS Process Model Suite-Raw Materials

- Three process models will be used in measuring and tracking the raw materials used during steelmaking.
- The Scrap and Slag Models will track incoming scrap, iron, fluxes, and carbon.
  - Using chemistry data for these, it will estimate the heat residual content and the gangue contribution to the slag. This is critical in ensuring proper flux usage and ensuring good slag foaming.
  - These models will also enable the back-calculation of gangue levels in scrap in order to continually tune raw material chemistry data and identify when raw materials deviate from specifications.
- Value-in-Use
  - The concept of value-in-use is that the price of a commodity is less important than the value that commodity brings to the process. When dealing with metallic feeds to the EAF, we are paying for the Fe units, but we have other components coming along for the ride. Dirt, plastics, alloying elements and other components all have a cost associated with them as they may impact flux requirements, environmental requirements, refining requirements etc.
  - The VIU model will collect information from the Scrap & Slag Models, then calculate the cost impact from each component relative to the mass of liquid steel tapped from the furnace. This information will be critical in evaluating different scrap suppliers and driving EAF continuous improvement

IDEAS Process Model Suite-EAF Operations

- Energy Tracking Model
  - This model will effectively be used to generate a static energy balance on the EAF operation. Static energy balances are a very useful tool for internal benchmarking of the process. The major components of this model are dedicated to:
  - Cooling Water Energy Losses
    - This information can be utilized to optimize electrical and chemical energy input profiles and to optimize slag foaming. Understanding energy losses in the EAF is key to achieving good operating efficiency.
  - Off-gas Energy Tracking
    - Energy losses to the off-gas system can represent more than 50 % of the total energy input into the EAF during some stages of the T-T-T cycle. Knowledge of periods of high energy losses can be used to adjust energy input profiles and improve EAF energy efficiency.
- Endpoint Model (C/O/Fe Balance)
  - The end-point control model is designed to help the operator achieve the desired steel temperature and dissolved oxygen level concurrently at the end of the heat. Tapping heats too hot can actually impede ladle furnace operations while over blowing the steel in the EAF leads to yield losses, refractory damage and damage to the EAF.

IDEAS Process Model Suite-Data Analysis/Interpretation

- SPC Process Trending
  - SPC trending of key process data from heat to heat is an extremely useful process tool. SPC trending allows for rapid diagnosis of upset conditions and is also very useful when the operating shift changes as the incoming operator can get a quick snapshot of the operations over the last shift.

- Real Time Mass/Energy Balance
  - Members of CIX developed the first real time mass/energy balance tool in the late 1990s. This tool has been applied in several meltshops with associated cost savings of up to $10/ton and productivity improvements of up to 30 %. This tool allows the process engineer to track the distribution of energy throughout the heat and identify periods of high efficiency and periods of low efficiency.

Integration of Process Data from Novel Sensors into Process Modules

- A major opportunity in EAF optimization is the use of novel sensor technologies. In the case of the IDEAS project the use of optical fibers will be tested for acquisition of several types of data.

- Direct temperature measurement of water-cooled EAF components. Temperature measurement via optical fibers is an EMI-immune method to capture the actual heat flux across an area of water-cooled roof, shell, or section of ductwork.

- Direct weight measurement of an EAF using optical fibers to measure strain on the EAF tilt platform. Again, in an EMI-immune measurement technique, we will apply this novel sensor technology to obtain real-time weights in the EAF during operation.

- Use of optical fibers for refractory integrity monitoring, particularly to measure health of DC EAF anodes. Optical fibers have the potential to measure a much more dense temperature profile of an anode, and possibly provide direct measurement of the wear rate of the anode refractory.

Distributed strain sensing
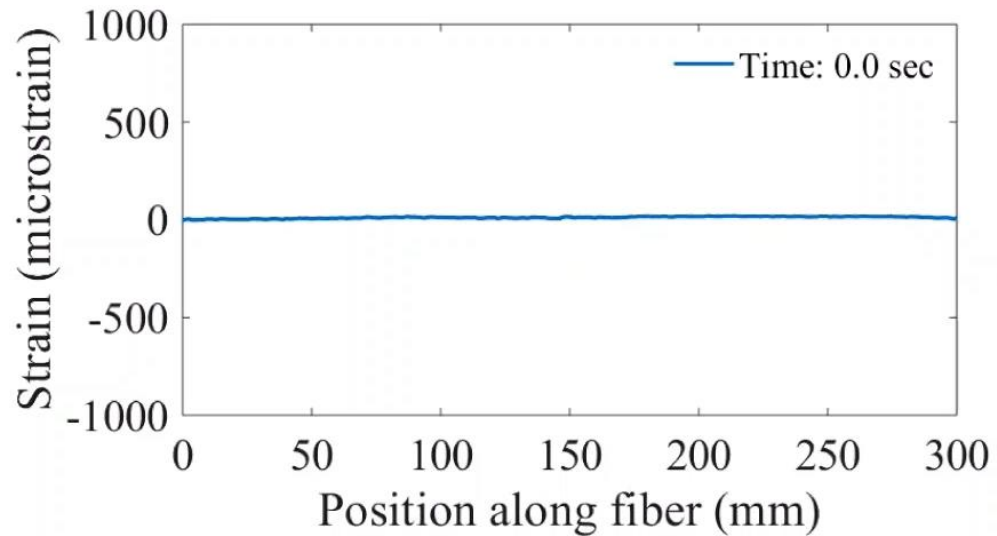
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Adaptable Chemical Energy Delivery

• EAFs function most effectively when sufficient energy can be delivered to the scrap in the furnace evenly, preventing the formation of icebergs, cold spots, or scrap sticking to the sidewalls.

• The Fluidic Cojet® with steerable flame technology will be investigated to work alongside the novel sensor technology and provide chemical energy to the EAF where it is most needed.

• Linde's proprietary Cojet® carbon injector has the ability to provide heating through a burner mode, supersonic oxygen, and carbon injection through one component, increasing operational flexibility.
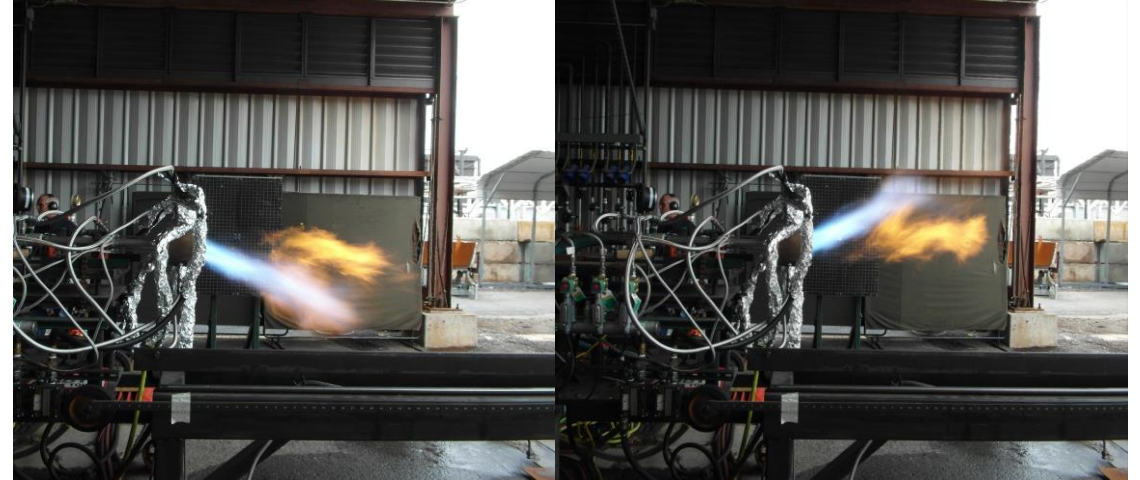
Fluidic CoJet®
Flame deflection in burner mode

The Role of the Engineer & Operator

- The EAF is one of the most complex process reactors encountered in the heavy process industries - amount of coupling between process parameters is enormous - amount of variation is also very large. EAF optimization at any steel plant is a full-time job.

- In the future we envision the role of the process engineer to be one of macro optimization of the process – tying together the results of multiple process tools to drive the high-level optimization of the process.

- We believe that in the future, operators will upgrade their function to provide the first level of process optimization. These men and women are the ones directly interfacing with the process, and so will need high quality training to develop a sound foundation with respect to process fundamentals. Equipment operators must also be provided with the right process tools so they can determine when process intervention or further investigation is required.

- The model of an operator sitting in a pulpit supervising an EAF operating profile will be insufficient in the future and must be reformed.

Conclusions

- Significant room for improvement exists in current EAF steel production operations world-wide. Our experience has shown that even in world class operations, productivity gains of 15 to 30 % are possible through the application of a structured optimization approach.

- Process improvement will lead to lower costs and overall lower CO_2 emissions per ton of crude steel. The first stage of lowering the carbon footprint of steelmaking should be process optimization.

- However, achieving this result will require the use of advanced tools, novel instrumentation, and a detailed understanding of the process based on scientific fundamentals.

Thank you

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