Using Stiff Extrusion of DRI Fines and Dust to Make Fluxed Pig Iron, a High-Value Charge for EAFs

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Agenda:

Topic
JC Steele & Sons Introduction
Lhoist Introduction
Introduction and Definitions
Methods and Materials
Benchtop Trials and Early Pilot Scale Results and Discussion
90 Metric Ton Pilot Study Results
Conclusions

About JC Steele & Sons

- Founded in 1889
- HQ in Statesville, North Carolina, USA
- 133 employees (500 worldwide)
- 10 locations worldwide
- Market Leader in Heavy Industrial Extrusion

The Steele Group:

STEELE Since 1889

Stiff extrusion and material processing machinery

HÄNDLE™

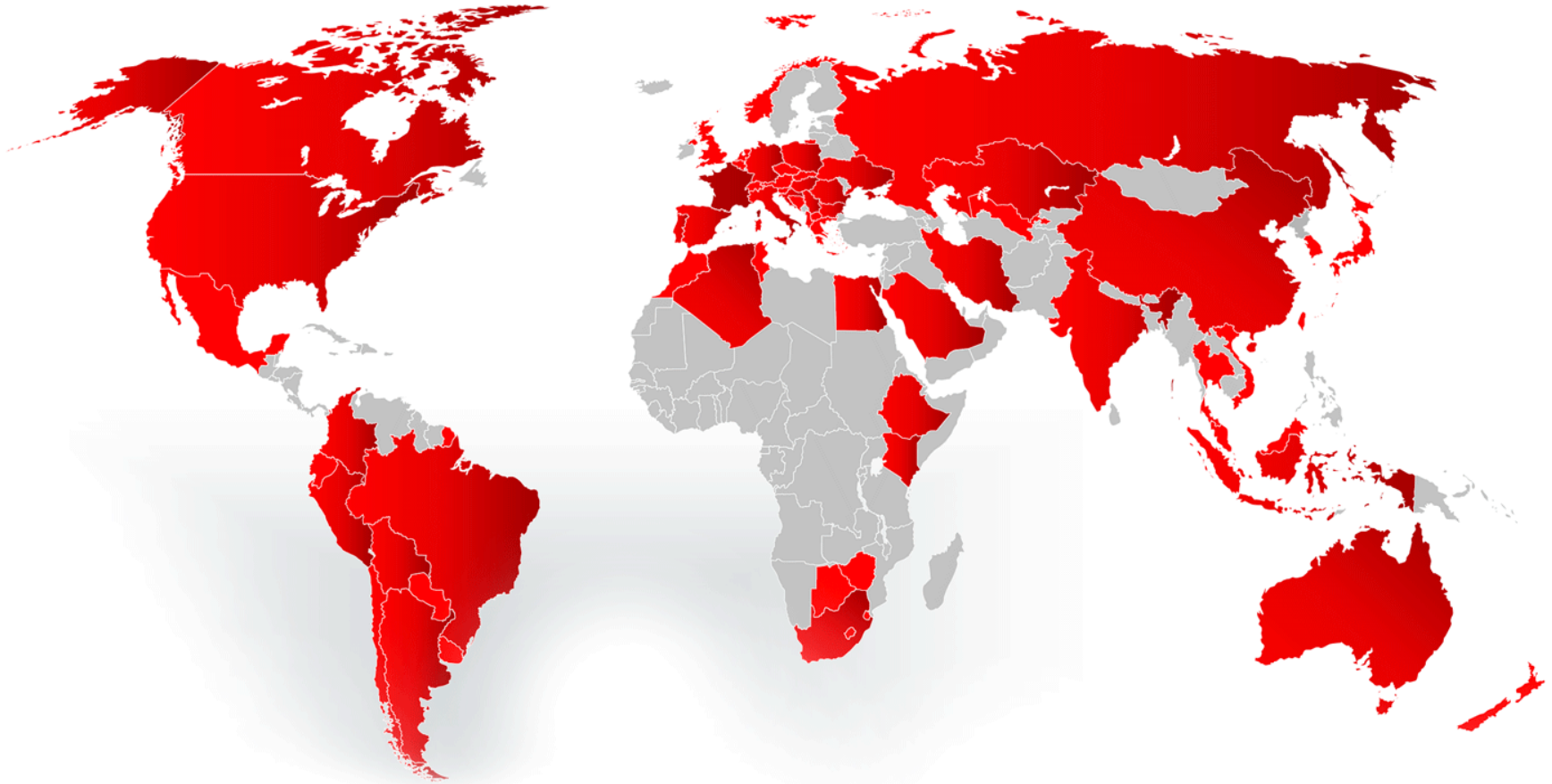
Soft extrusion/material processing machinery with plant engineering capabilities

Direxa™ ENGINEERING

Engineering, Procurement and Construction firm specializing in plant and application engineering

J.C. Steele & Sons – Around the World

- Delivered product to 50+ countries since 2020
- Steele Group represented in 37 countries
- Steele Group equipment extrudes 50 million+ tons annually



Lhoist - 135+ YEARS OF EXPERTISE

Founded in 1889 and headquartered in Belgium, the Lhoist Group is one of the world's leading lime, dolime, and mineral solutions producers.

FAMILY-OWNED COMPANY

Our company has grown from generation to generation and now has a presence in more than 25 countries around the globe with facilities in Europe, North America, Latin America and Asia-Pacific.

OUR ESSENTIAL PRODUCTS FOR YOUR LIFE

Our products are derived from natural resources and play a crucial role in daily society's needs. They are essential for various applications that are needed today and necessary to support tomorrow's energy transition.

Lhoist – Around the world

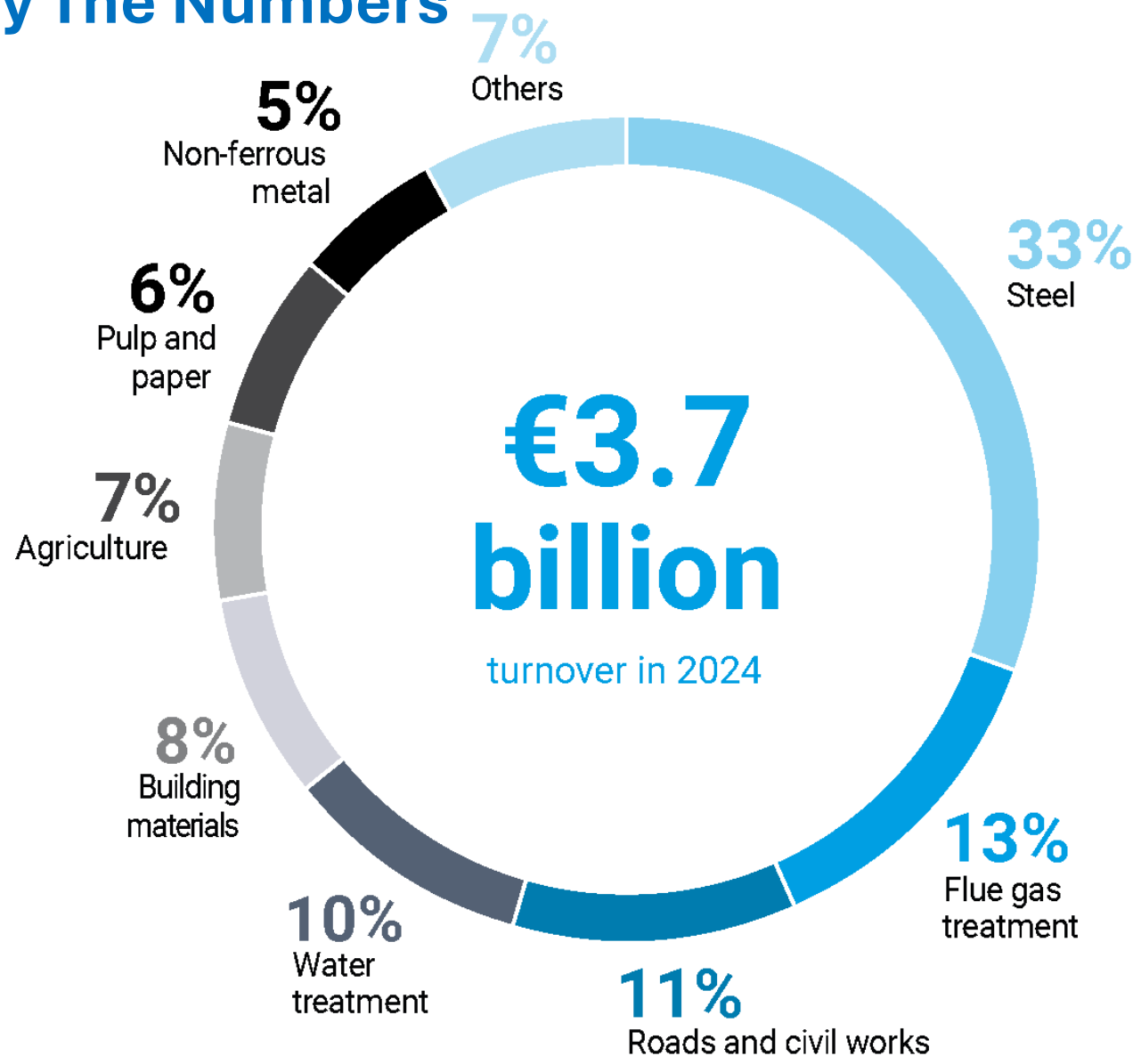
135+
sites in **25** countries

80+
sales in **80+** countries

2
R&D centers:
Nivelles (BE), Irving (US)

6.650
employees from
70+ nationalities

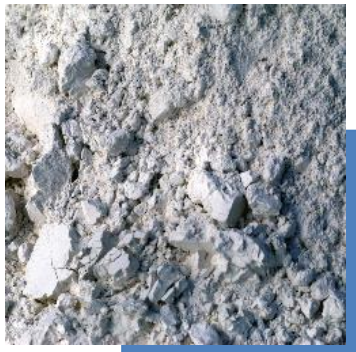
Lhoist Group By The Numbers



Lhoist – Our Products & Customers

MINERALS

- Limestone
- Dolomite
- Clay and others



CALCINED PRODUCTS

- Quicklime (pebble, ground, milled)
- Burnt dolomite (soft-/hard-/overburnt)
- Hydrated lime

SPECIALTY PRODUCTS

- Milk of lime
- Fluidised lime
- Low dust emission lime
- High porosity hydrated lime
- Formulated products

Lhoist is committed to offering the best advice, most appropriate products and technical services to meet our customers' needs.

NUCOR · Minerals Technologies · RWE · NEDMAG · FirstEnergy · OMYA · Ternium · Xella · DILLINGER · TATA STEEL · outokumpu high performance stainless steel · thyssenkrupp · ArcelorMittal · STAHL. DAS SIND WIR. · HKM

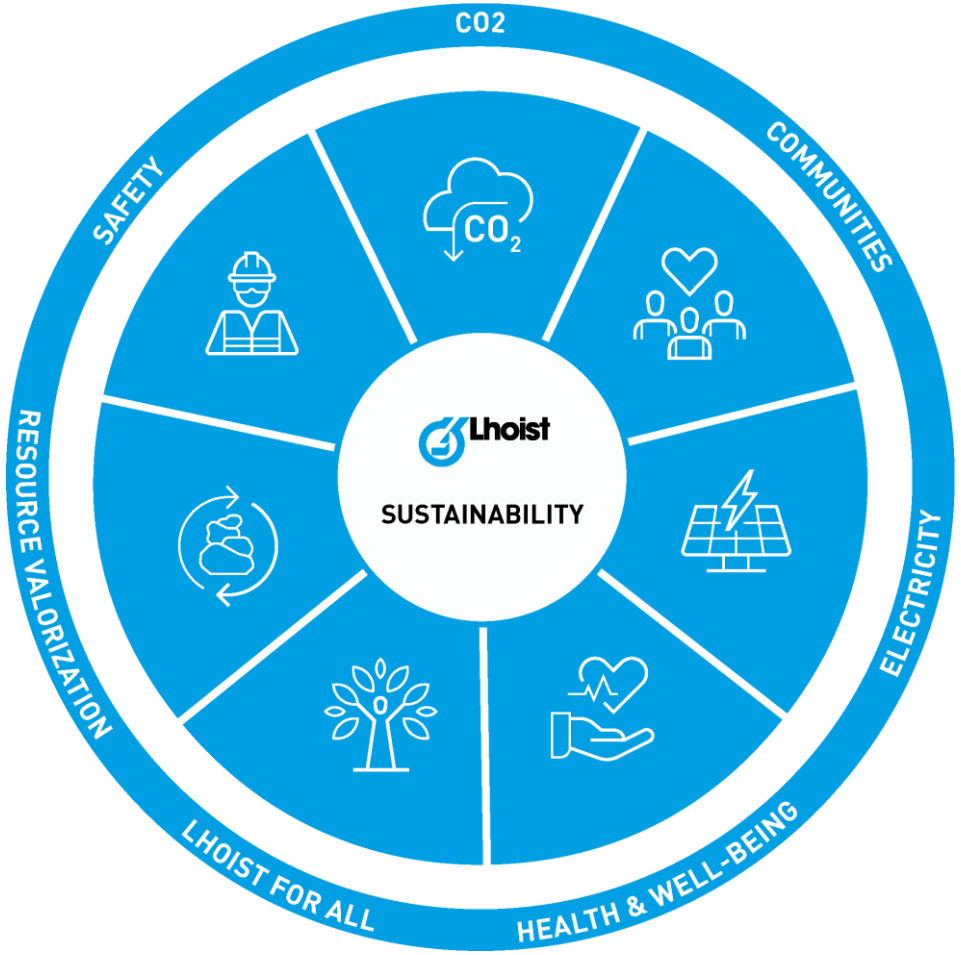
2030 Sustainability Vision: SHAPING THE FUTURE TOGETHER

Safety – **Ensuring a "Go for Zero" policy, for example with a Stop & Think program, and regular safety discussions in the field**.

CO_2 – Focusing on decarbonization, leading the way first with alternative fuel dosing projects followed by multiple CCUTS projects.

Electricity – Buying or generating electricity from renewable sources.

Resource Valorization – Ensuring that all materials generated through our calcination processes are commercialized, recycled or reused. **Our commitment extends beyond our company; we also aim to support other industries valorize their byproducts.**



Fluxed Pig Iron:
Extruded DRI Dust and Fines

Introduction and Definitions

- DRI dust and DRI fines – what to do with them?
- For this work we define **DRI dust** as < 0.5 mm, with 95% less than 50 microns

  and **DRI fines** as < 6.35 mm
- **Extruded briquette**: A shaped, extruded product with high green strength
- Use polymeric binder to produce a Bingham mixture which is extrudable and water-free
- "Fluxed Pig Iron" or **FPI**: Extruded briquettes of DRI fines and dust using polymer as the binder agent and a flux such as **lime-based products**

Methods and Materials

- Benchtop (small scale) testing using a J.C. Steele & Sons 3EX Laboratory Extruder
- Over 250 bench-scale trials using different D:F ratios, lime-based products, carbon types, and polymers
- Three broad categories of FPI:
  - Type A: High Dust to Fines Ratio, with lime-based products and polymer (focus of the 90 ton trial)
  - Type B: High Fines to Dust Ratio, with lime-based products and a polymer binder (2 tons)
  - Type C: Varying Ratio of Dust to Fines with added carbon in addition to the polymer binder (benchtop only)

Methods and Materials

- Pilot scale used J.C. Steele & Sons Even Feeders and Stiff Extruder, outfitted with temperature control and die system
- All pilot scale testing produced Type A or Type B extruded briquettes
  - Commercial polymer was used to reduce variables
  - Lime added was fully hydrated dolime (Lhoist Type S)
- Additional testing included
  - Extruded briquette density
  - Tumble and abrasion indices
  - Split tensile (compressive) strength
  - Water immersion testing

Benchtop Trials and Early Pilot Scale Results and Discussion

- Development started in 2022
  - Heating systems went from prototype designs to engineered, commercially available, robust systems on both the 3EX and 10AEX platforms
- Goals of smaller scale testing:
  - Is an extrudable mix suitable for commercial development?
    - YES – 90 ton pilot test
  - Are the physical and chemical properties of the extruded briquettes acceptable?
    - YES – Next few slides and EAF testing

Benchtop Trials and Early Pilot Scale Results and Discussion

- FPI physical properties
  - Density: Dependent on DRI D:F ratio, % polymer, % added flux
    - Example: Type A mixes have a loose bulk density around 1.50 g/cm^3 and extruded briquettes are 3.25 – 3.5 g/cm^3
  - Split tensile testing: Depends on coarse and fine percentages and % polymer

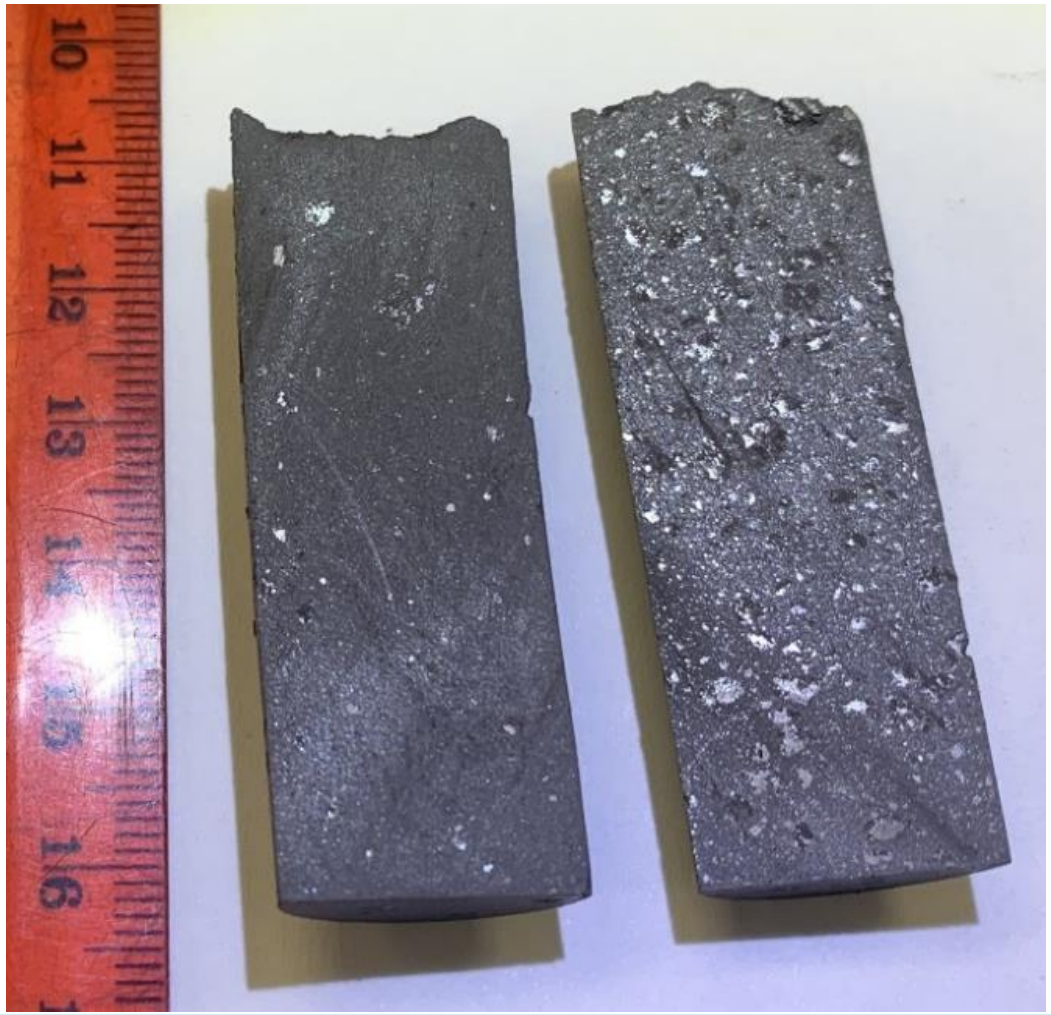
Run No.	FPI type	% polymer	Split tensile (Mpa)
50114.702	Type C	Highest	2.59
50114.703	Type C		3.30
50128.701	Type C		4.70
50128.702	Type C	Lowest	5.28

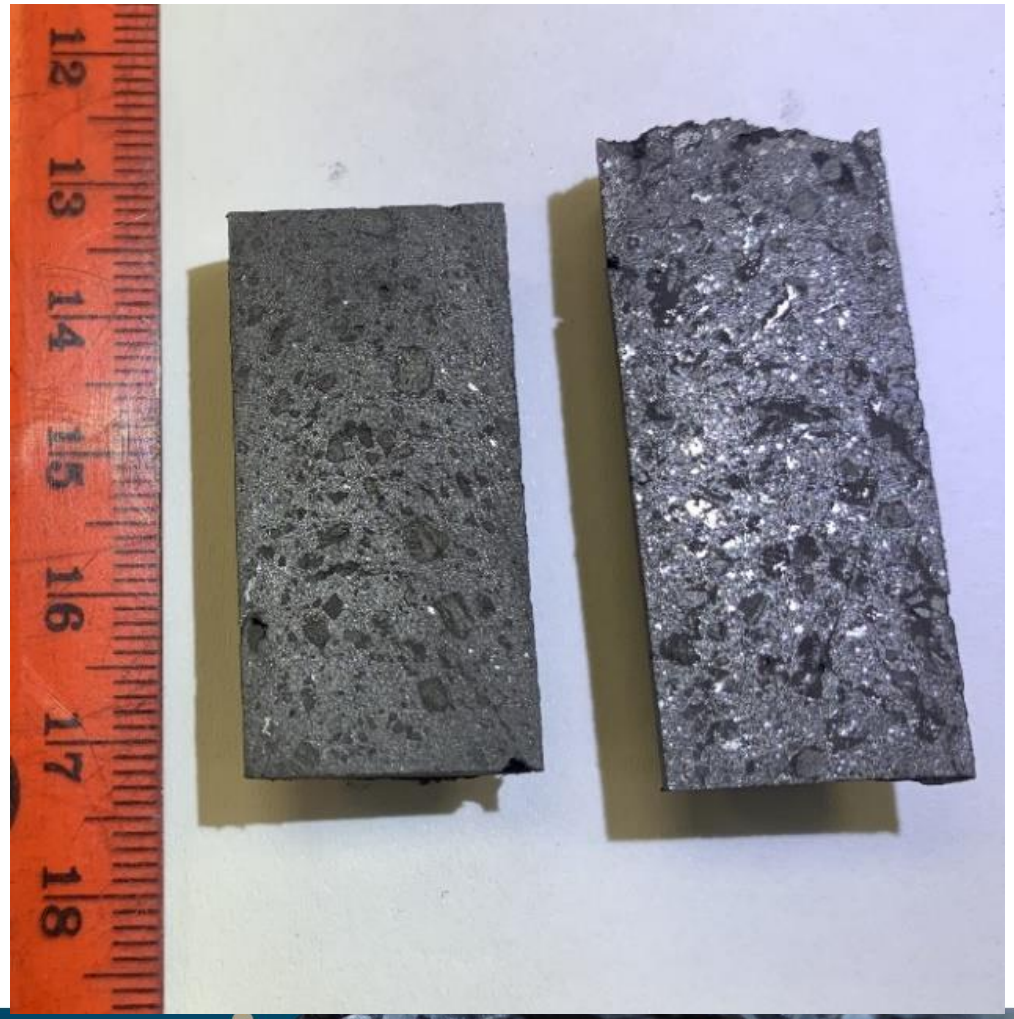
Benchtop Trials and Early Pilot Scale Results and Discussion

- FPI physical properties
  - ISO 3271 or ISO 15967 Tumble test: Tumble Index (TI) and Abrasion Index (AI)
    - Samples from the 3EX benchtop extruder:
      - TI = 98.8% AI = 0.3% (pictured)
    - Samples from the 10AEX pilot scale extruders
      - TI = 98.2% AI = 0.6%

Benchtop Trials and Early Pilot Scale Results and Discussion

- FPI physical properties
  - FPI extruded briquette sectioning and water immersion





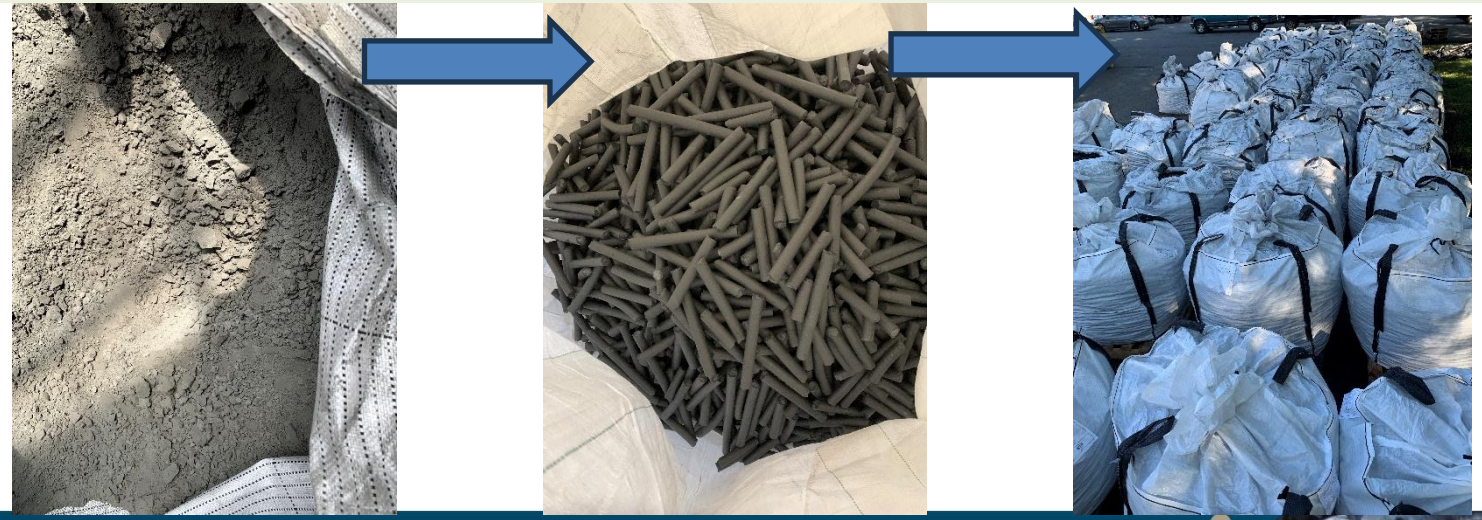
Benchtop Trials and Early Pilot Scale Results and Discussion

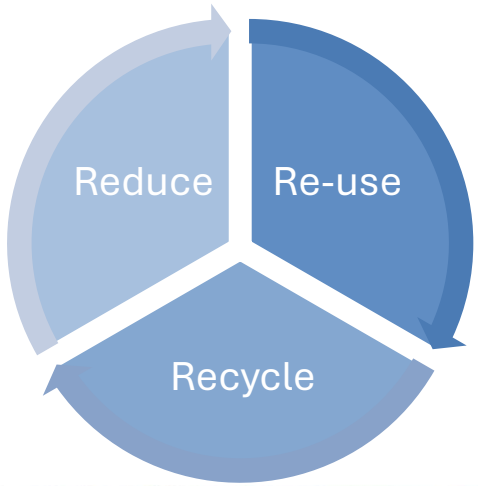
- FPI physical properties
  - FPI extruded briquette sectioning and water immersion
    - Type A FPI extruded briquettes were submerged in tap water for 4 weeks
    - Similar results for Type B made with coarse Lhoist Dolime® - no signs of lime hydration within the pellet

90 Metric Ton Pilot Study Results - Goals

- FPI extruded briquettes has been tested in a steel mill with a total production capacity of 2.6 million tons per year, with each tap aiming for 170 tons.

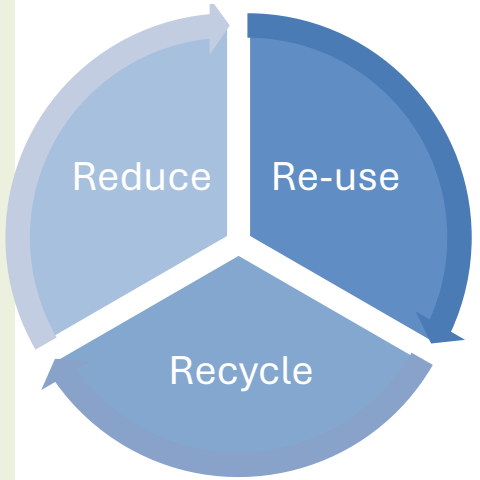
- The trial aimed:
  - Maximize the Value-In-Use of the FPI extruded briquettes.
  - Commissioning a new process using FPI. This involved integrating the FPI extruded briquettes into the existing EAF operations and making any necessary adjustments to ensure seamless implementation.
  - Enhance the overall efficiency, productivity, and sustainability of the steelmaking process.



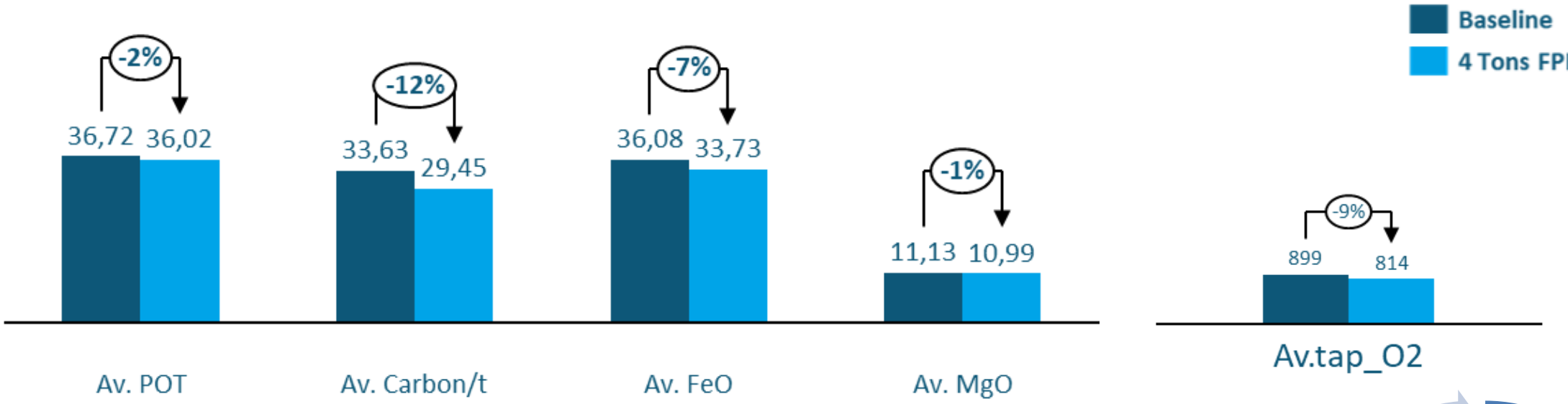


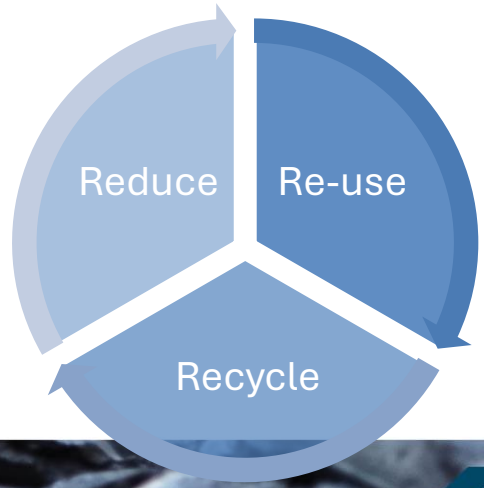
90 Metric Ton Pilot Study Results – Main KPIs

- Main KPIs were as follows:
  - Metallurgical targets are not compromised in the process of EAF steelmaking.
  - No disruption of normal EAF furnace operation is noticed.
  - Chemical energy efficiency is improved.
  - A more thorough transfer of carbon to the steel bath in the EAF is noticed.
  - EAF slag chemistry remains consistent and controllable and is as predictable as using traditional alternative iron units plus charge carbon.
  - Tap-to-tap times, kWh/t consumption (electricity), gas consumption, and/or electrode consumption metrics are improved in the EAF process.
  - Iron yield is improved.
  - A decrease in required injection carbon or slag foaming agents is noticed.



- Process improvement indicators:
  - Operational Improvements





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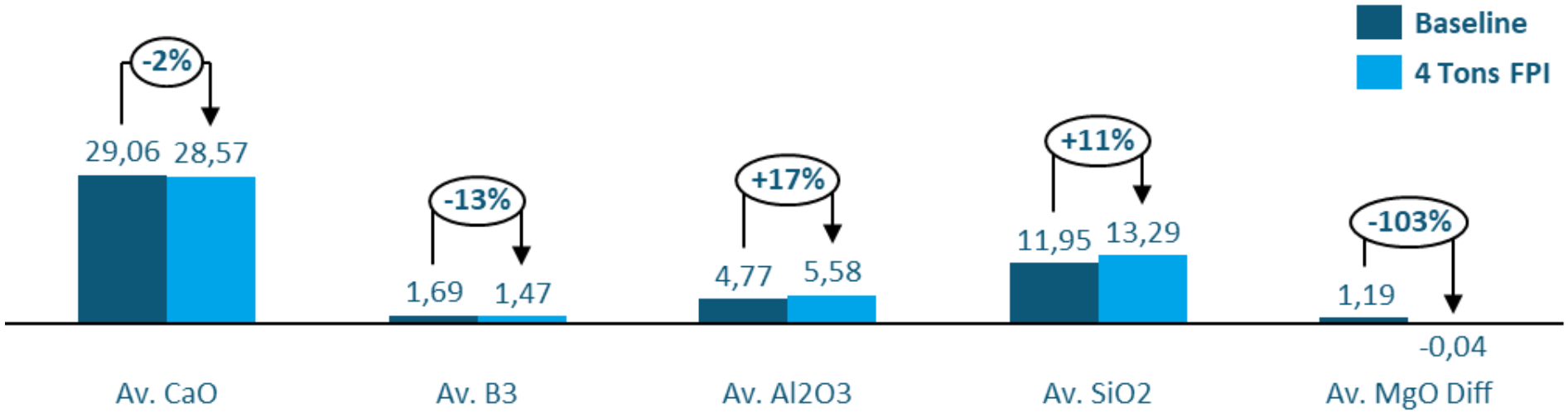
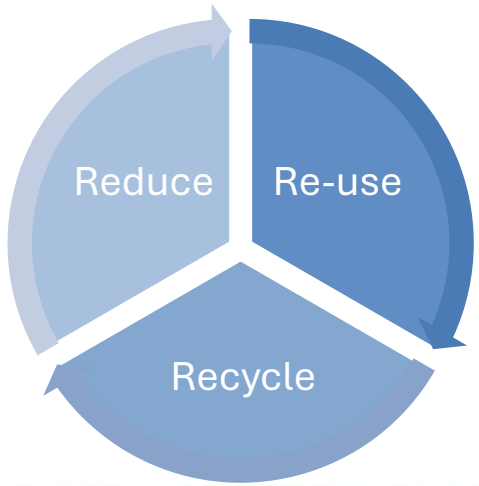
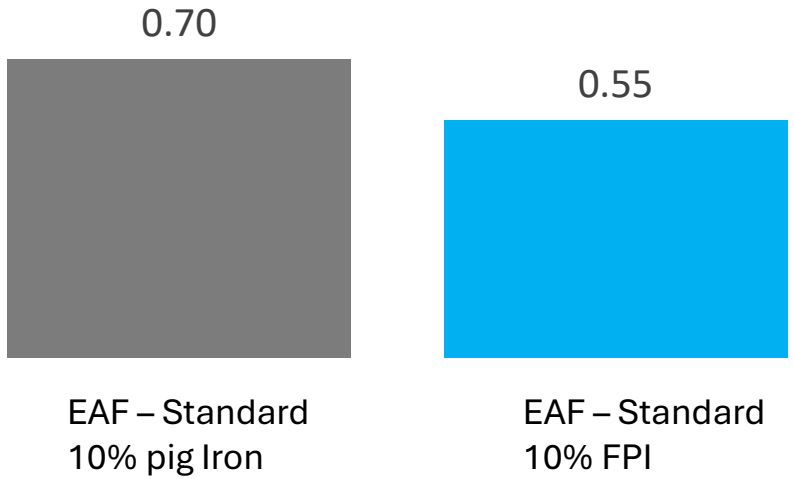
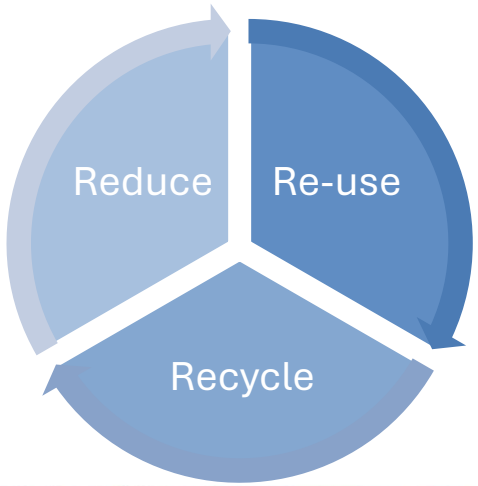




- Process improvement indicators:
  - Environmental Improvements:
    - Pig iron is produced from the BF process @ 2.0t CO2/t.
    - DRI process emissions @ 0.54t CO2/ t DRI. (Scope 1,2 & 3)
    - Replacing pig iron with FPI represents 20% saving in CO2 emissions

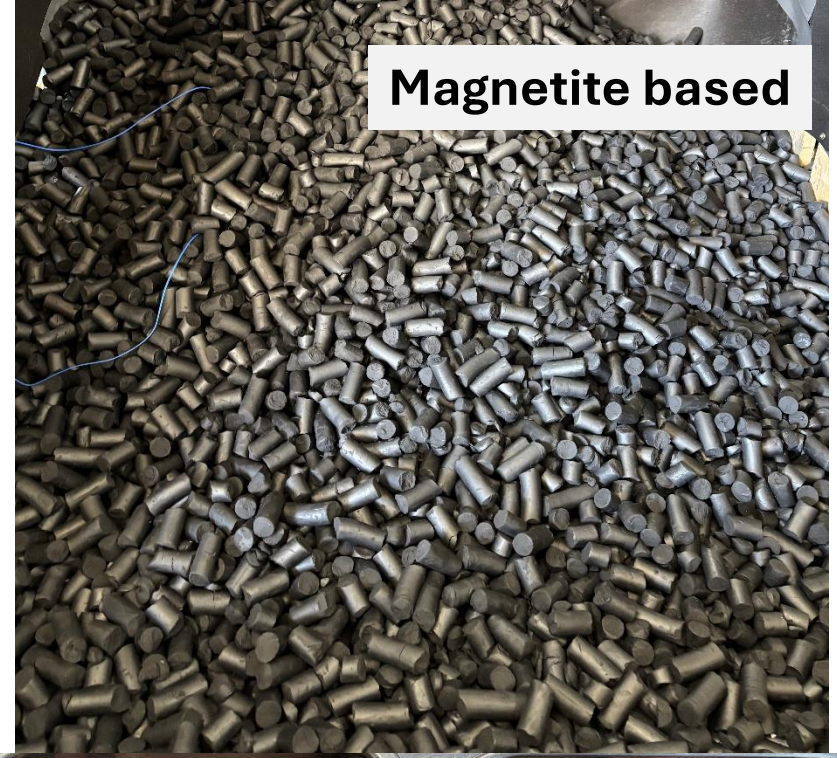




Conclusions

- Mixes including DRI fines and dust can be agglomerated using heated stiff extrusion with polymer and without water to form a dense, durable, waterproof, magnetic, high-value charge for EAFs.
  - Split tensile strength 4 – 6 MPa (400 – 850 PSI); TI > 98%; AI < 1%
- The mix may also contain lime-based products to produce a Fluxed Pig Iron (FPI) extruded briquette.
- Additional sources of carbon such as coke or anthracite coal can also be added to the mix.
- When FPI was trialed in an EAF, results showed reductions in:
  - Required charge carbon and injection carbon, power-on times (POT), Tap O2, and FeO in the slag.
  - This work shows the potential for FPI to improve yields, increase operational and energy efficiencies, lower CO_2 emissions, and reduce costs when used as part of a charge in an EAF.

Stiff Extrusion: Similar Charges for EAFs and BFs



Thank you!

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