ESTEP SPRING DISSEMINATION EVENT

5-6 JUNE 2025 KRAKOW (POLAND)

TransZeroWaste - Upgrading of low-quality iron ores and mill scale with low carbon technologies

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ESTEP

HOTEL ★★★★ GALAXY JORDAN GROUP

Łukasiewicz GIT

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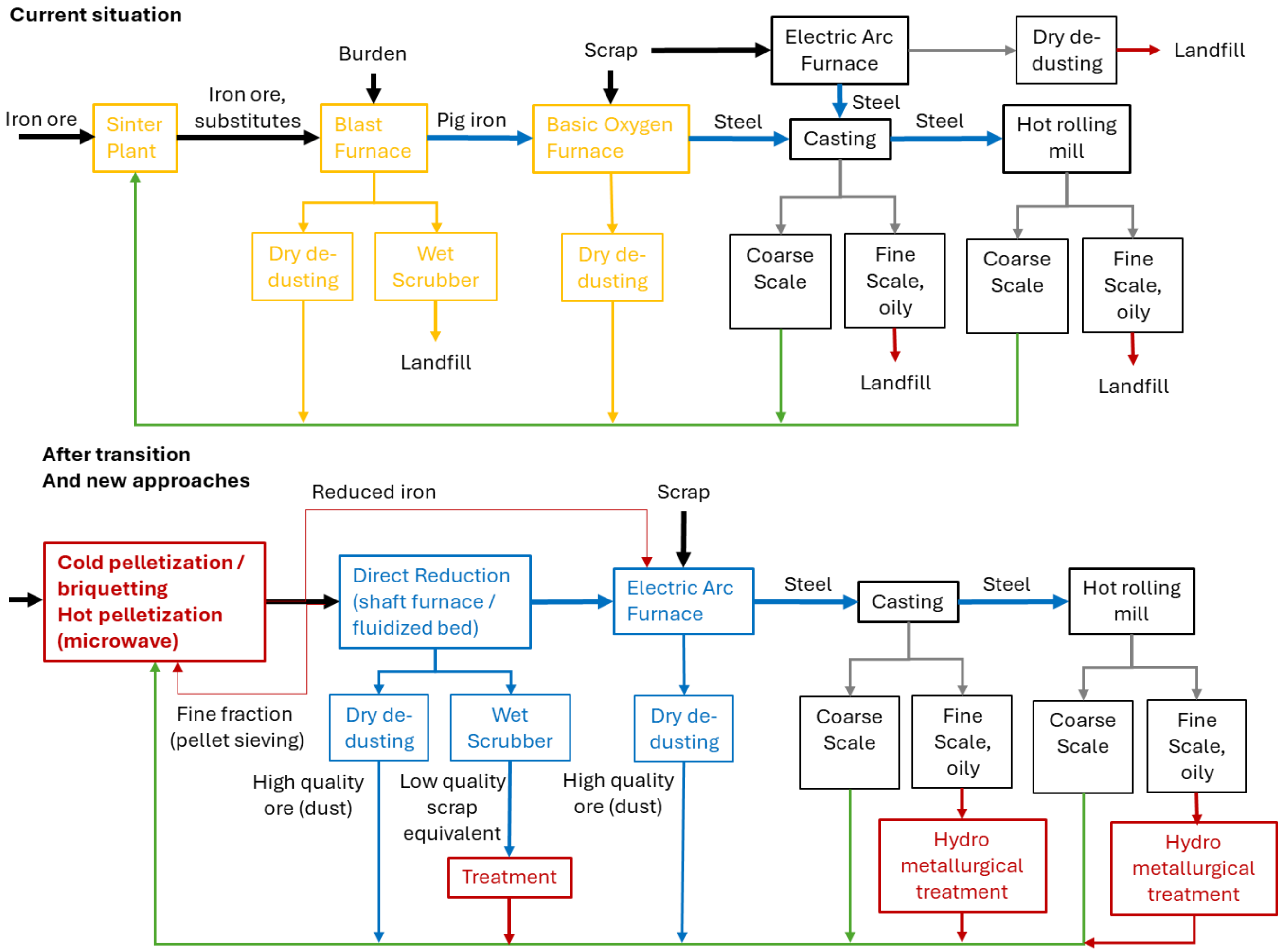
Situation - Transition of the steel industry towards climate-neutrality



Current situation

- **95 % internal recycling** within BF-BOF-route via sinter plant
- **No internal recycling of EAF** dust and a major amount of landfill requirement

Due to transition (climate-neutrality 2050)

- **Cut-off current recycling** within BF-BOF-route for over 6 million tons per year (EU27)
- **Occurrence of new by-products** with unknown compositions and quantities

Need for new options for by-products processing

- Development of **suitable recycling technologies** to avoid landfill and recuperate valuable secondary raw materials
- **Enlarge potential raw material basis** for **ensuring** a sufficient **material supply**

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State of the art, technical challenges & Key objectives

State of the art

- **organic-/non-organic binders for pelletising/briquetting**
- **Zn is limiting reuse of iron containing materials, current 2-20 wt.-% Zn → landfill**
- **Oil is limiting reuse of oily scale (aim < 0,3 %)**

Technical challenges

- Development of low-CO_2-technology for reuse-potential
- Unknown potential for minimum CO_2-footprint and hot behaviour in DR-plant

Key objectives TransZeroWaste

- **Upgrading low-grade iron ore** by combining with iron-rich by-products
- **Development of innovative techniques to produce high quality pre-material** for current & future low CO_2-production routes
- **Separation of disturbing components** from by-products to replace scrap
- **Development of the technological basis and digital tools** supporting the transition towards net-zero-waste in the European steel industry

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Technological apporaches and Innovations

TRANS ZERO WASTE

Main technological approaches	Innovation / Progress beyond state-of-the-art
Cold pelletisation and briquetting for direct use in existing and future steel works	**Use of low carbon and "green" binders** applied to new by-products and its combinations / properties. Optimum agglomerate properties for use in DR-process or EAF
Hot pelletisation with microwaves for upgrade of low-quality iron ores *and iron-containing by-products* to increase the content of metallic iron and decrease the iron oxide content	**Low-CO_2 parallel de-zincing and reduction** of Fe-containing by-products. **New concept of coupling** allowing a larger **scale up** and **efficiency**
Hydro-metallurgical treatment for removal of impurities from iron containing oily mill scale (casting, hot rolling)	**Low-energy and -CO_2 emission process compared** to **thermal treatment** methods including **cleaning agent** recovery -> opening **reuse** potential for **oil sludges** as **iron ore substitute**
Development of technological basis and **digital tools** supporting the transition towards zero waste in the European steel industry	**First time application of decision support tool in the steel industry** based on life cycle assessment (LCA), life cycle costing (LCC) and circularity indicators – aim: identification of most sustainable processing routes for materials with different Fe contents

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Cold pelletisation and briquetting for direct use in existing and future steel works

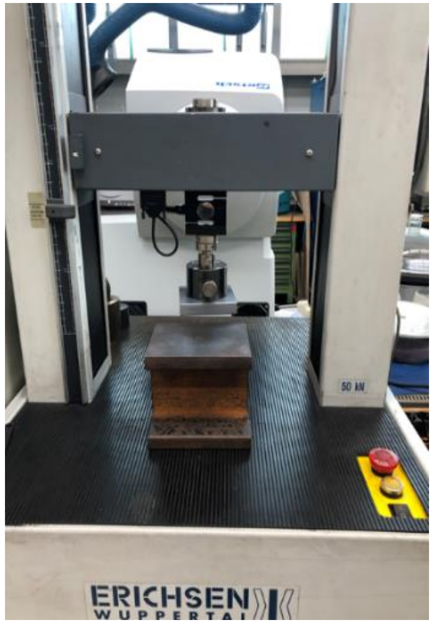
Process development:
→ cold pelletisation,
→ cold briquetting
for use in
- DR-processes (e.g. shaft furnace)
- EAF-/BF-/BOF as low-CO_2-substitute

Pelletisation

Produced pellets
(ca. 8 mm)

Optional:

Burning in muffle furnace
(1250 °C; 20 min)



Compression testing machine

Briquetting

Tablet press & Pressing parts
10 mm

Briquettes
10 mm

Cold pelletisation and briquetting for direct use in existing and future steel works

Briquetting trials (BFI)

Screening of binders (13x):

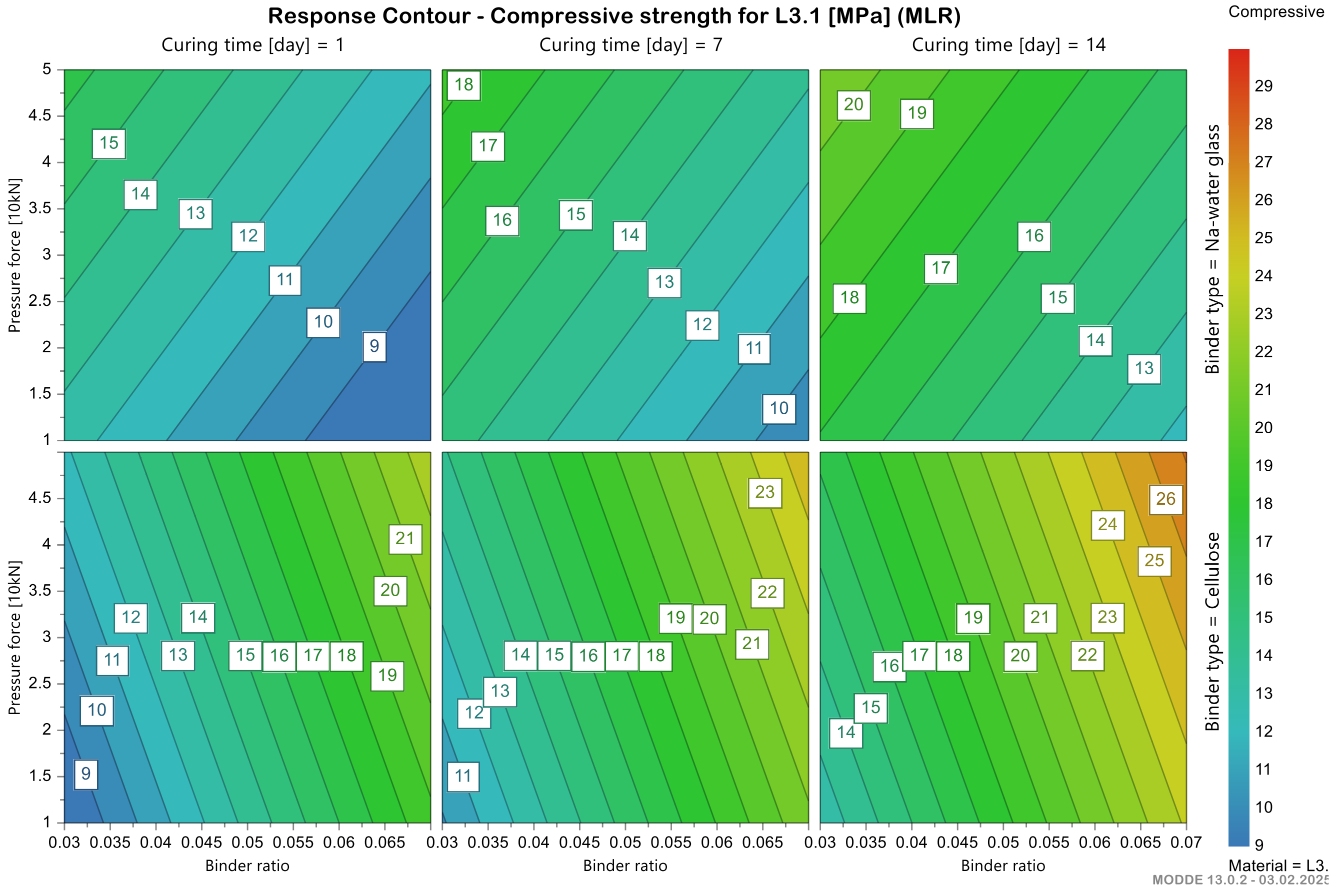
Best performing binders: sodium-waterglass, cellulose, bentonite (up to 37 MPa)

Software-based Design of Experiments (DoE)

- Two by-products & two binders
- Highest influence on compression strength: binder type & amount; curing time; pressing force
- Low-/No significant influence: material type, particle size distribution/grinding

Main conclusions:

Cold compressive strength of briquettes close to requirements of iron ore pellets (35 MPa)



Briquetting results: Response contour diagram of cold compression strength for one by-product (function of: press force, binder ratio, curing time, binder type)

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Cold pelletisation and briquetting for direct use in existing and future steel works

Pelletising trials (BFI)

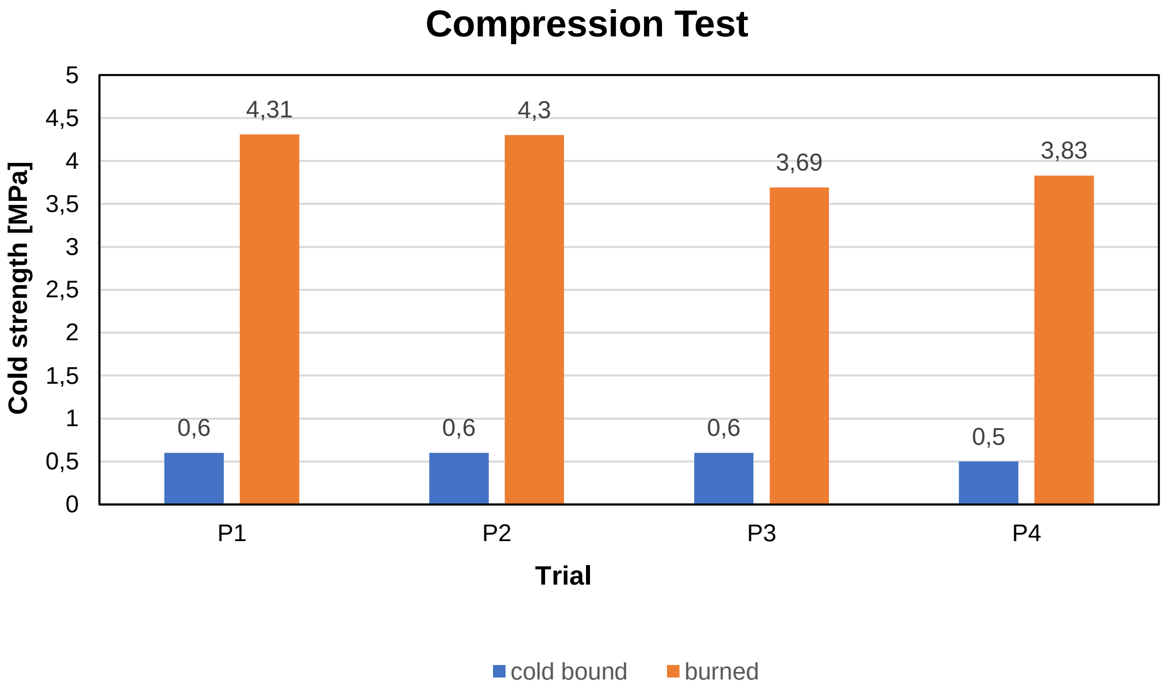
- Two by-products & two binders (bentonite, cellulose)
- Cold bound ↔ burned (1250 °C)

Main conclusions:

- Low compression strength for pelletisation, even after burning (< 5 MPa, insufficient for use in DR-Process or EAF)
- Small differences between the different by-products

Next steps briquetting & pelletising

- Continuation of trials for optimization of briquetting and pelletisation procedure and mixes
- Use of de-oiled mill scale sludge samples
- Verification of lab results in technical scale and field trials (CSIC, CELSA)



Pelletising results:
Cold compression strength, two by-products & two binders

Cold pelletisation and briquetting for direct use in existing and future steel works

Hot tests of briquettes (GIT)

Main results:

- Thermoplastic properties:
  Wide softening range for briquettes bound with cellulose
  → possibly disadvantageous for shaft furnaces
- Reducibility Test (ISO 11258):
  Repeatability of reduction degree needs to be improved

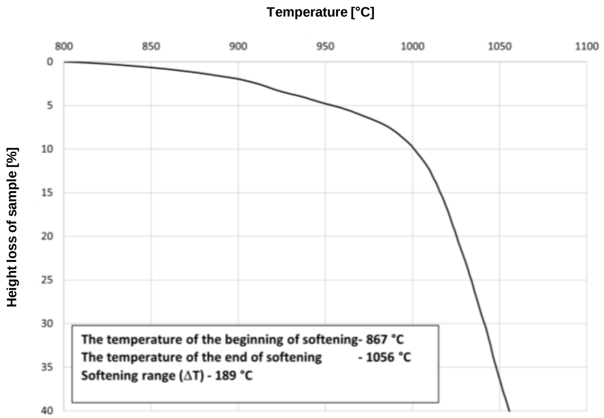
Next steps:

Improvement of procedure for

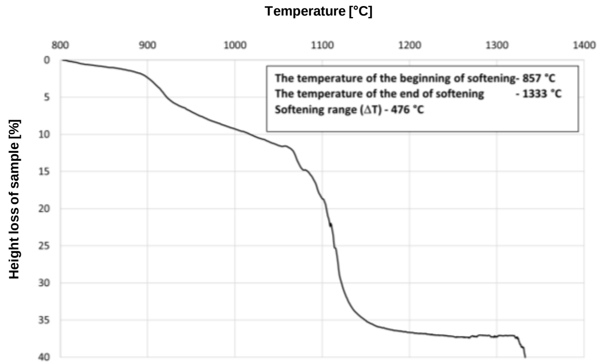
- minimized material consumption
- higher repeatability and accuracy

→ continue improved hot tests

Thermoplastic Properties Test

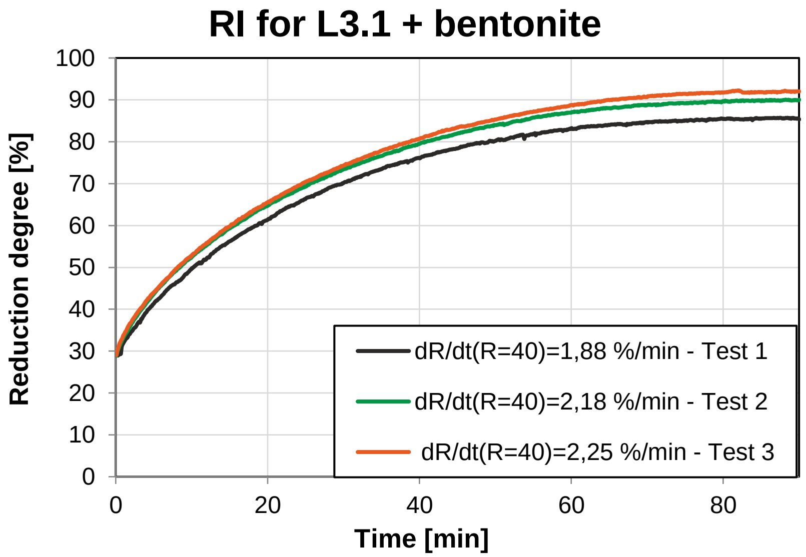


Binder: Sodium silicate



Binder: Cellulose

Reducibility Test (ISO 11258)



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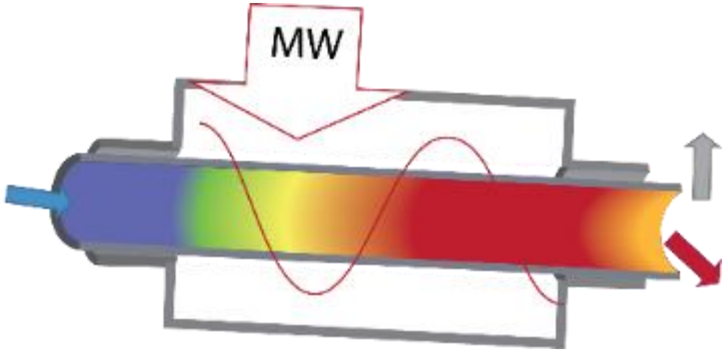
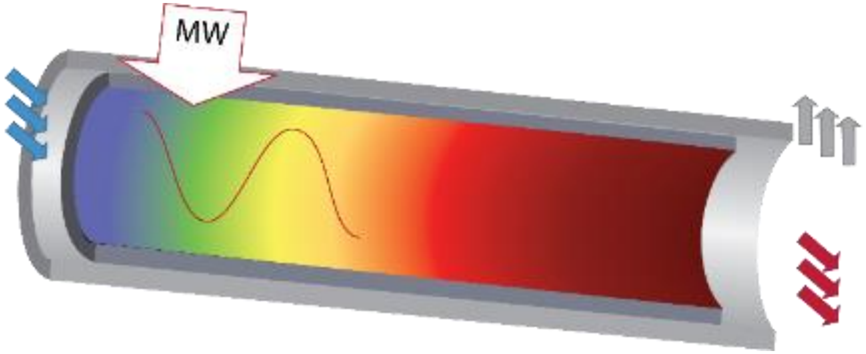
Hot pelletization with microwaves
New concept of rotary applicator

Upgrade the hot pelletizing with microwaves

- Development of a new process using the *DESTINY microwave applicator concept* (CNT with support of BFI, K1, UPV)
- Development of a new concept of tube as applicator for large scaling up capacity (CNT, UPV)
- Innovative microwave treatment concept for hot pelletizing supported by findings of pre-trial investigations for adaptation, optimization and further enlarged potential (CNT, UPV, DH)
- Demo trials will be performed at DH with CNT and BFI



DESTINY BASED
Ceramic tube crossing the MW cavity



TransZeroWaste UPGRADING
Metallic tube **is** the MW cavity
Goal: 30-70 kg/h

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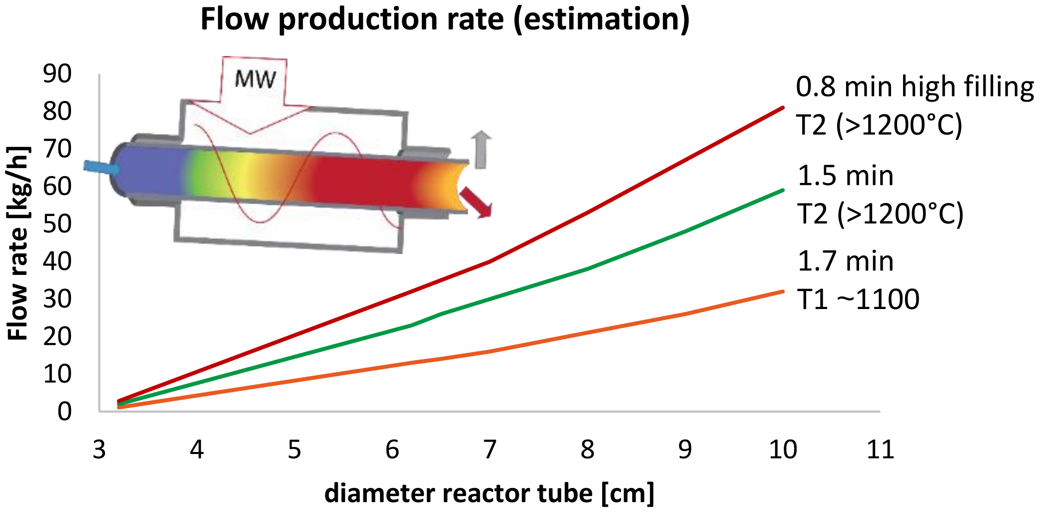
Hot pelletization with microwaves
New concept of rotary applicator

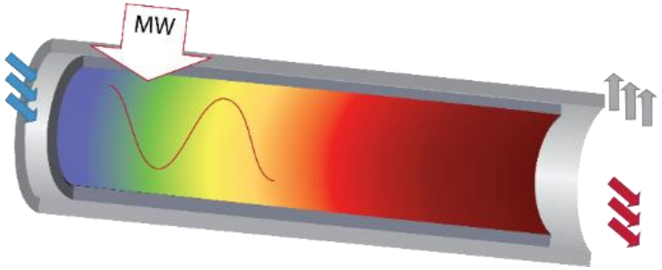
Capacities of each concept of applicator

High control of power
Capacity for high temperature (up to 1450°C)



60 kg/h in rotary
80 kg/h in high filling

High volume capacity
Higher requirement of dielectric properties



> 120 kg/h
Higher residence time capacities

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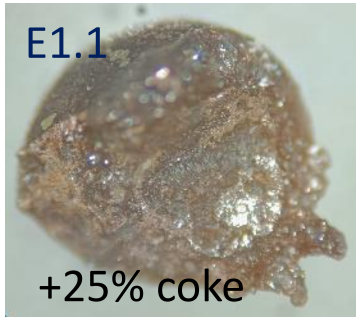
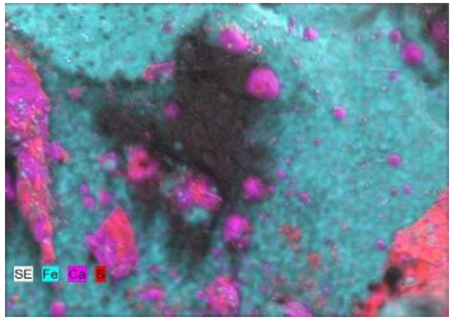
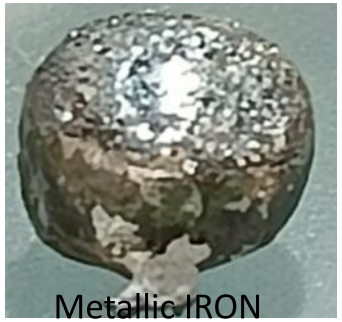
Hot pelletization with microwaves

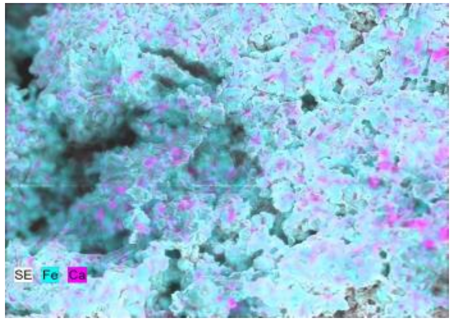
Stationary trials



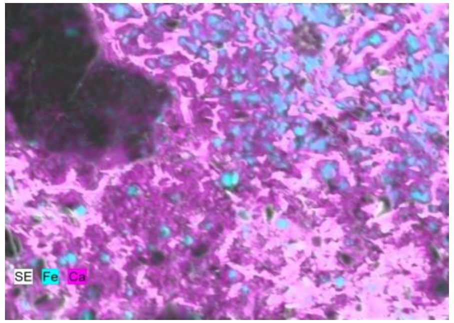




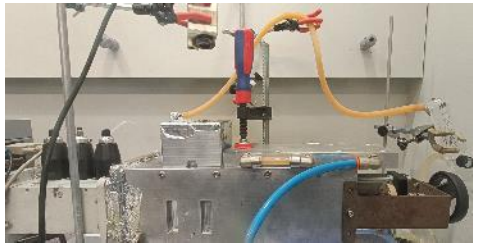
- Free metallic iron formation when carbon
- Samples with high content in SiO_2 and CaO generate Fe-spinels trapping the Fe
- All samples treated containing enough reductant are suitable for reduction
- Oil is a reductant agent. Gas analysis is still pending in oil containing wastes

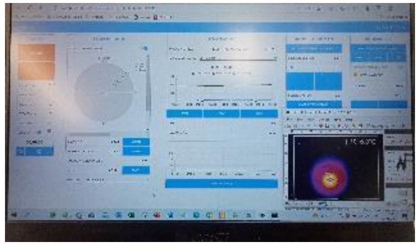


Metallic IRON



Ca-rich phases
(Fe-Ca spinels)
Free iron disseminated





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Hydro-metallurgical treatment for removal of impurities - aim / cleaning agent selection / results

- **Situation:** no or limited metallurgical reuse of oily iron carriers as scale and sludge due to oil contents
- **Aim:** Removal of oil and grease for a mandatory step for metallurgical reuse oil contents < 0.1 to 0.3 wt.-%
- **Investigated sludges:** continuous casting line (oil-content: 4 - 6,5 wt.-%), hot rolling mill (oil content: 3,5 wt.-%)
- **Evaluation criteria for selection:** oil removal efficiency, cleaning agent dose/costs, composition, recoverability

Cleaning agent	Group	Compound	pH (value)	Water solubility
1	**Tenside**	Alkoxylate	5,5 – 8,5	Dispersible
2	**Non-ionic tenside**	Polyethylene glycol, propoxylated	7	Insoluble
3	**Tenside**	EDTA + etidronic acid	8,7	Fully water-miscible
4	**Tenside**	Oleylamine	5 – 7	Aqueous emulsion
5	**Solvent**	Monoterpen	4,1	Fully water-miscible
6	**Solvent**	Mixture alcohol ethoxylates, amine	k.A.	insoluble
7	**Inorganic, alkaline**	Combination potassium - tenside	k.A.	Fully water-miscible
8	**Inorganic, alkaline**	Combination sodium, tenside, leach	12,7	Fully water-miscible
9	**Inorganic, acidic**	Citric acid	4,3	Fully water-miscible

Loaded cleaning agent 6 (left) and 8 (right)

- **Determined:** solvent (alcohol mixture) or inorganic alkaline (mixture sodium, tenside, leach) for both sludges
- **Oil removal** agent 6: 76% / 86% - oil removal cleaning agent 8: 68% / 72% (hot rolling sludge / CC line sludge)
- **Dosage:** 9.8 / 15 mg/ g or oil 4.4 / 9.3 mg/g oil (hot rolling sludge / CC line sludge)

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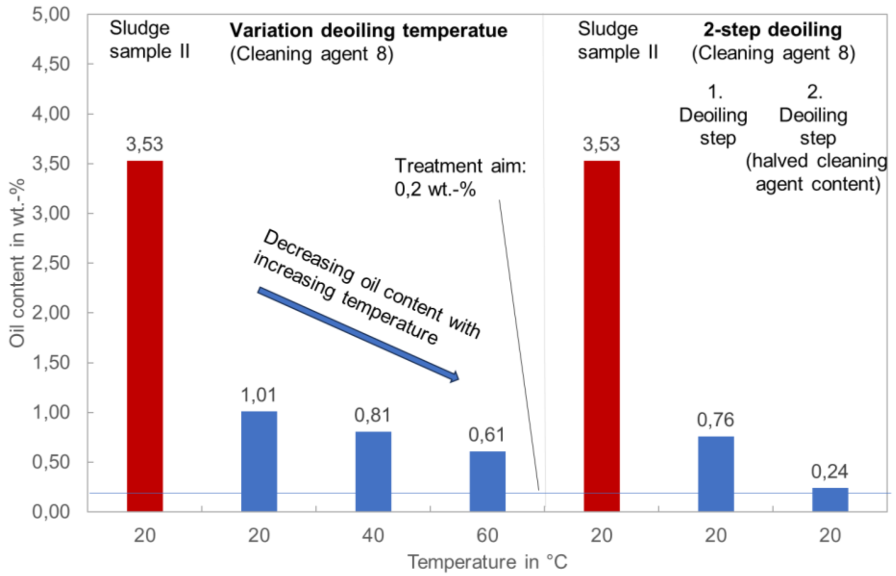
Hydro-metallurgical treatment for removal of impurities

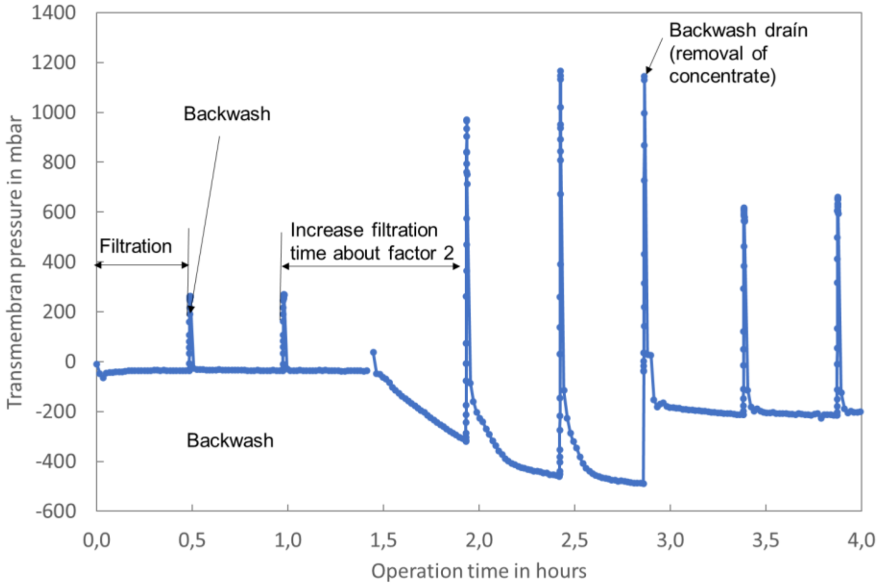
Parameter optimisation (hot rolling sludge)

- Increase of oil removal from 71% to 82% by heating cleaning agent from 20° to 60°C
- Increase of oil removal to 93% by two-step-washing
- No improved de-oiling by intake of ultra-sound



Cleaning agent recovery

- Under pressure filtration with chemical resistant ceramic flat sheet membranes suitable
- Flux: 80 L/ m²*h with Al-oxide membrane
- Cleaning by back wash and period drain sufficient



Field trial in preparation

- De-oiling of sludge
- Following metallurgical treatment in H_2-direct reduction
- Final metallurgical reuse in operational EAF

Pilot plants:

Magnetic separator (left)

Ceramic flat sheet filtration (rigth)

Environmental, Circularity and Economic Evaluations

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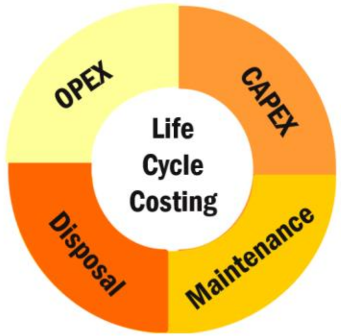
3 Sustainability Aspects



Life Cycle Assessment (LCA)

- **Environmental footprint** of developed technologies.
- Environmental evaluation of the overall steel production.

Life Cycle Costing (LCC)

- **Economic footprint** of developed technologies.
- Use of several indicators (LCC, NPV, …).

Circularity Indicators (CIs)

- Show how much products are recycled
- Waste reduction & value maximization.
- Recycling score

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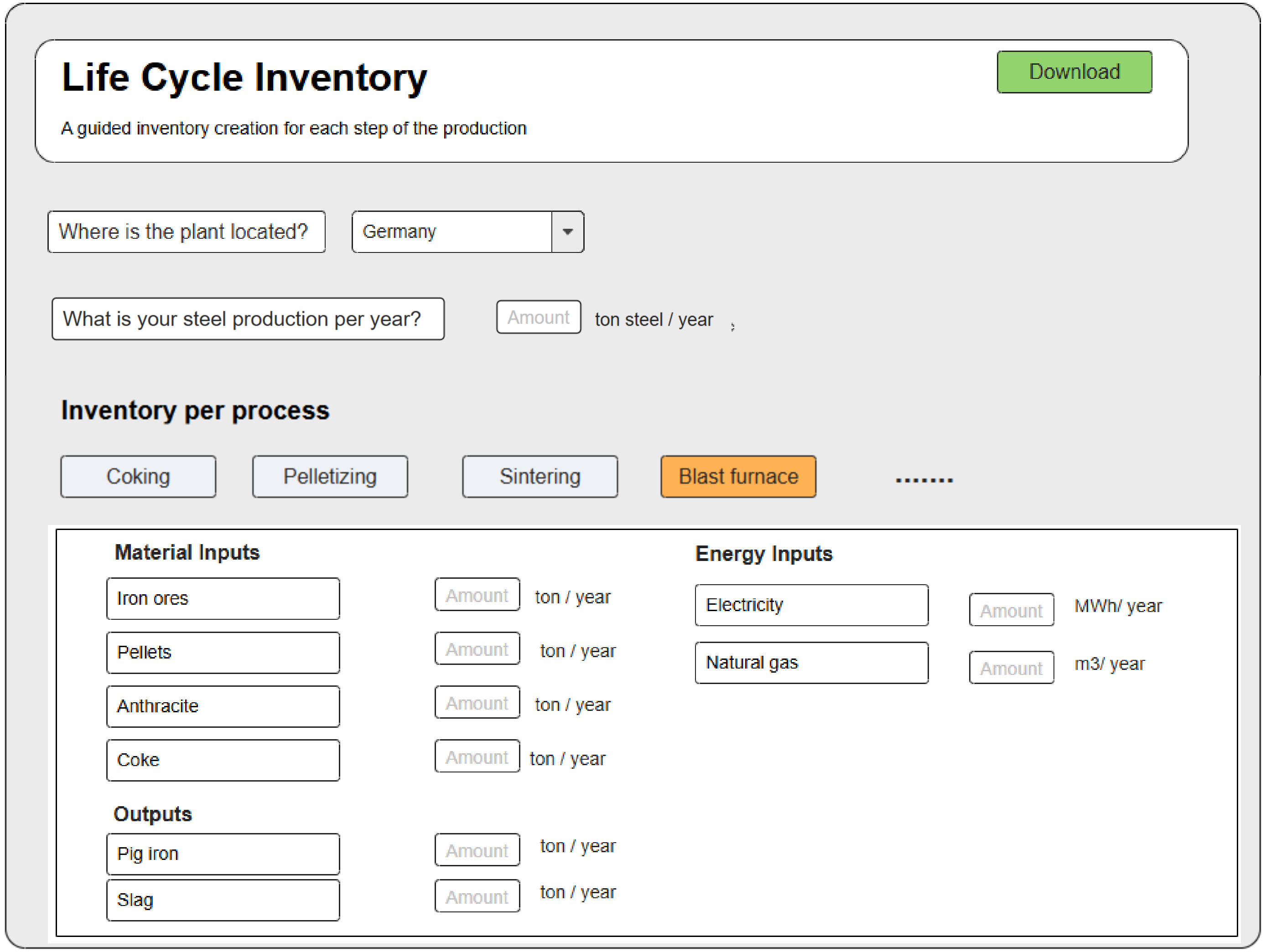
Support decision tool development: overview – inventory definition

Development of an application:

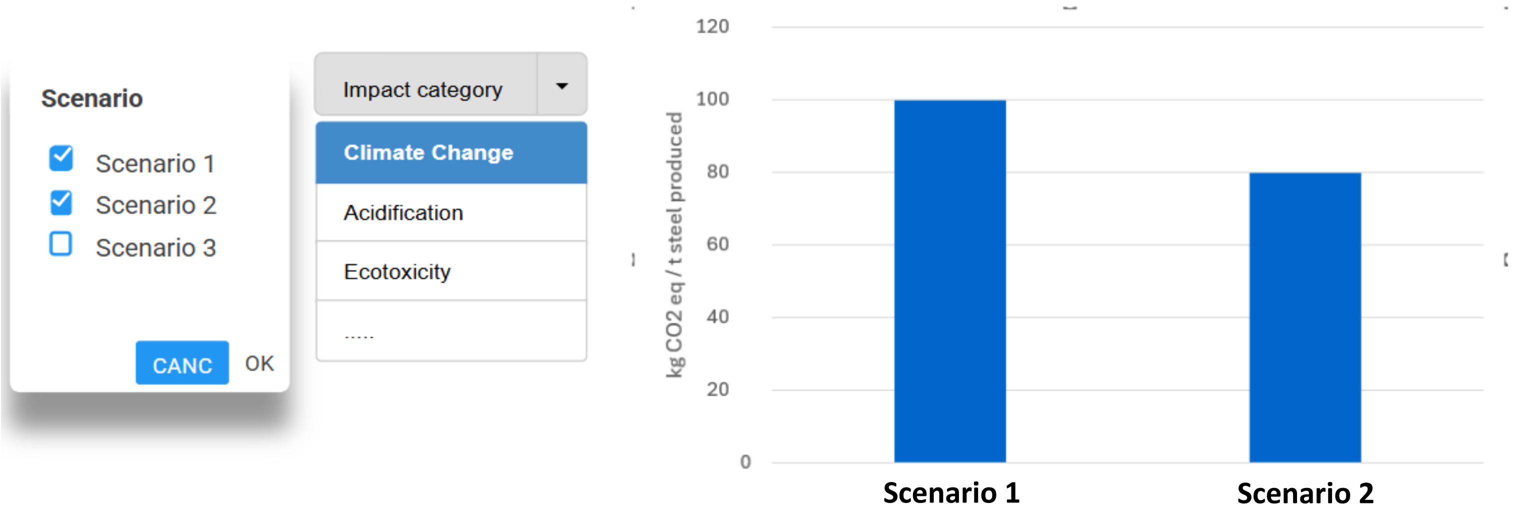
- Integration of 3 sustainability indicators
- Scenarios comparison
- Support awareness and future investments

- Example of case study definition
- Inventory creation
- Possibility of defining precisely the production route with assisted procedure.



Support decision tool development: overview – scenarios comparison

Scenarios comparison



- Results of each scenario are presented
- Comparison between multiple scenarios is also possible

Next steps:

- Calculation of the environmental, economic and circularity aspects (LCA, LCC, CIs)
- Development of the tool
- Contribution to carbon-neutral targets & circular industrial value chains

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Thank You!

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