FLASHPHOS

The complete thermochemical
recycling of sewage sludge

FlashPhos Closing Event
Results, Impact & Way Forward

21 April 2026

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 958267.

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recycling of sewage sludge

Introduction to FlashPhos

Christian Schmidberger, University of Stuttgart

FlashPhos Closing Event – Results, Impact and Way Forward

Leoben, 21.04.2026

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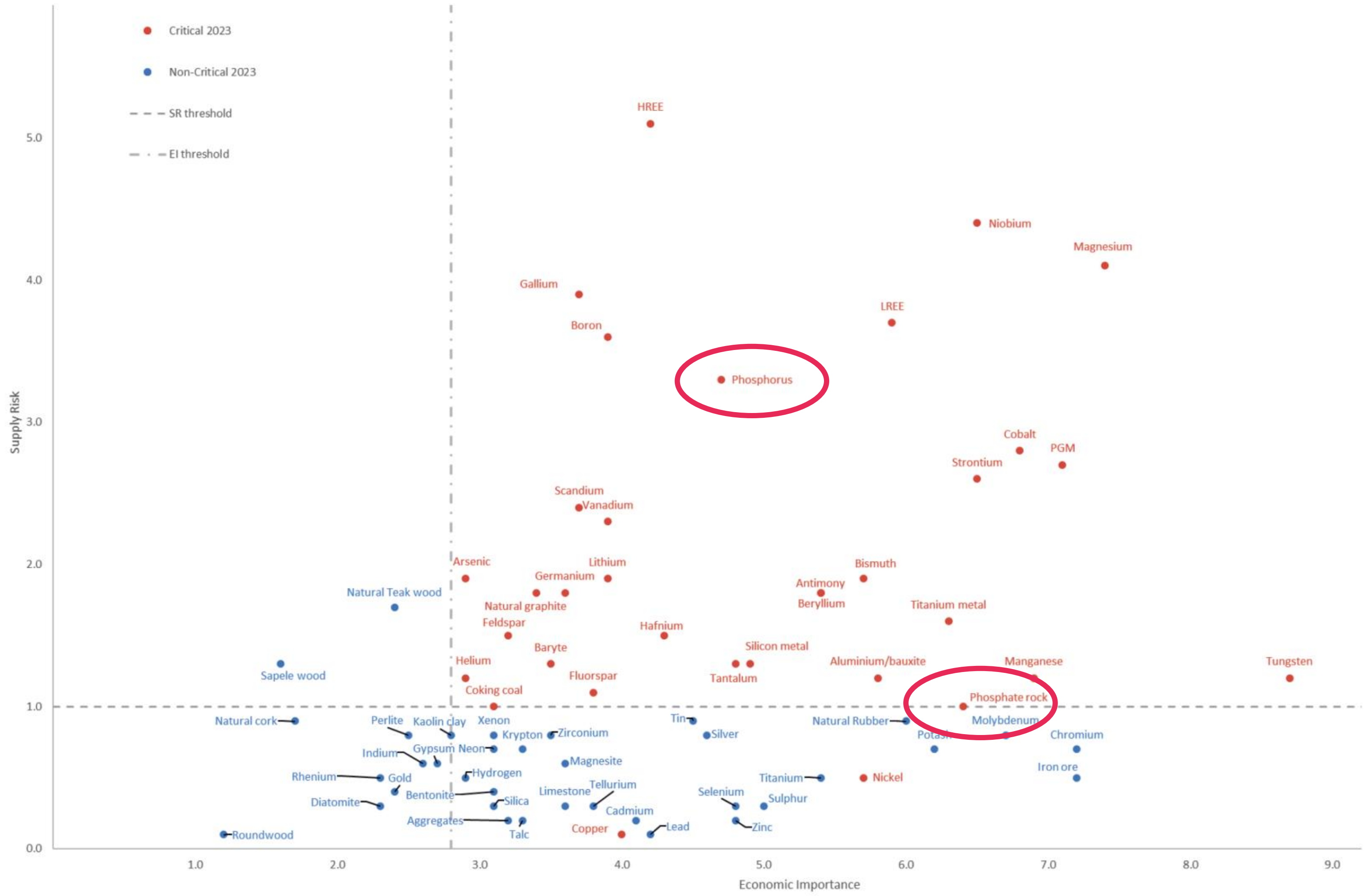
RAW MATERIAL CRITICALITY



Source: Study on the Critical Raw Materials for the EU 2023; European Commission; 2023; Brussels

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MOTIVATION FOR FLASHPHOS

- Classification of phosphorus as critical raw material by the European Commission in 2014
- Focus on secondary phosphorus sources → Circular economy

- Change in directive of sewage sludge disposal in Germany
  - Binding phosphorus recovery for waste water treatment plants
  - Stepwise implementation until 2032

- Other European countries plan to implement similar directives

- 1.77 Mio. tons of sewage sludge in Germany to be disposed every year

➢ A new market for phosphorus recovery technologies

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FACT SHEET

- **Grant agreement ID**: 958267
- **Topic:** CE-SC5-07-2020 - Raw materials innovation for the circular economy: sustainable processing, reuse, recycling and recovery schemes
- **Timing:** 05/2021-04/2026 (60 months)
- **Project Budget:** € 15 226 965,71
- **EU contribution:** € 11 897 102,28
- **Coordinator:** University of Stuttgart

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FLASHPHOS HISTORY

- 2021/05: Virtual Kick-off Meeting
- 2021/11: First Steering Committee Meeting in Leoben
- 2022/06: First General Assembly in Sevilla
- 2023/02: First of **6** scientific paper by TUGRAZ
- 2023/05 - 2025/04: Extensive work at ARP and Flash Reactor
- 2023/11: First campaign on Dryer-Grinder
- 2024/04 - 2025/04: Dryer-Grinder experiments at USUTT
- 2025/07 - 2026/03: Commissioning of and experiments on Flash Reactor
- 2026/04: Final Conference and end of project

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OBJECTIVE

FlashPhos at a large scale a thermochemical process, to convert **sewage sludge** into

- High-quality **white phosphorus** (P_4),
- Climate friendly **cement substitute**,
- an **iron alloy**,
- a **heavy metal concentrate**,

offering a full **economically**, **ecologically** and **socially** sound **circular concept** from problematic wastes to valuable products.

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WHY WHITE PHOSPHORUS?

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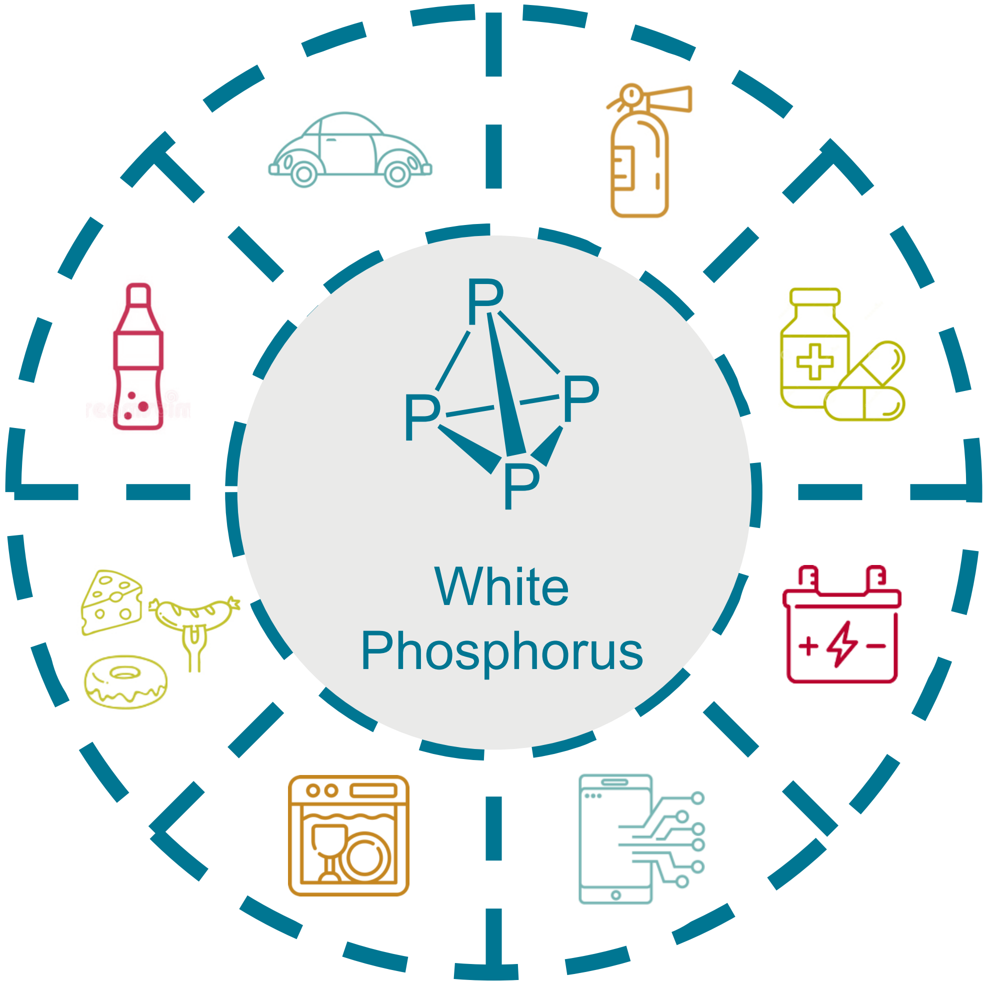
- White phosphorus (P_4) is used to make
  - **thermal phosphoric acid** (H_3PO_4),
  - **phosphorus chlorides, sulphides** and other P-derivatives

  for the **chemical industry**.
- P_4 is thus a **critical raw material,** e. g. for
  - Food
  - Electronics
  - E-mobility
  - Water treatment
  - Fire protection
  - Metal processing



pictograms by: Wikipedia/NEUROtiker; Flaticon/dishwasher; Freepik/dooder; Dreamstime/DigitalBazaarr; Freepik/macrovector-official; vecteezy/yuliyalins; Dreamstime/Alfianiqbal20; SVGREPO

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Germany

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EXPECTED RESULTS

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Pilot plant with up to 250 kg/h dry sewage sludge throughput

Demonstrate generation of high-quality products **exceeding state-of-the-art** P_4 production & sludge recycling

Demonstrate production of **climate-friendly** alternative **cement substitute**

Demonstrate unique novel one-step **drying-grinding process**

Basic engineering + safety assessment of **full-size FlashPhos plant** (TRL 8)

Full **circular economy** model

Sustainable resource management

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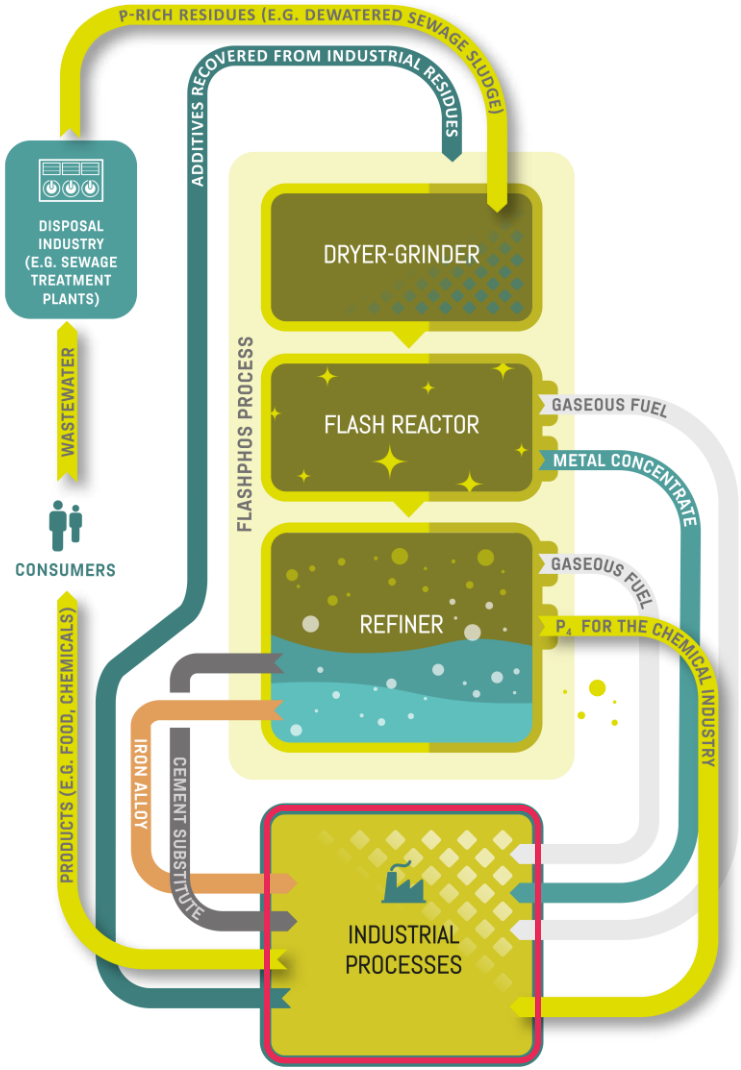
TECHNICAL CONCEPT AND CIRCULARITY



INPUT

- Dewatered sewage sludge
- Industrial wastes as additives
- Process heat
- Electrical energy

OUTPUT

- White phosphorus
- Gaseous fuel
- Climate friendly cement substitute
- Iron alloy
- Metal dusts
- Process heat

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WORK PACKAGES

WP1 Project management & coordination (USTUTT)

WP5 Resources management (USTUTT)

Process engineering core

WP2 Modelling & Simulation (TU GRAZ)

WP3 Component testing/Lab scale Experiments (INSPYRO)

WP4 Process Development & Pilot Plant Design & Construction (ARP)

WP6 Demonstration tests with industrial scale pilot plant (USTUTT)

WP7 Scale-up of the process & implementation in host industries (A TEC)

WP8 Safety & environmental assessment (INERCO)

WP9 Exploitation & market deployment (ITALMATCH)

WP10 Communication & Dissemination (SEZ)

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CHALLENGES

- Consequences of …
  - COVID-pandemic
  - Suez channel blockage
  - Russian Invasion in Ukraine

➢ Causing high inflation rates, unavailability of components and long delivery times

➢ Additional time-consuming efforts to keep project timeline

- Complexity of specific Engineering tasks

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FLASHPHOS CONSORTIUM

phosphorus chemistry, phosphorus production engineering, phosphorus economy, cement technology, cement production, recycling technology, alternative fuel engineering, drying technology, metallurgy, slag chemistry, refractory engineering, thermal process engineering, process modelling and simulation, plant modelling and simulation, safety engineering, industrial plant engineering, thermal plant construction, gas treatment, slag treatment, slag valorisation, performance of laboratory and pilot scale experiments, chemical analytics, industrial economy, circular economy, waste and resources management, material flow analysis, geoinformation systems, environmental and socio-economic impact assessment, …

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ENTER THE FLASHPHOS WORLD

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FLASHPHOS

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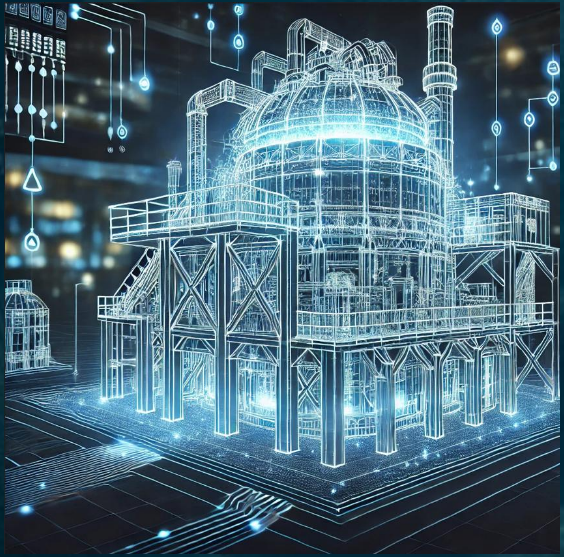
Feedstock and sewage sludge mapping

Input materials

1. INTRODUCTION | 2. ADDITIVES | 3. SEWAGE SLUDGE | 4. LOCALIZATION

Piloting



InsPyro

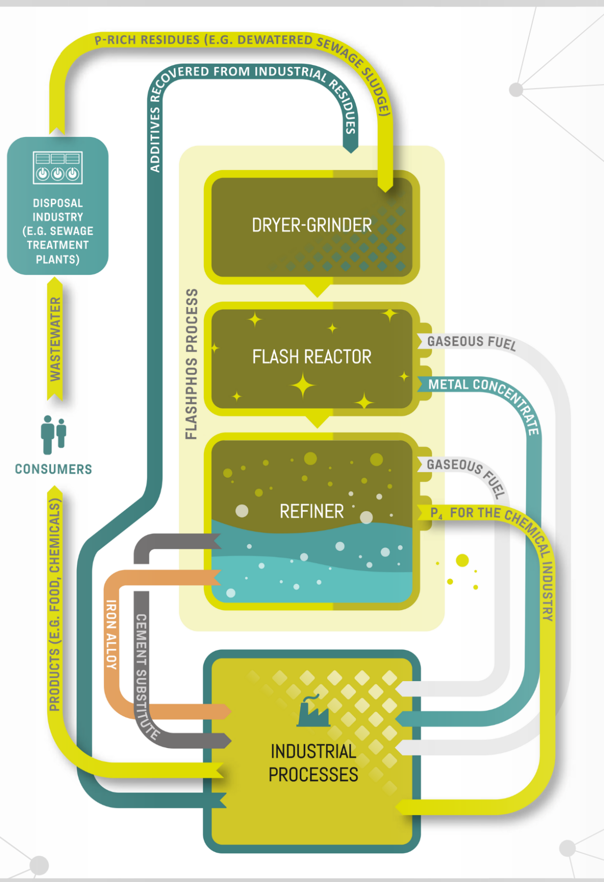
Dyckerhoff

böhler

Italmatch Chemicals

MITechnology of Austria
Edlinger

Scale up



INERCO

A TEC GROUP
A Member of LOESCHE Family

vdz

Input materials

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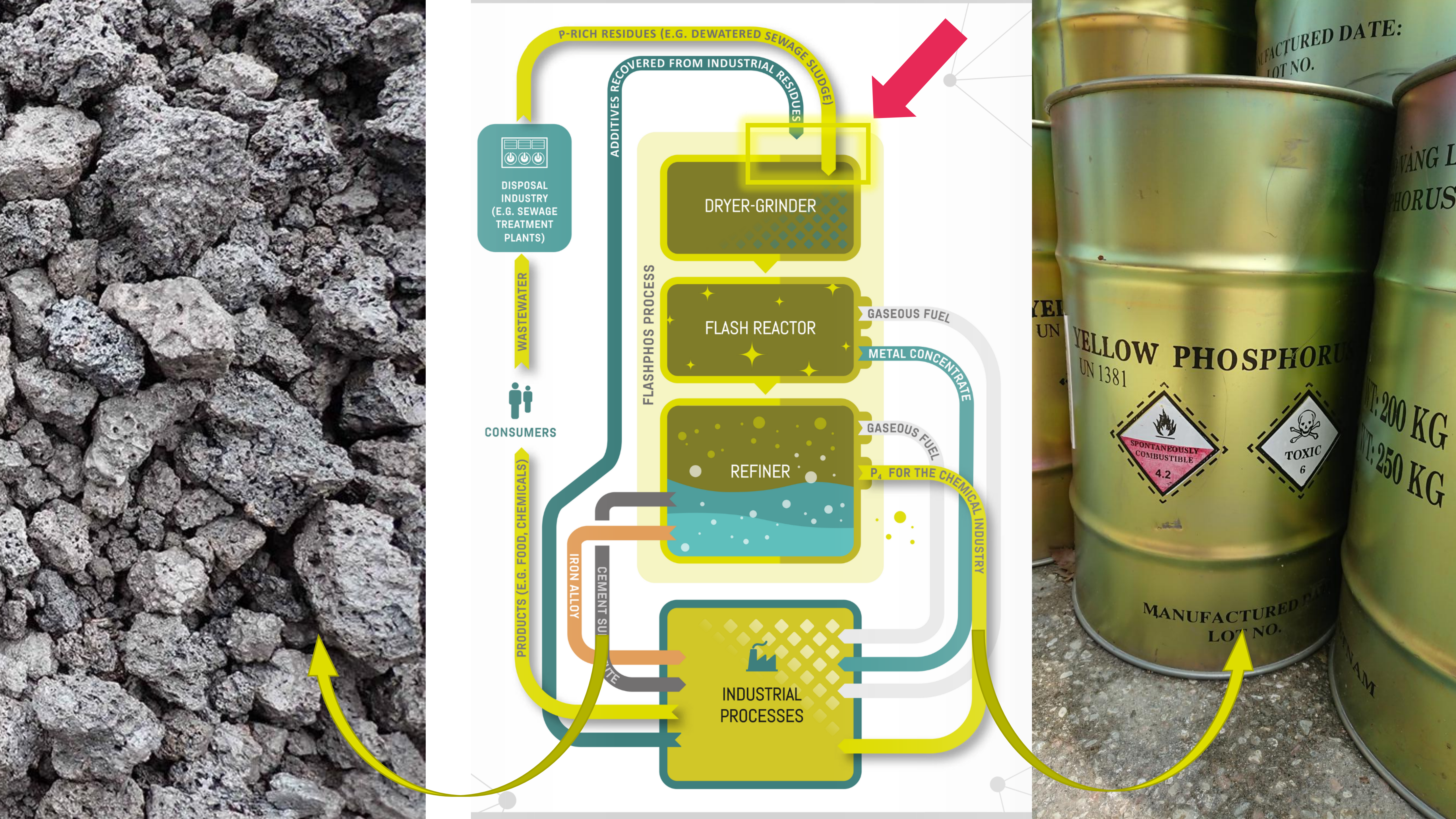
P-RICH RESIDUES (E.G. DEWATERED SEWAGE SLUDGE)
ADDITIVES RECOVERED FROM INDUSTRIAL RESIDUES
DISPOSAL INDUSTRY (E.G. SEWAGE TREATMENT PLANTS)
WASTEWATER
CONSUMERS
PRODUCTS (E.G. FOOD, CHEMICALS)
FLASHPHOS PROCESS
DRYER-GRINDER
FLASH REACTOR
GASEOUS FUEL
METAL CONCENTRATE
REFINER
GASEOUS FUEL
P_4 FOR THE CHEMICAL INDUSTRY
IRON ALLOY
CEMENT SU
INDUSTRIAL PROCESSES
YELLOW PHOSPHORUS
UN 1381
SPONTANEOUSLY COMBUSTIBLE
4.2
TOXIC
6
MANUFACTURED DATE:
LOT NO.

FLASHPHOS

13 Additives screening

Dyckerhoff

böhler

MITechnology of Austria

Edlinger

Cement bypass dust
Cement kiln dust
Meat and bone meal
Ladle furnace slag
Gypsum based construction waste
Flue gas desulfurization gypsum
Municiple solid waste incineration fly ash
Silica fume
Waste foundry sand
Waste glass
Brick debris
Coal fly ash
Ca-P-waste

Constituents	CaO (%)	SiO2 (%)	Fe2O3 (%)	FeO (%)	P2O5 (%)	Al2O3 (%)
Cement bypass dust	52,17	15,44	1,77	-	-	3,42
Cement Kiln dust	48,70	13,70	1,10	-	0,20	3,40
Ladle furnace slag	48,77	20,21	-	1,96	0,03	8,92
Meat and Bone Meal	43,90	1,42	0,45	-	37,70	0,19
Gypsum based CW	37,30	2,43	0,36	-	0,02	0,81
Flue gas desulphurization gysum	31,59	0,56	0,03	-	0,01	0,17
MSWI Fly ash	27,53	16,15	2,73	-	0,58	7,80

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Additives procurement

Cement bypass dust
Cement kiln dust
Meat and bone meal
Ladle furnace slag
Gypsum based construction waste
Flue gas desulfurization gypsum
Municiple solid waste incineration fly ash
Silica fume
Waste foundry sand
Waste glass
Brick debris
Coal fly ash
Ca-P-waste

Site visit at rendering facility

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3 Additives in focus

Cement bypass dust
Cement kiln dust
Meat and bone meal
Ladle furnace slag
Gypsum based construction waste
Flue gas desulfurization gypsum
Municiple solid waste incineration fly ash
Silica fume
Waste foundry sand
Waste glass
Brick debris
Coal fly ash

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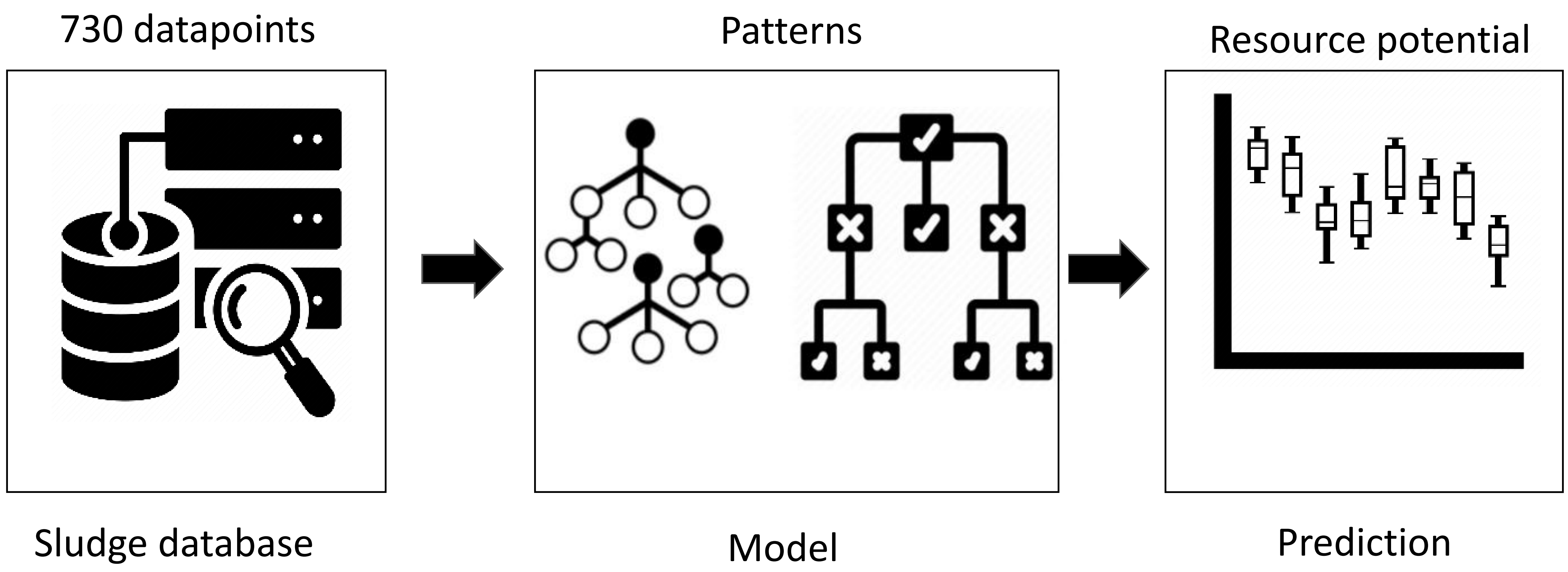
Input composition



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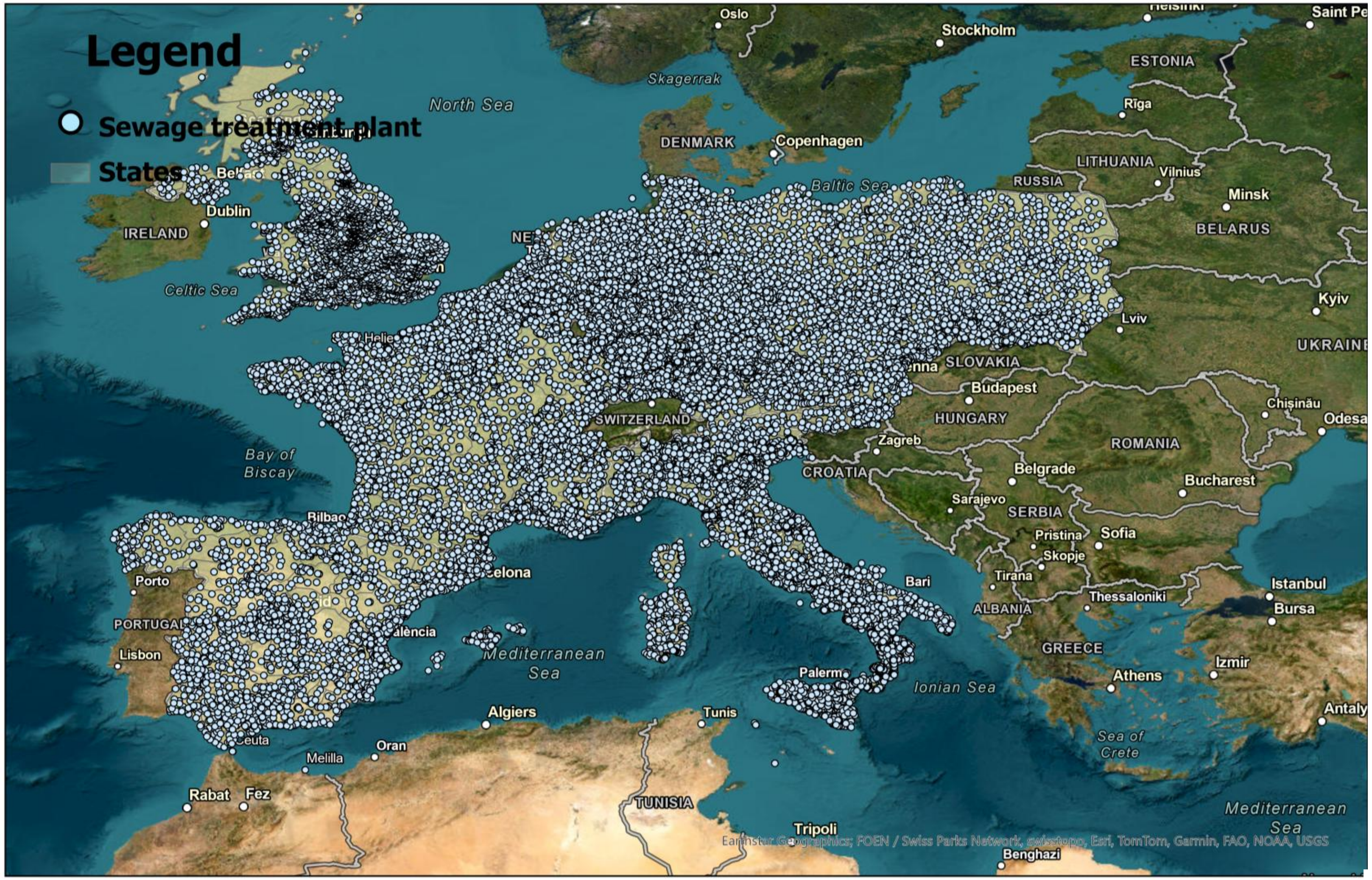
Modeling



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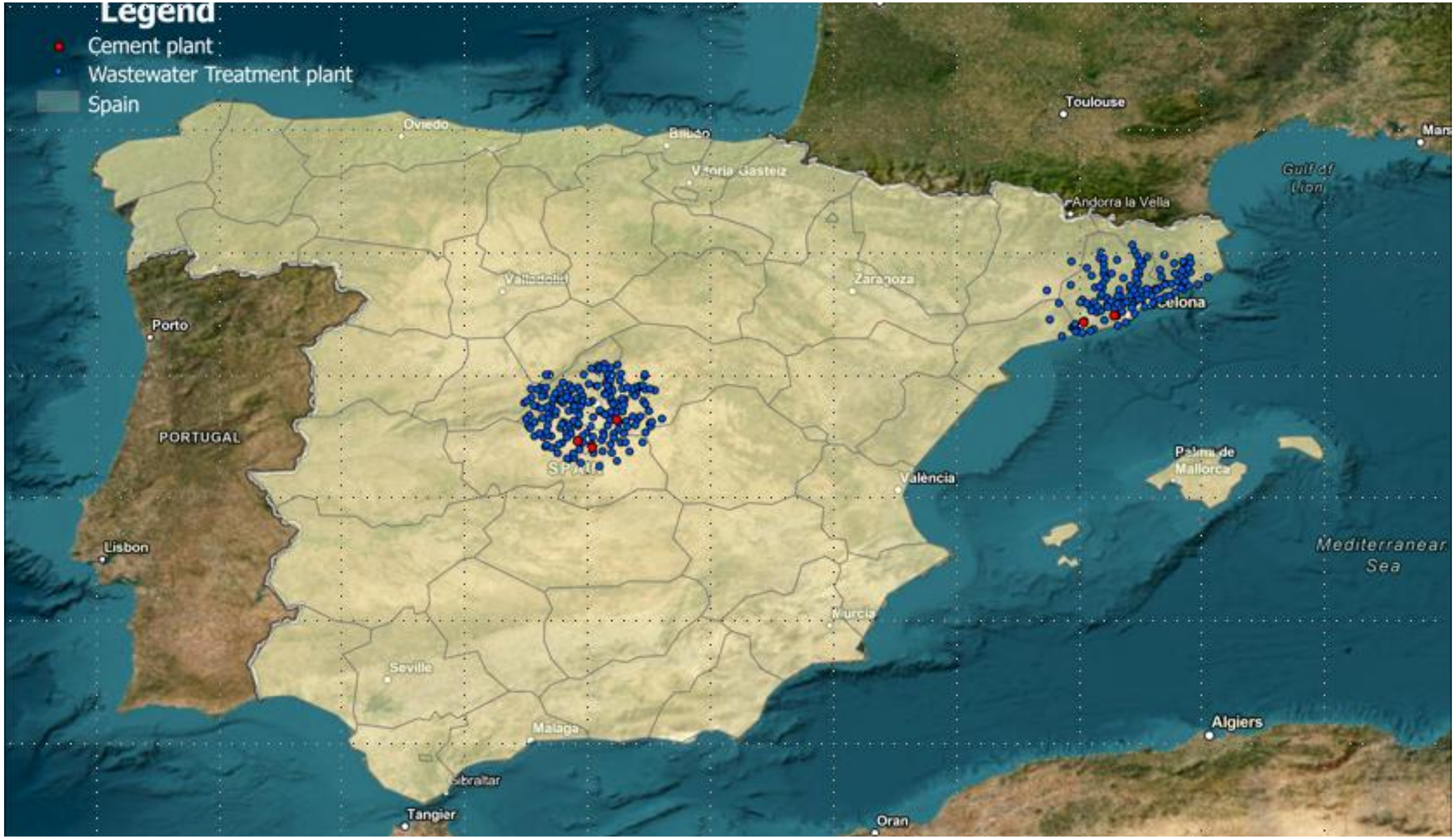
Localization phosphorus recovery areas



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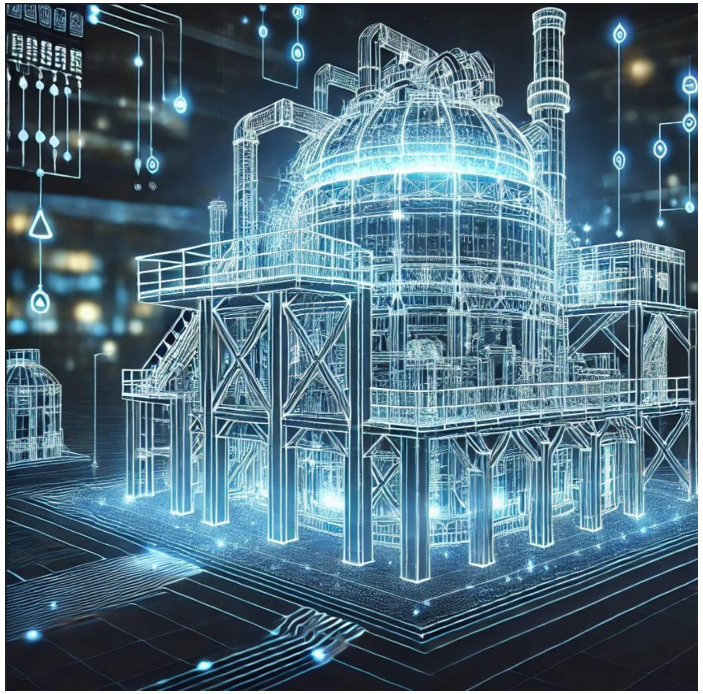
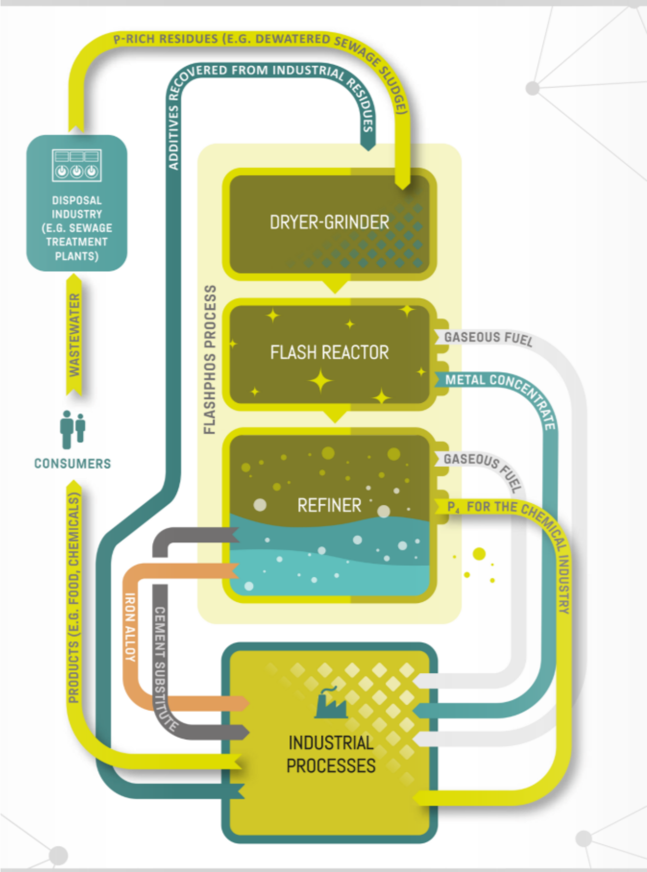
Modeling

Database sewage sludges
sludge predictions



Digital twin

InsPyro



Buzzi Unicem, Dyckerhoff, böhler, MITechnology of Austria, Edlinger

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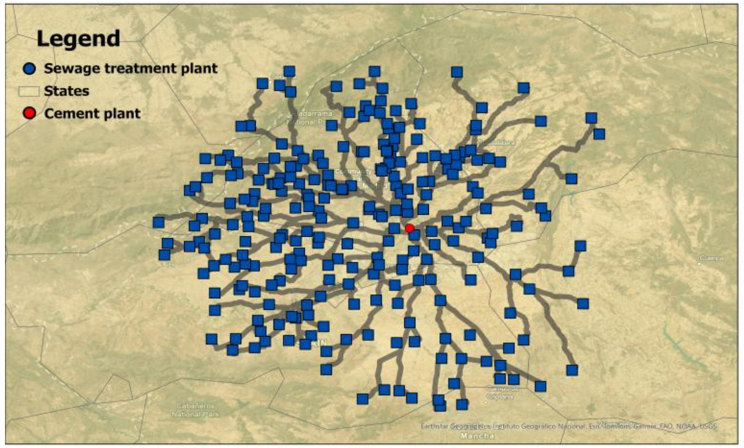
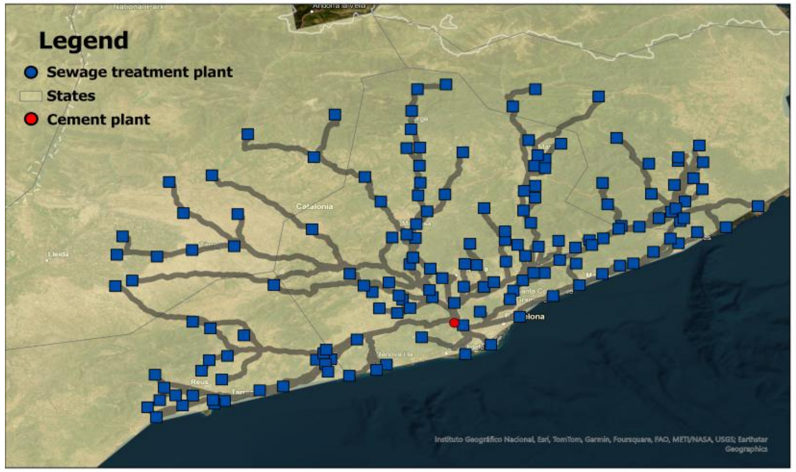
Evaluation phosphorus recovery areas



Madrid

Factor	Value
P-recovery potential	++
Road length	--
Distr. UWWTP	+
Sludge price	-



Barcelona

Factor	Value
P-recovery potential	+
Road length	-
Distr. UWWTP	++
Sludge price	-

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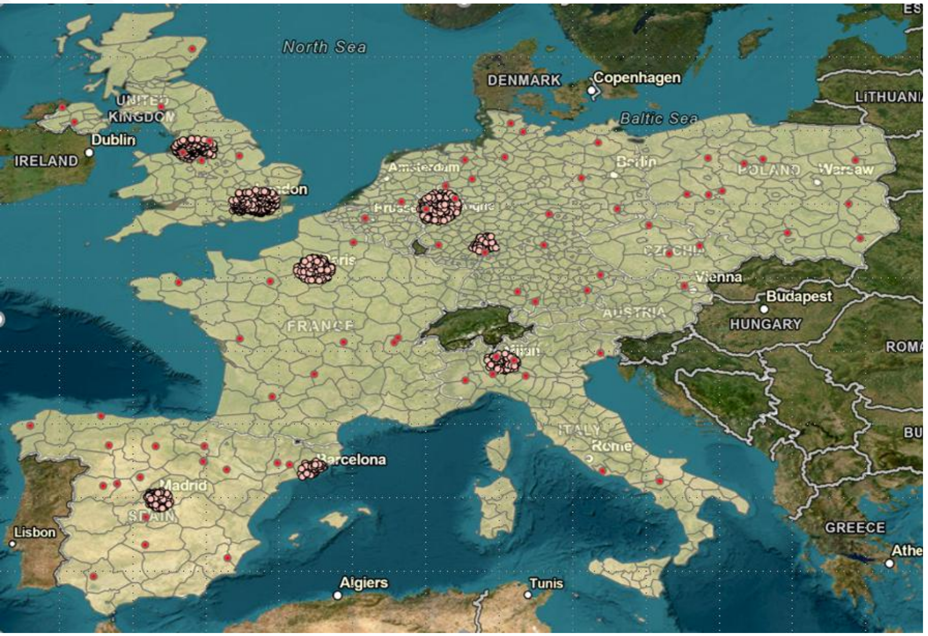
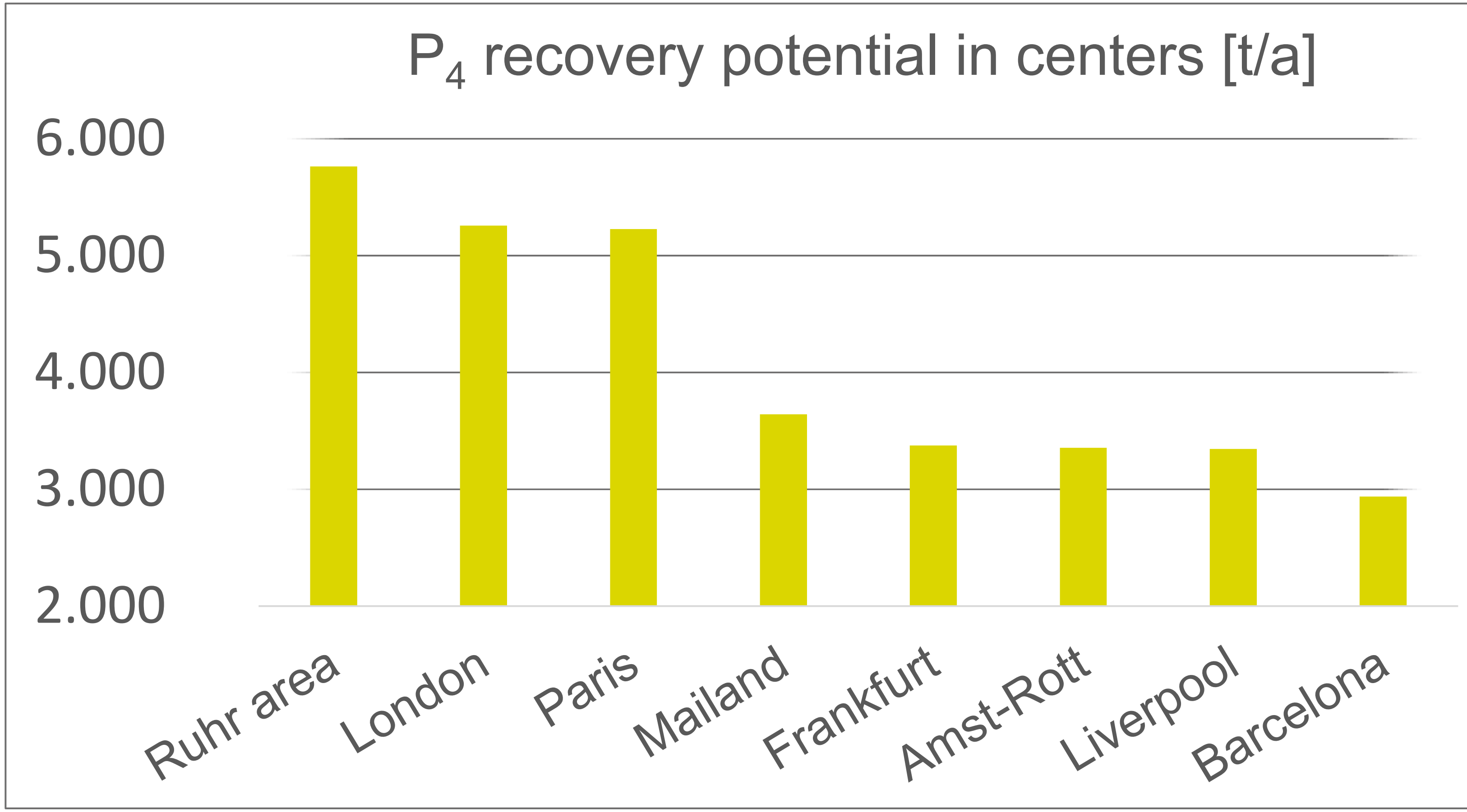
Evaluation 9 phosphorus recovery centers





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ACKNOWLEDGEMENT

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

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The complete thermochemical recycling of sewage sludge

DRYER-GRINDER

Ayumi Schober

University of Stuttgart

21.04.2026 I Leoben, Austria

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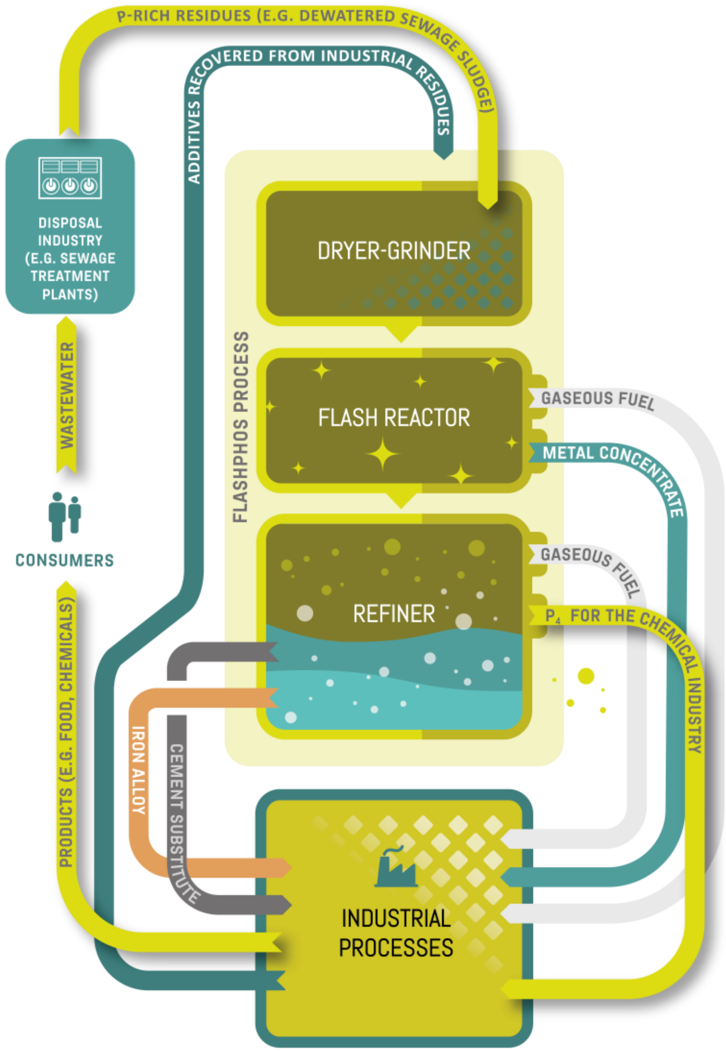
FLASHPHOS PROCESS



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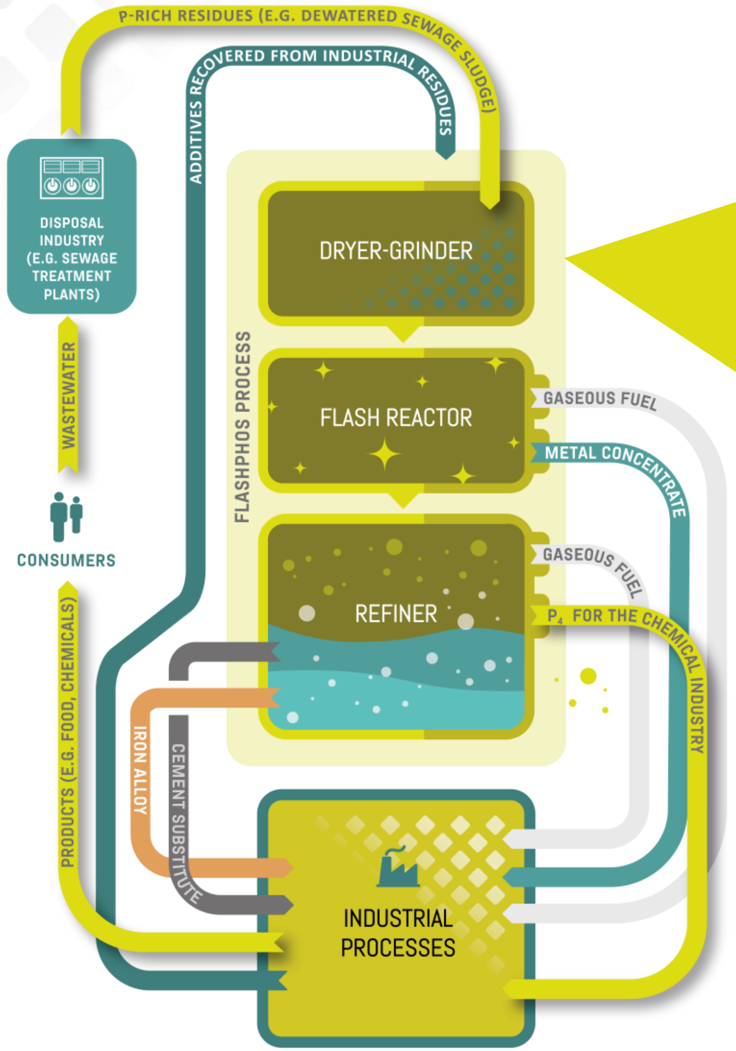
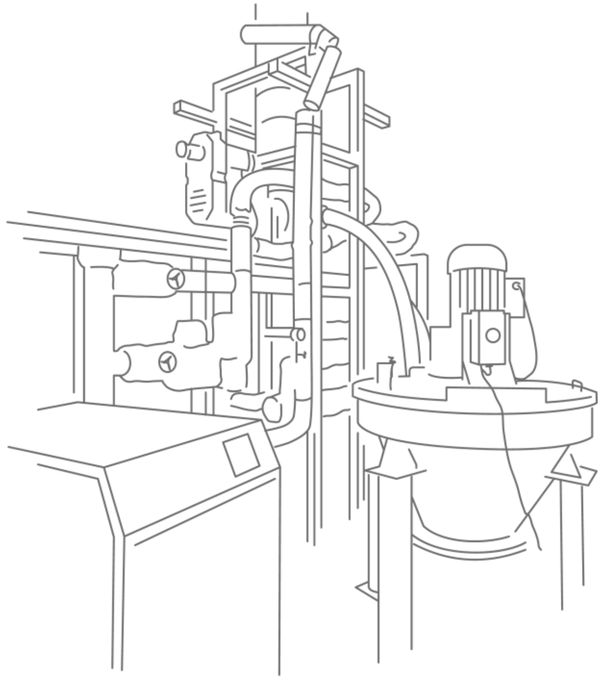
FLASHPHOS PROCESS





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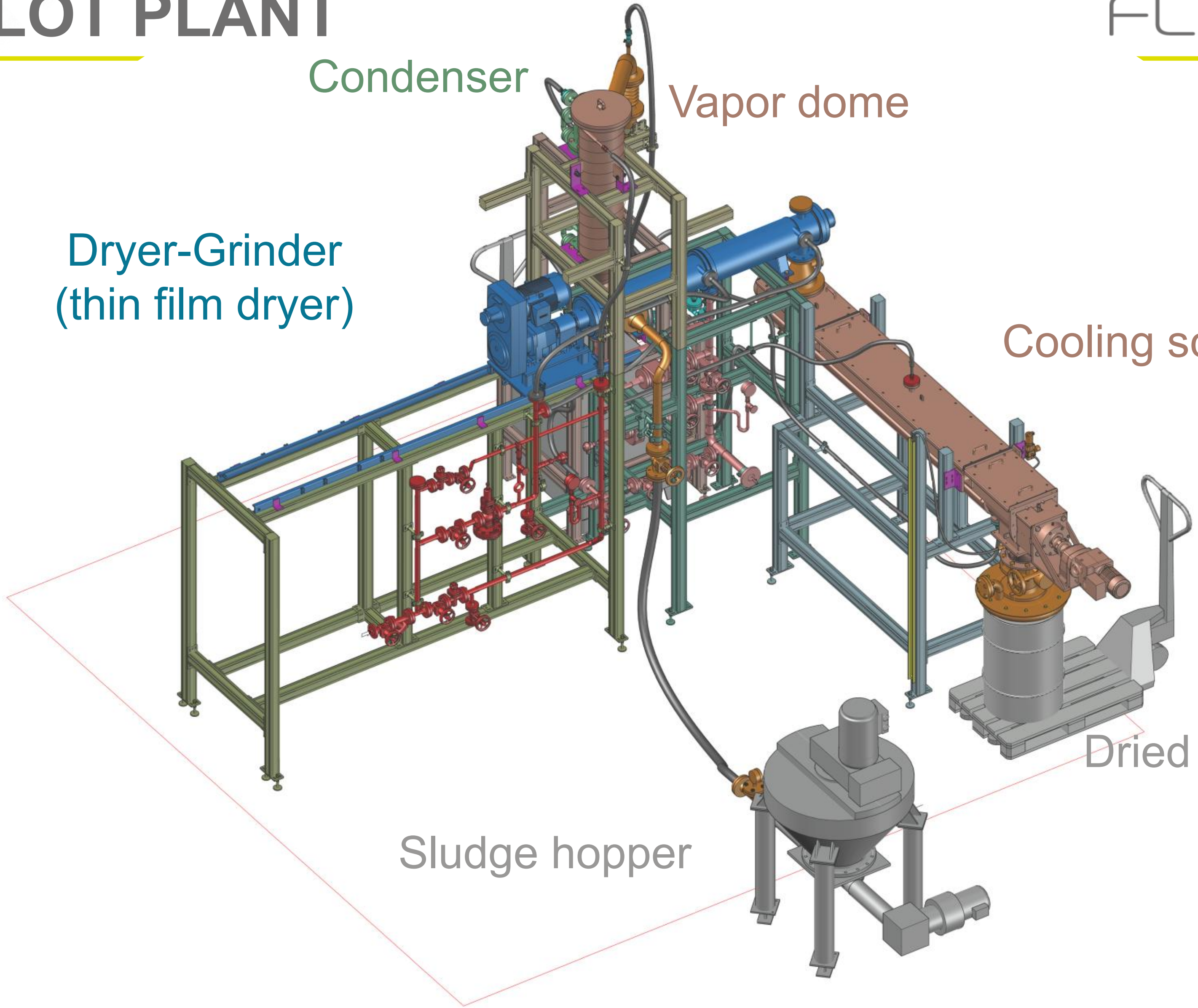
SMS PILOT PLANT



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PILOT PLANT AT UNI STUTTGART

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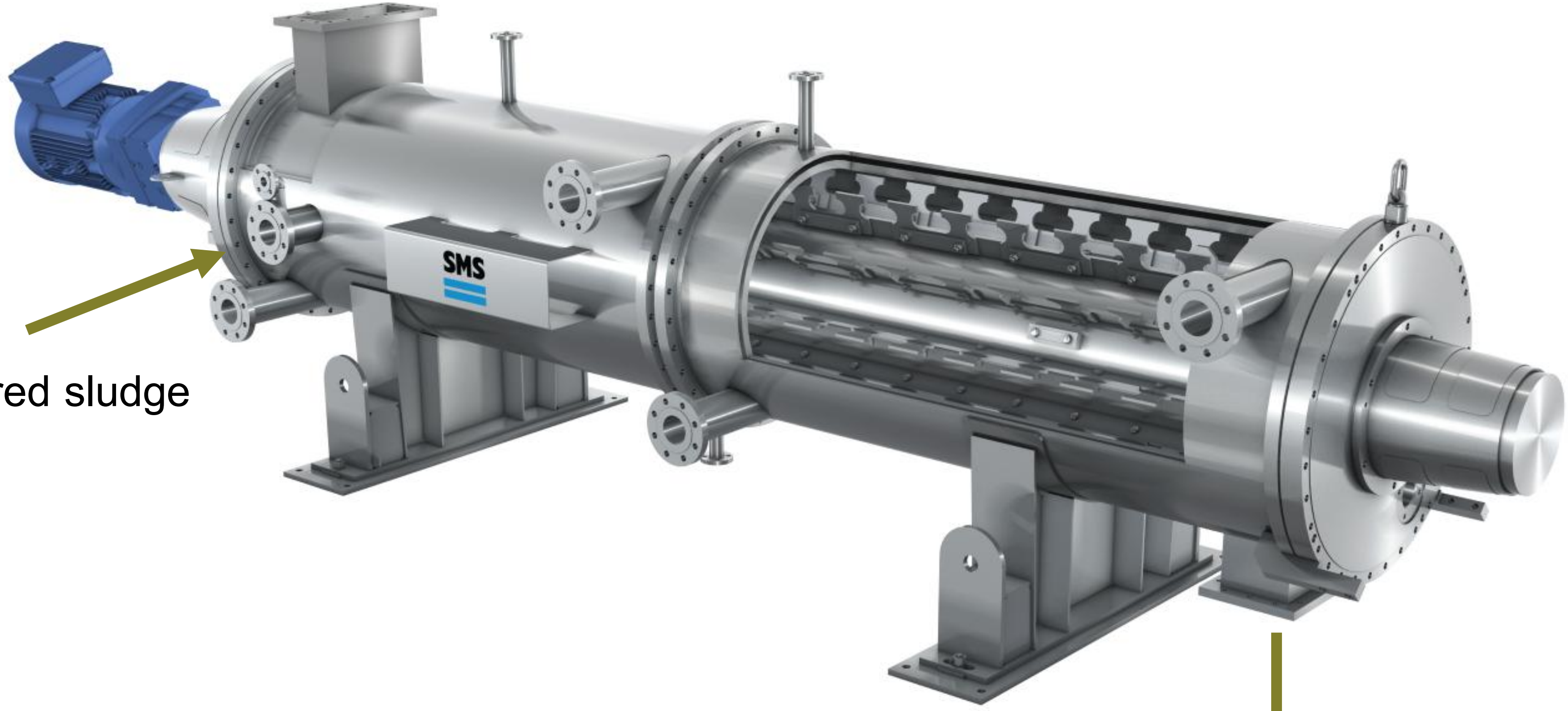
DRYER-GRINDER – THIN FILM DRYER



Dewatered sludge

Dried sludge

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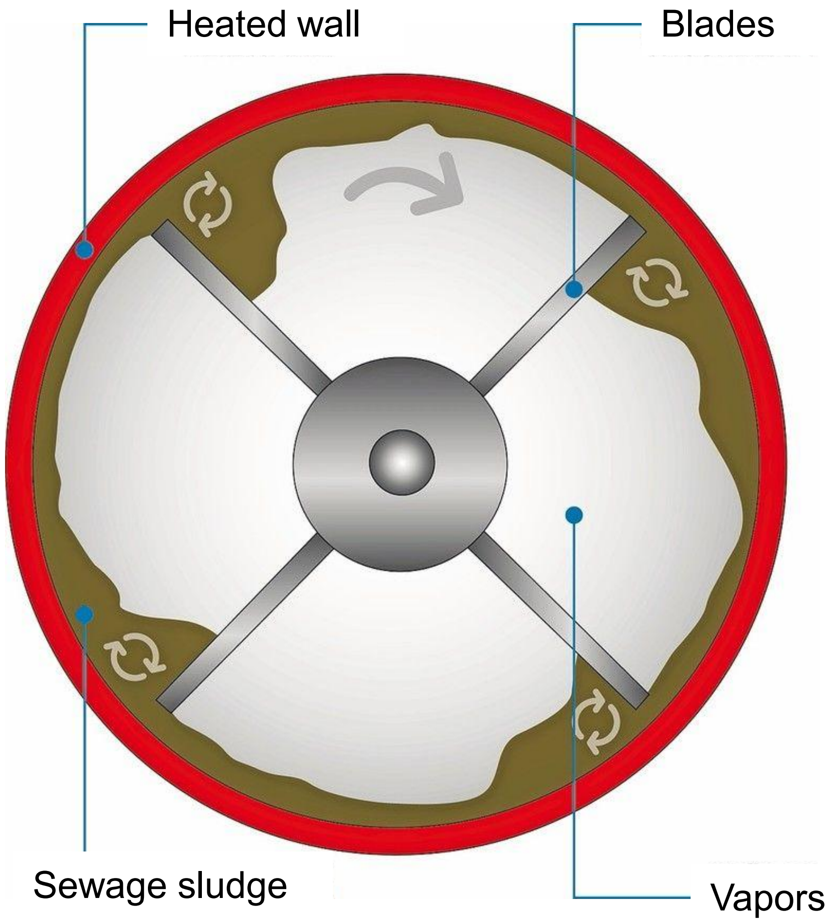
RESEARCH GAP

- Formation of a **sticky phase during drying**
  - Increase of **adhesion and cohesion forces**
  - Reduction of drying efficiency and inherent **particle agglomeration**

How can we reduce the particle size?



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DRYER-GRINDER ACTIVITIES

Process optimization

Operation parameter

Sensitivity analysis

Production of dried and fine sludge for Flash Reactor

Long operation (8h/day)

Storage and transportation to Leoben

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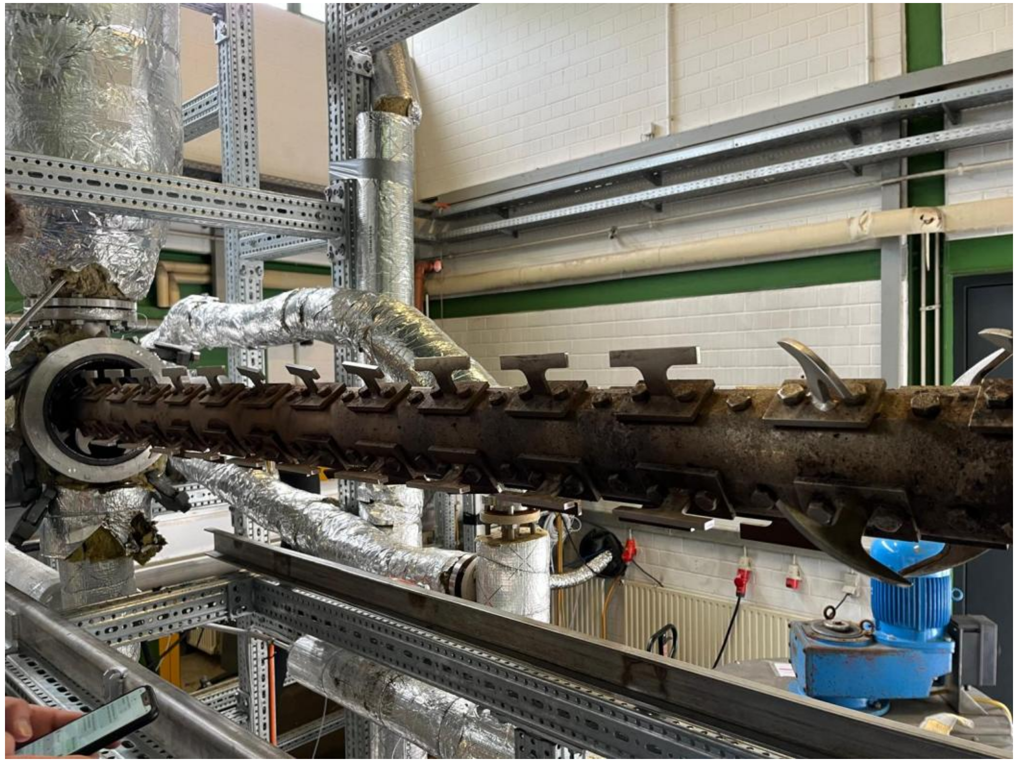
DRYER CONFIGURATIONS

- Different configurations tested for operation parameter investigation

Configuration 1



Configuration 3

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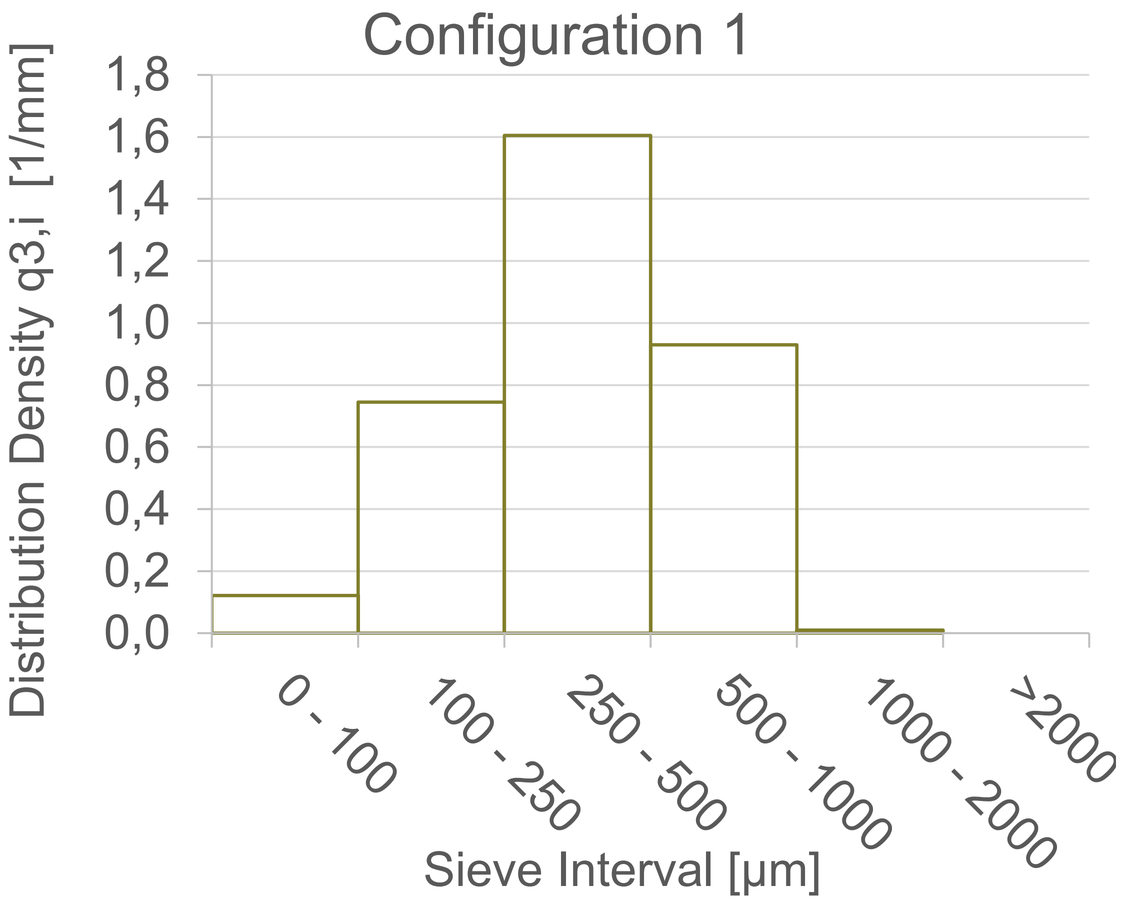
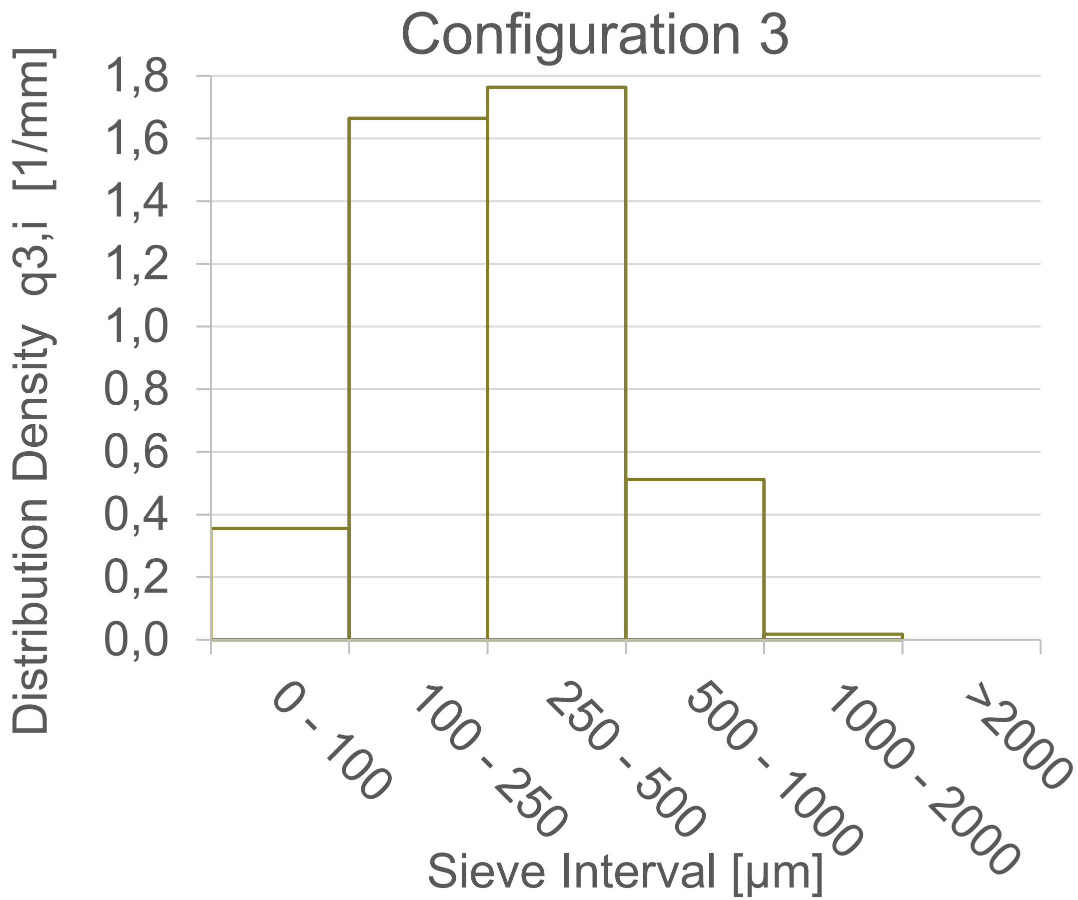
PARTICLE SIZE RESULTS

Comparison of Particle Size Distribution (sieve analysis):





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DESIGN OF EXPERIMENTS

2^3 Full-Factorial Design with Center Points

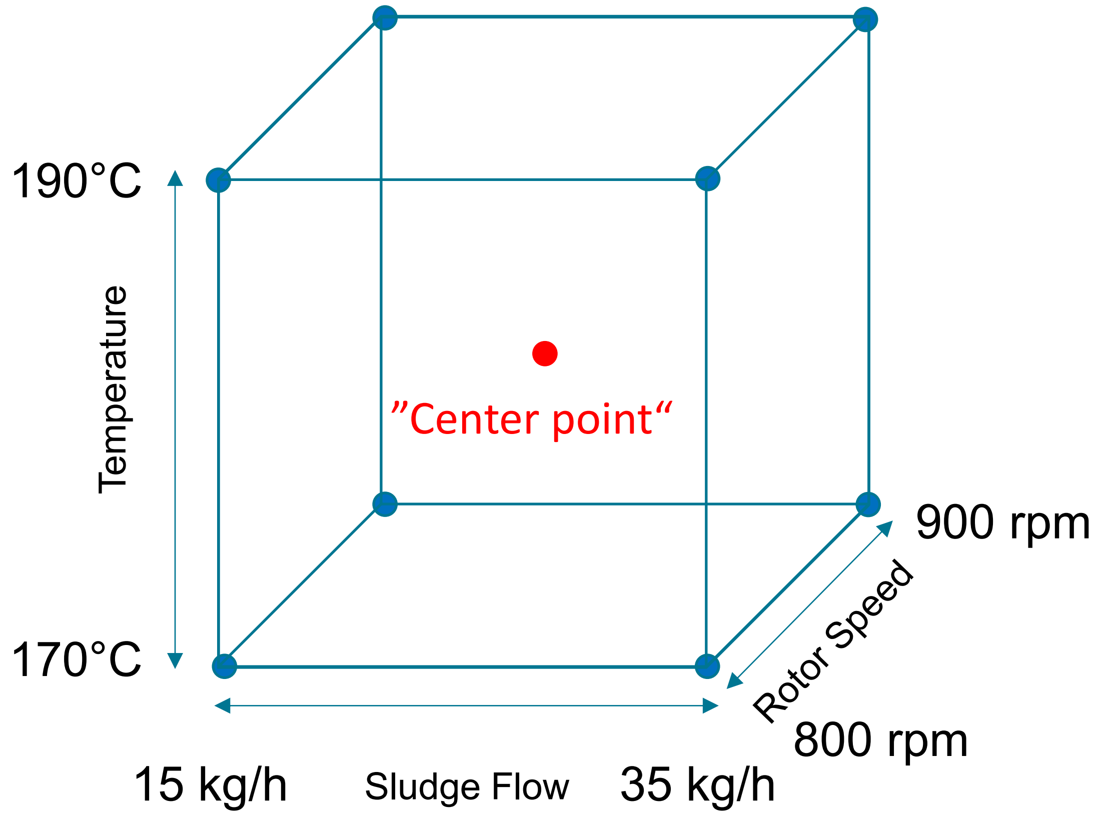
Feed Rate (15-35 kg/h)

Rotor Speed (800-900 rpm)

Heating Temperature (170-190°C)

Reduction of Particle Size (D90)

Three batches = 3 Blocks,
3 Replicates,
36 Experiments



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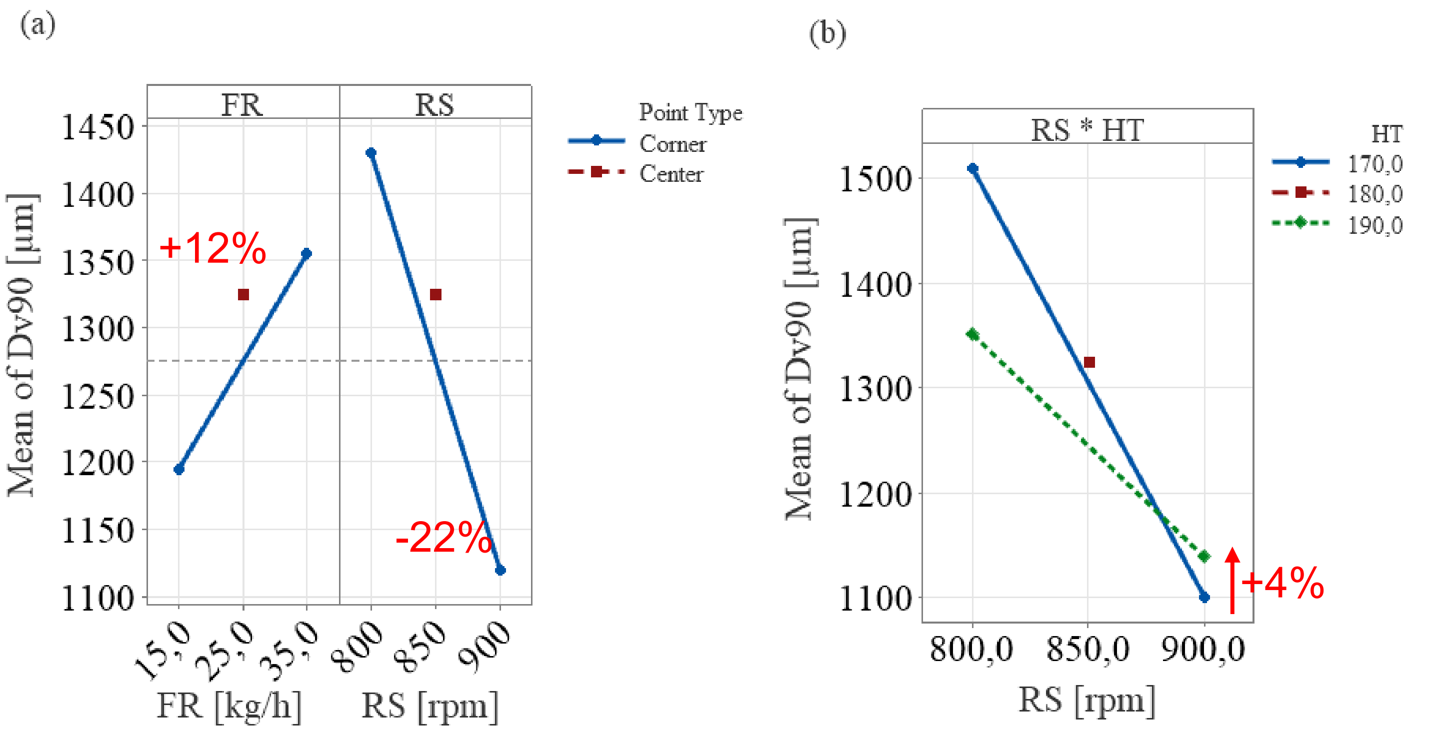
DOE RESULTS



↑FR ↑ Torque and overload

↑ RS ↑ shear forces

↑ RS*HT ↑ crystallization + release of adhesive networks

(Schober et al., 2026)

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OPTIMAL OPERATION

900 rpm → Required shear force for pulverization

15 kg/h → Sufficient retention time for acting mechanical forces

170 °C → Sufficient heat to dry sludge sufficiently

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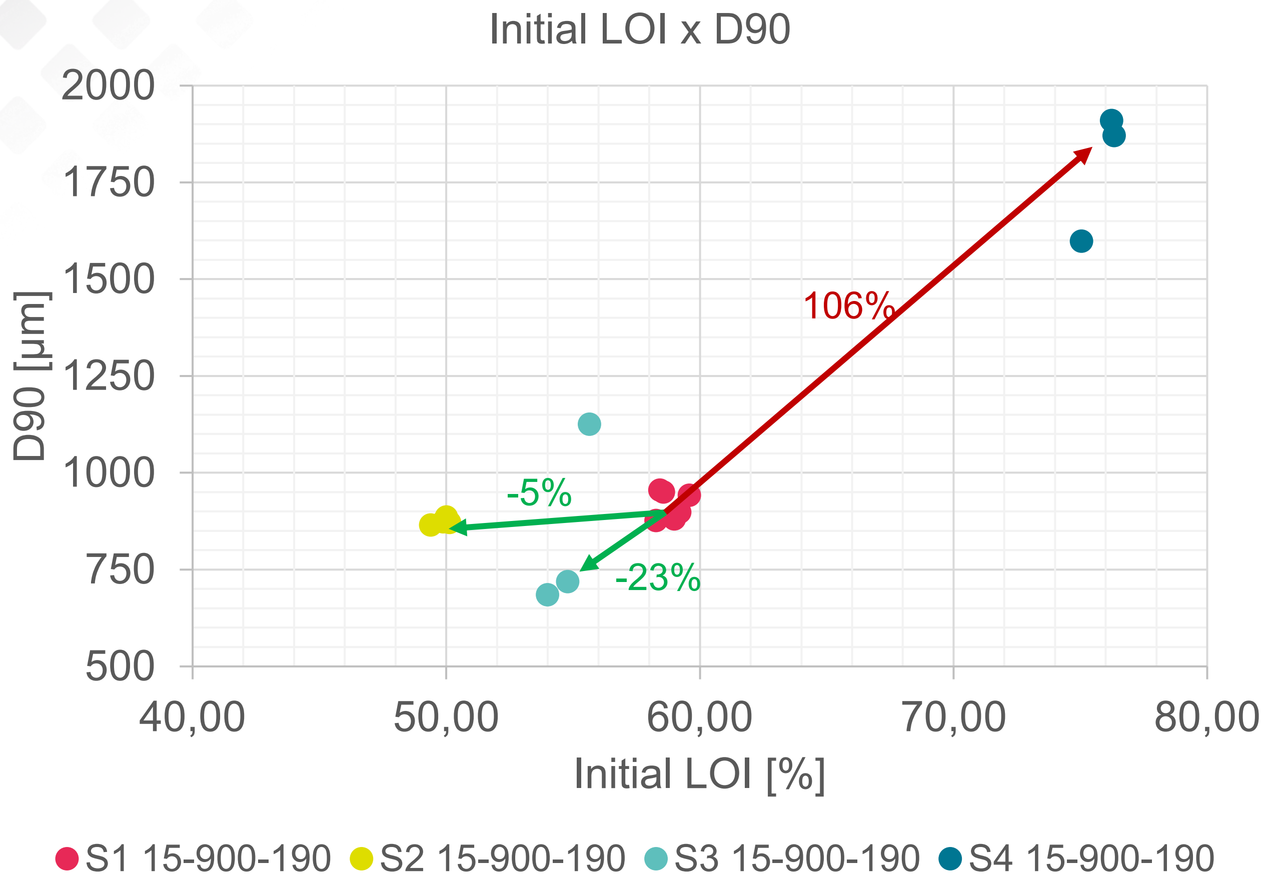
SENSITIVITY ANALYSIS



Under optimal conditions, comparing to S1 sludge:

- **High LOI-values** associated with **increased** particle size
  - Increase of adhesion and cohesion forces

- S3 differs the **mineral composition** from S1.
  - S3 contains more CaO

  → Further characterization is required

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CONCLUSION & OUTLOOK

- Demonstration of Dryer-Grinder pilot plant under real operational conditions, achieving TRL 7
- Higher rotor speed increase shearing force applied at particles, decreasing D90 particle size of dried sludge
- Organic content reduces grinding performance by possible adhesion and cohesion forces increase
- Further investigation required on mechanical and rheological characteristics of the sludge during drying

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FLASH REACTOR

Christian Schmidberger, University of Stuttgart

FlashPhos Closing Event – Results, Impact and Way Forward

Leoben, 21.04.2026

Universität Stuttgart

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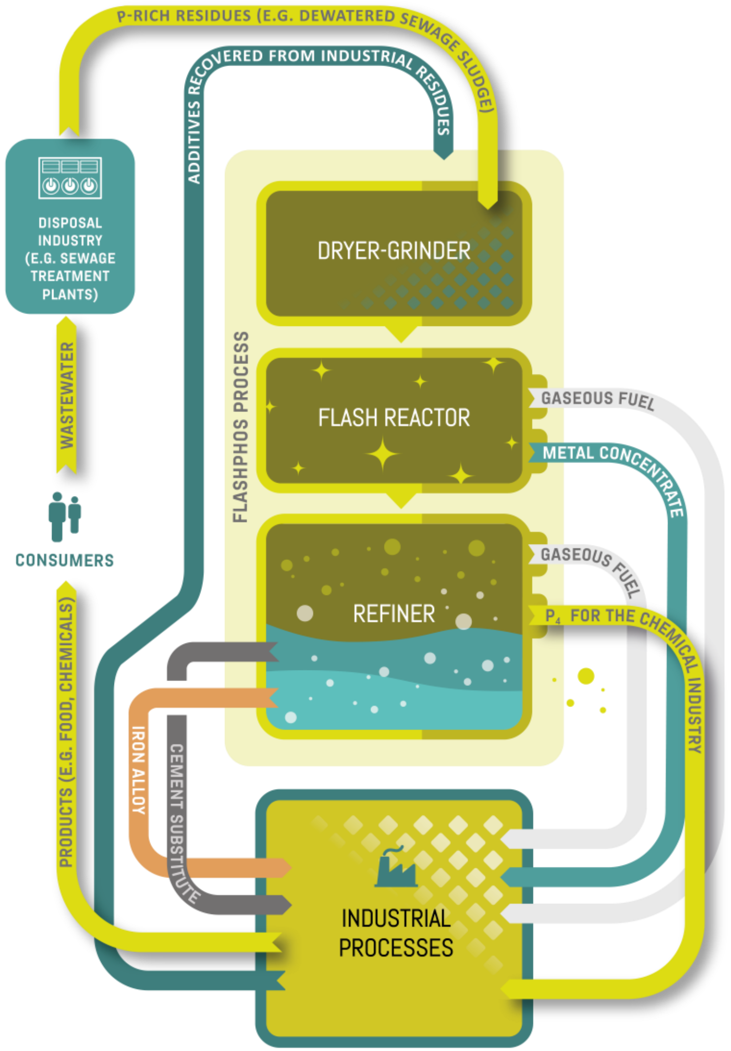
FLASHPHOS PROCESS



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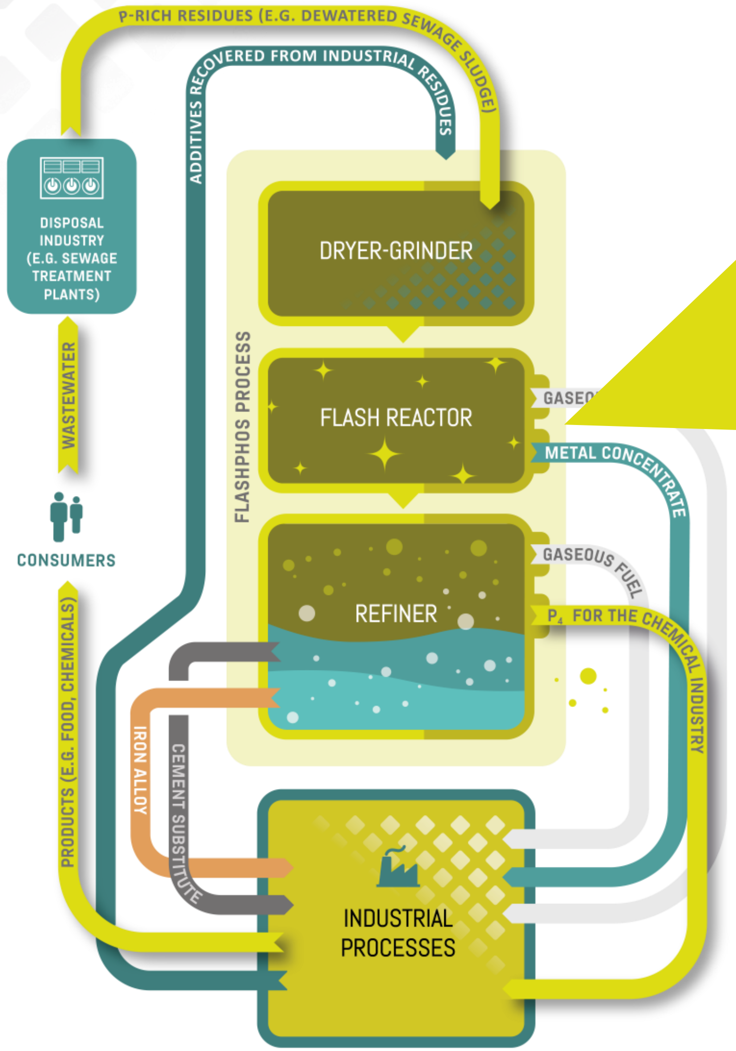
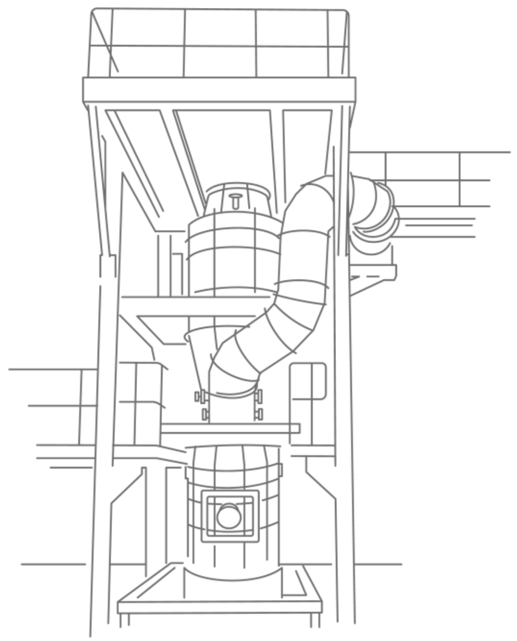
FLASHPHOS PROCESS





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EXPERIMENTAL SETUP AND MATERIAL

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EXPERIMENTAL SETUP

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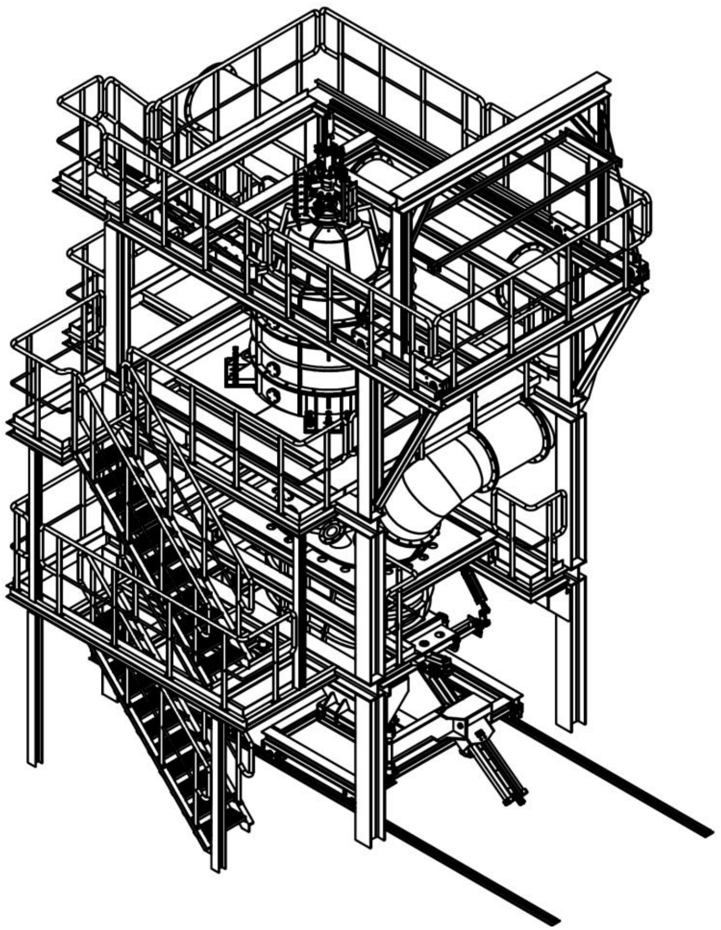
- Refractory lined reactor
- Thermal heat input: $Q_{in} = 580\ kW_{th}$
- Oxygen-enrichment
- Nominal residence time: $2.8\ s$
- Particle size $d_{90} \approx 100\ \mu m$

- Temperature measurement in
  - Refractory
  - Gas stream
- Measurement probe injection into gas stream
  - Online gas measurement: CO_2, CO, H_2, O_2
  - Particle sample

- Analysis of particle sample using ICP-MS



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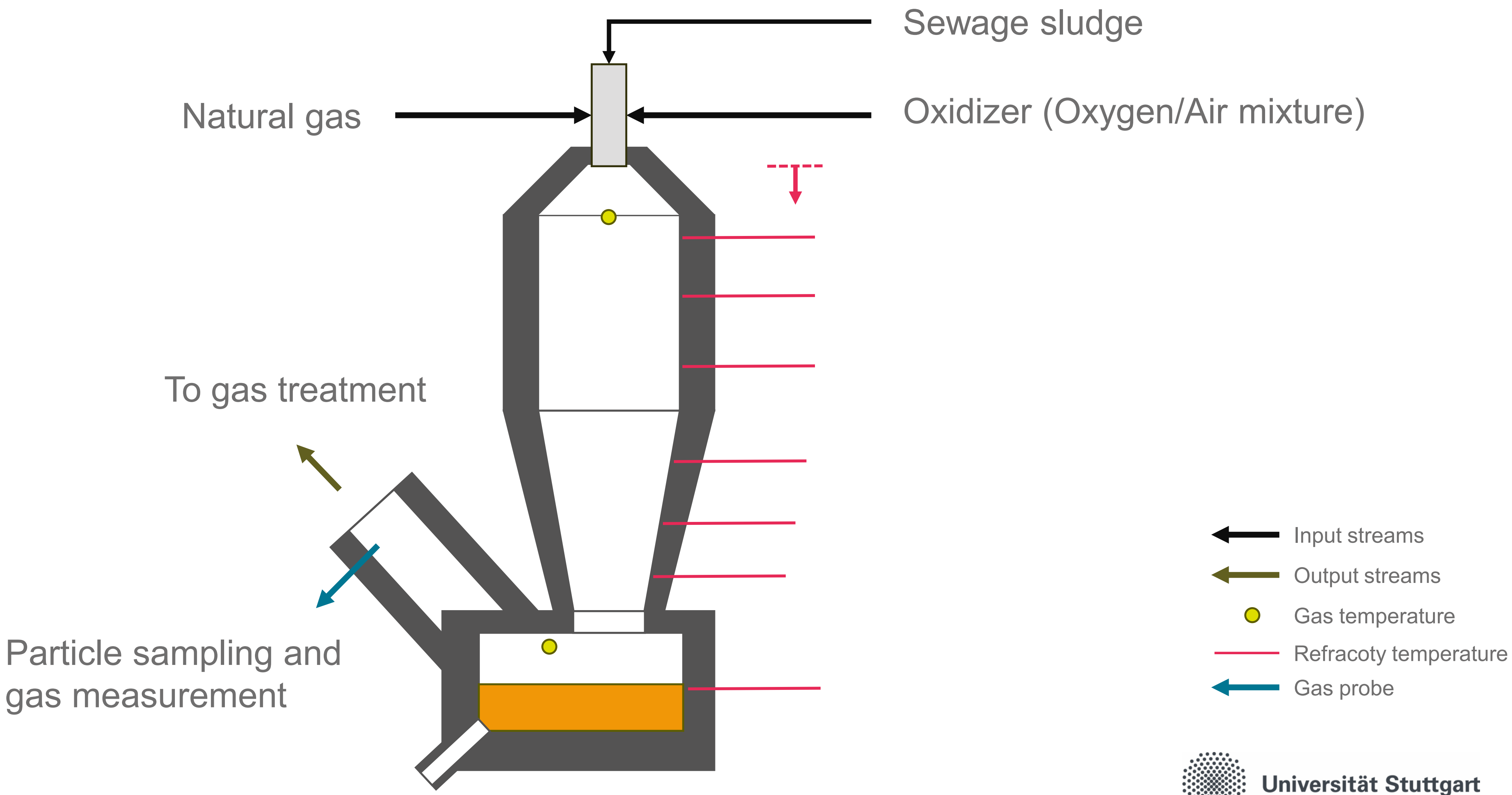
EXPERIMENTAL SETUP



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FLASH REACTOR

- Gas treatment
  - Post-combustion chamber
  - Quench
  - Filter
  - Scrubber

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SEWAGE SLUDGE ANALYSIS

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Table 1: Sewage sludge composition

$H_{u,wf}$	$\gamma_{H_2O,ar}$	$\gamma_{ash,wf}$	$\gamma_{V,wf}$	$\gamma_{FC,wf}$	$\gamma_{C,wf}$	$\gamma_{H,wf}$	$\gamma_{N,wf}$	$\gamma_{S,wf}$	$\gamma_{Cl,wf}$	$\gamma_{O,wf}$
MJ/kg	wt.%									
10.2	6.8	42.9	52.0	5.1	28.9	3.9	3.6	0.8	0.3	19.6

Table 2: Sewage sludge ash composition

$\gamma_{Al_2O_3}$	γ_{CaO}	$\gamma_{Fe_2O_3,}$	γ_{K_2O}	γ_{MgO}	$\gamma_{P_2O_5}$	γ_{SiO_2}	γ_{SO_3}	γ_{others}
wt.%								
10.8	18.2	19.8	1.9	5.8	18.7	19.8	3.1	1.9

H_u: net calorific value
ar: as received
wf: water free
V: volatiles
FC: fixed carbon

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RESULTS

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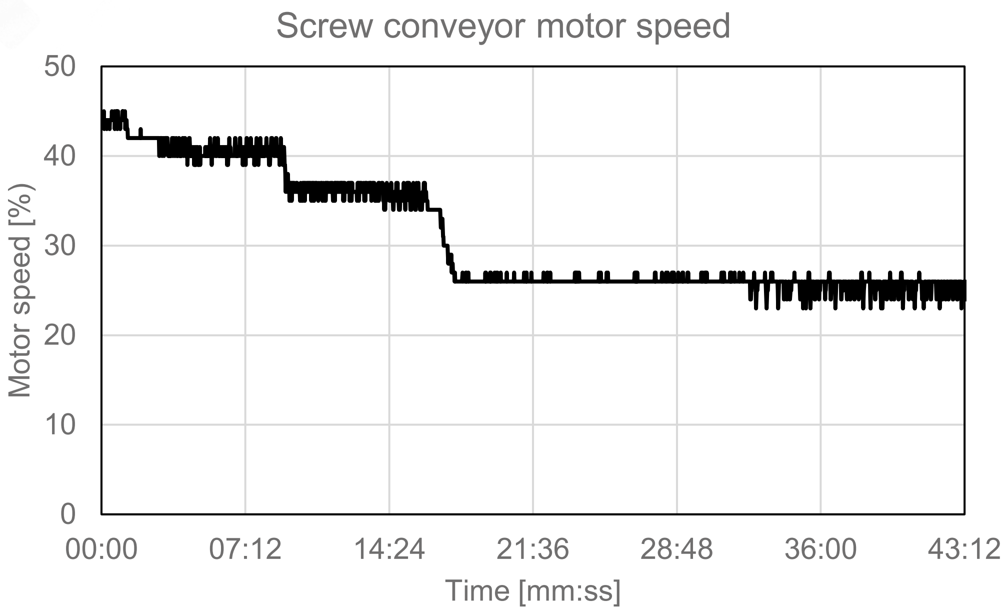
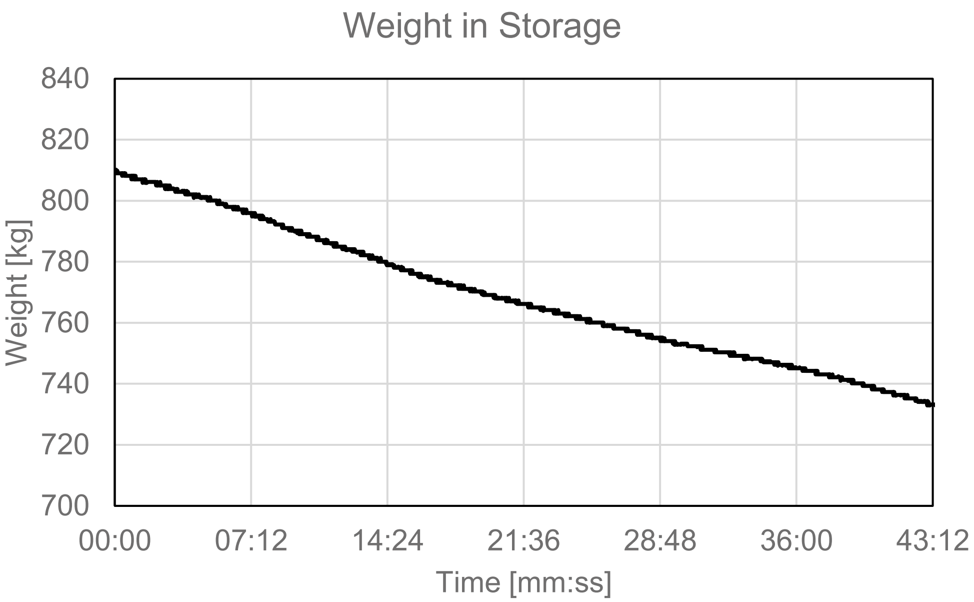
FLASH REACTOR DOSING SYSTEM





- Stable dosing – Linear weightloss for constant motor speed
- Good response of mass flow to changes in motor speed

➢ Suitable selection of dosing technology

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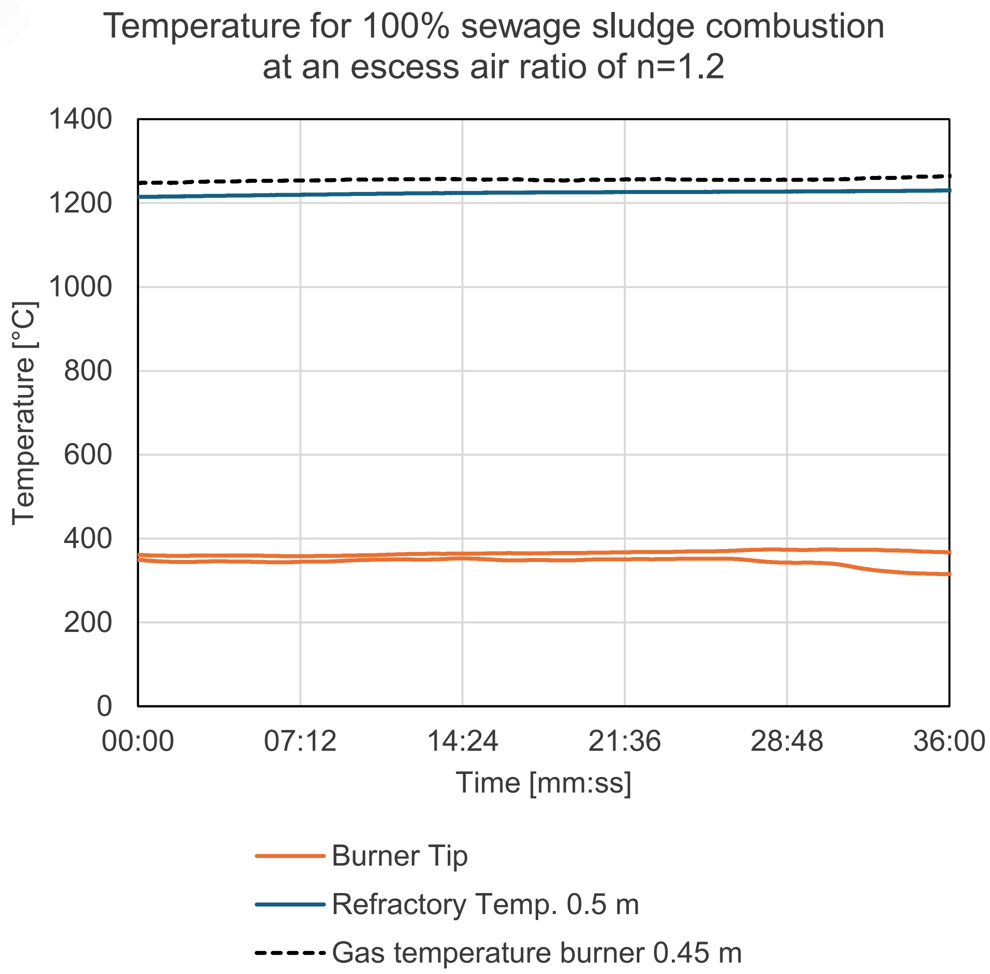
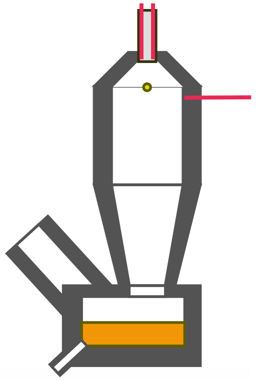
FLASH REACTOR BURNER



- Constant temperature trend
  - Constant sewage sludge dosing
  - Stable ignition of sewage sludge
- Temperature management of burner successful



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FLASH REACTOR TEMPERATURE

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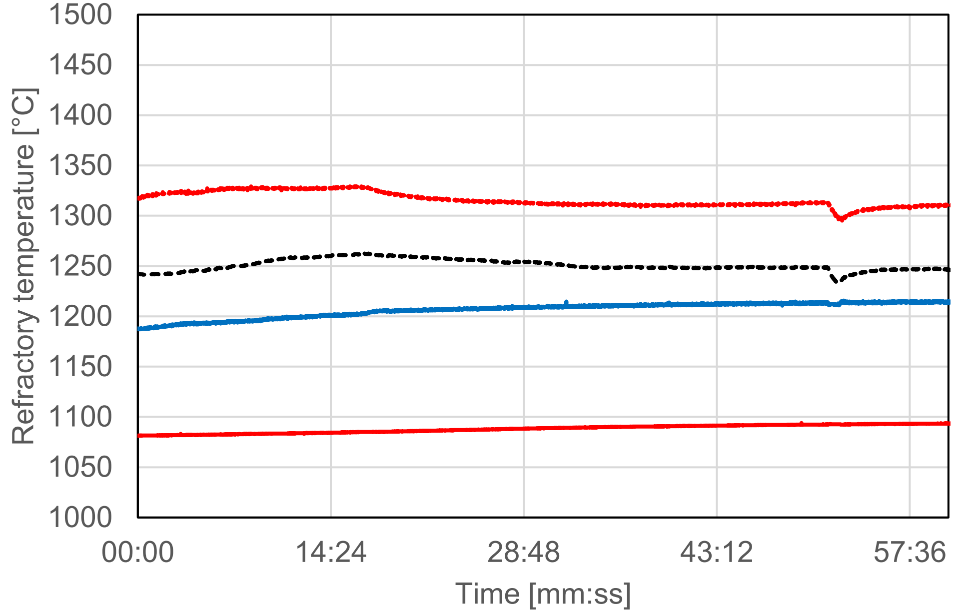
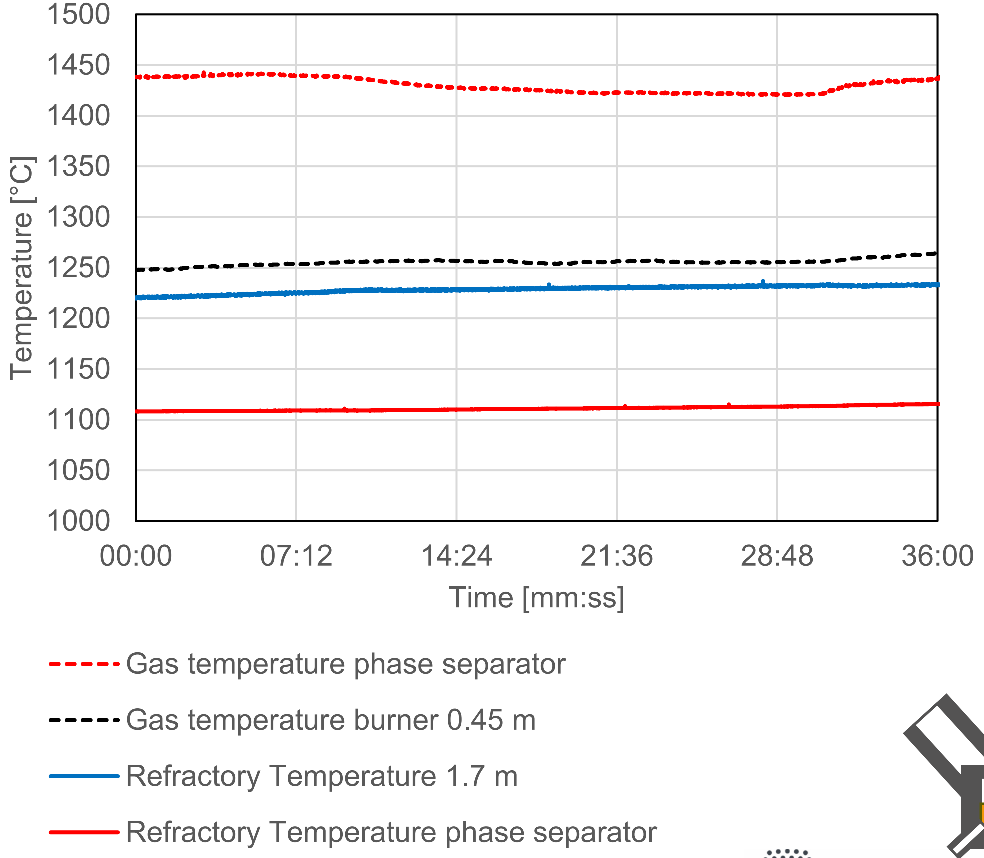
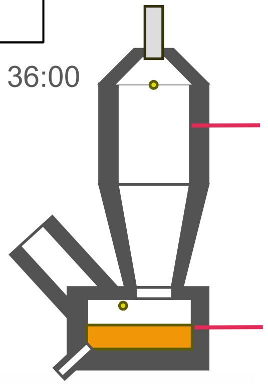
Temperature trend for 50-50 natural gas and sewage sludge at excess air ratio n=1.2



Temperature trend for 100% sewage sludge at excess air ratio n=1.2





- Similar temperature range in burner vicinity and refractory
- Higher temperature with pure sewage sludge operation due to oxygen-enrichment (26 vol.-% O_2)

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FLASH REACTOR GAS ANALYSIS

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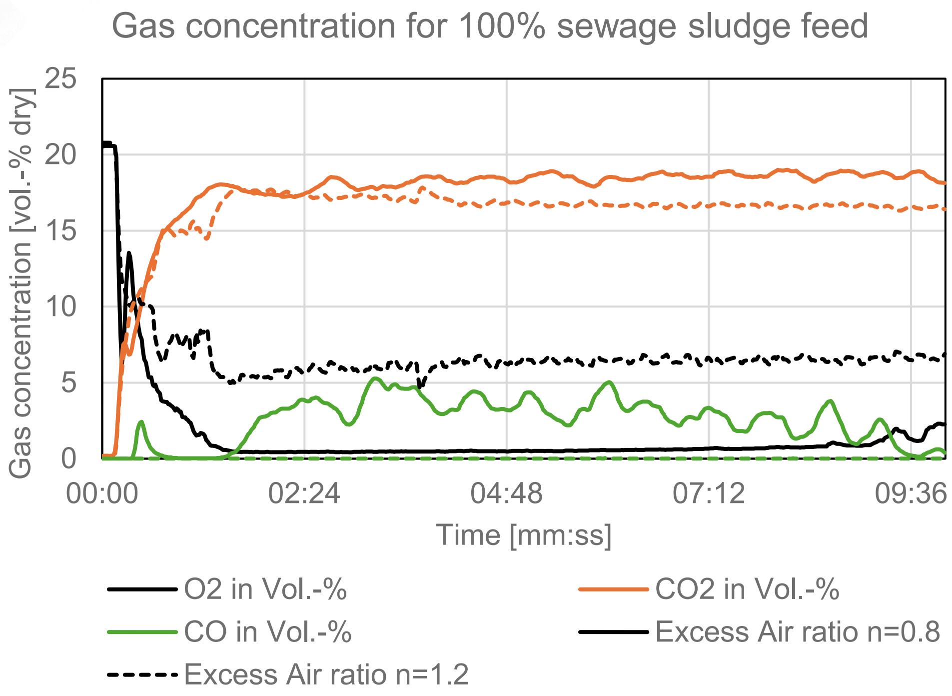
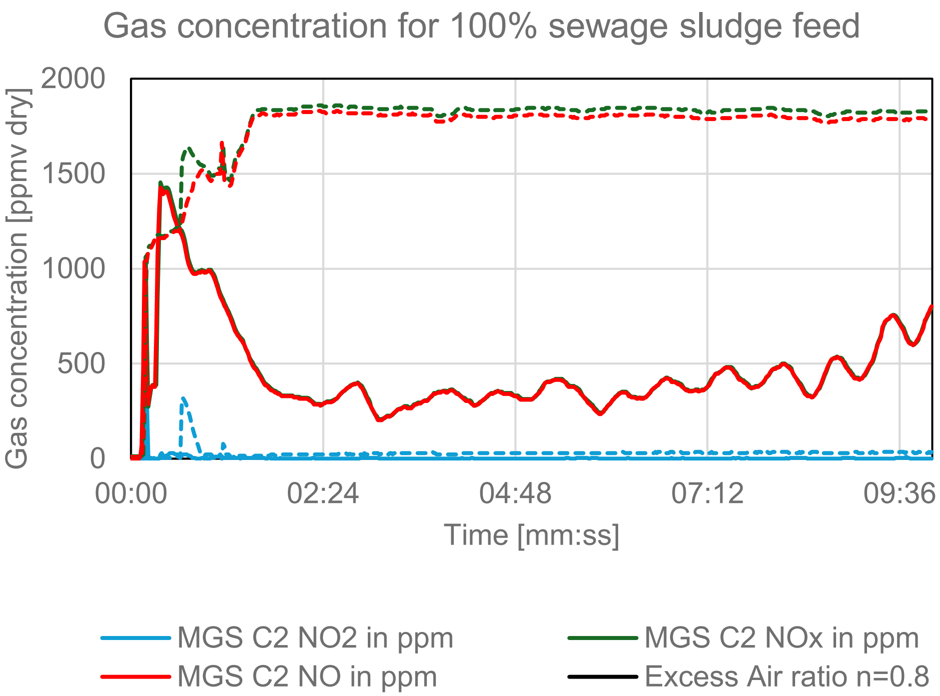
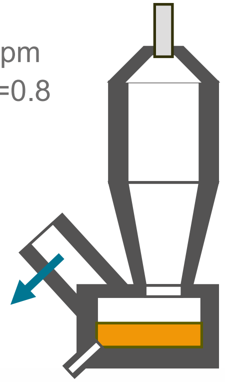


- Steady state operation of Flash Reactor achievable



- High temperarure causing NO/NOx emmissions
- Sub-stoichiometric conditions reduce NO/NOx emmissions



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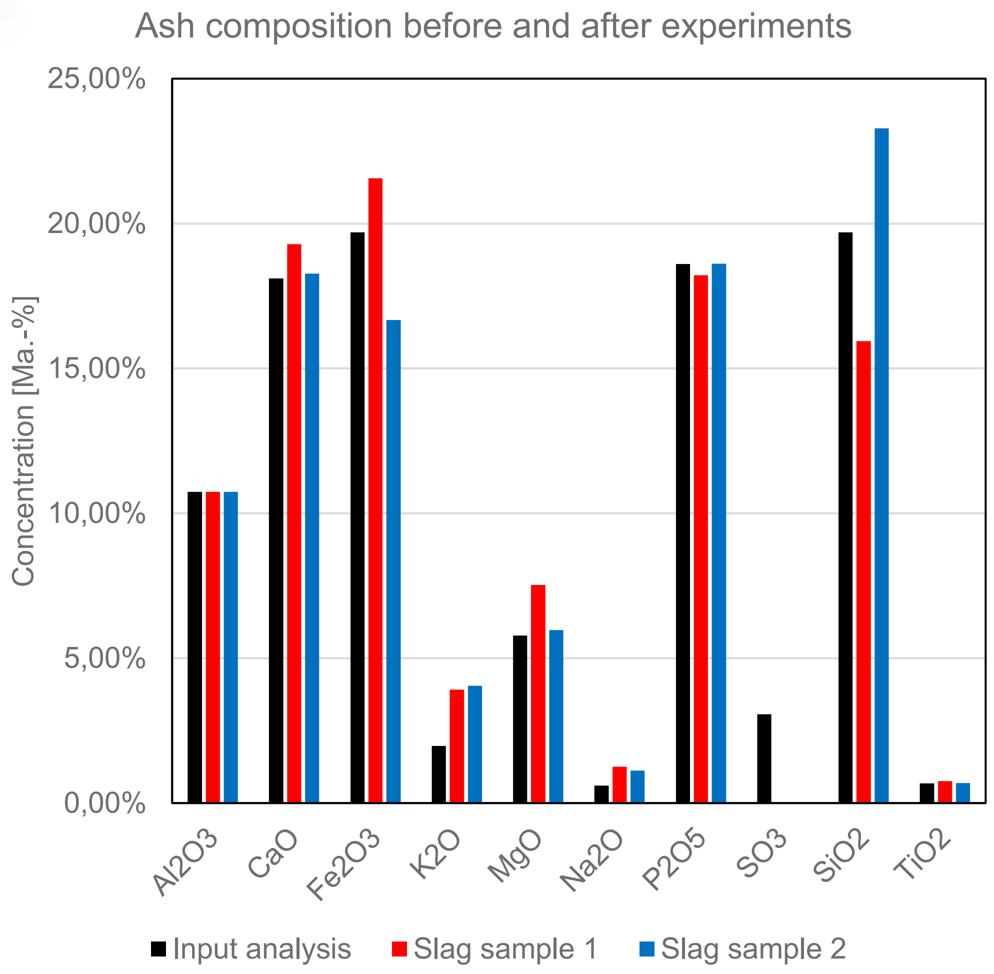
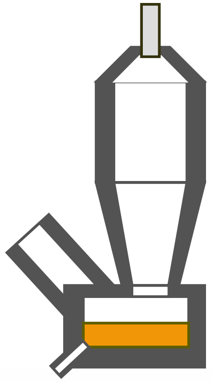
FLASH REACTOR SLAG ANALYSIS



- Accumulated slag sample containing slag
  - Sub-stoichiometric
  - Over-stoichiometric
- Sulphur ends up in the gas phase
- No phosphorus losses



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CONCLUSION & OUTLOOK

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CONCLUSION

- Good performance of developed compontents
  - Dosing system
  - Burner
  - Gas treatment system
- Successful production of slag as input material for refiner
- No phosphorus losses in Flash Reactor
- Reducing operations lowers NOx emmissions

OUTLOOK

- Optimization of slag tapping
- Different sewage sludges
- Longterm experiments

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

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The complete thermochemical recycling of sewage sludge

REFINER SECTION

Luigi Di Rienzo

Italmatch chemicals

21.04.2026 I Leoben, Austria

Italmatch Chemicals

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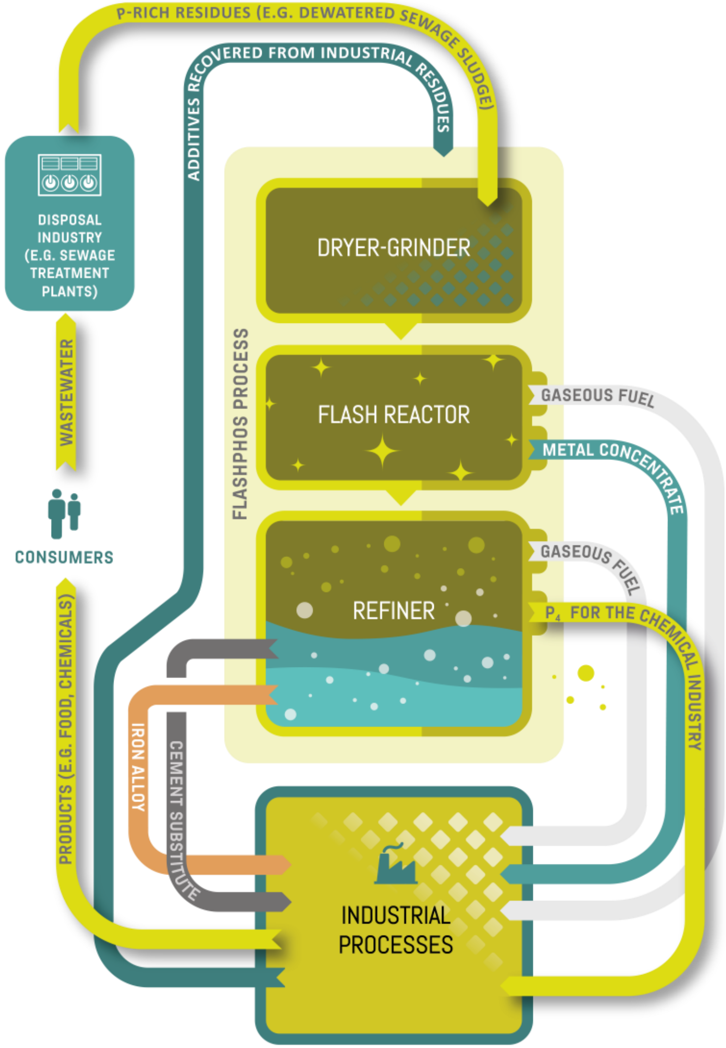
FLASHPHOS PROCESS



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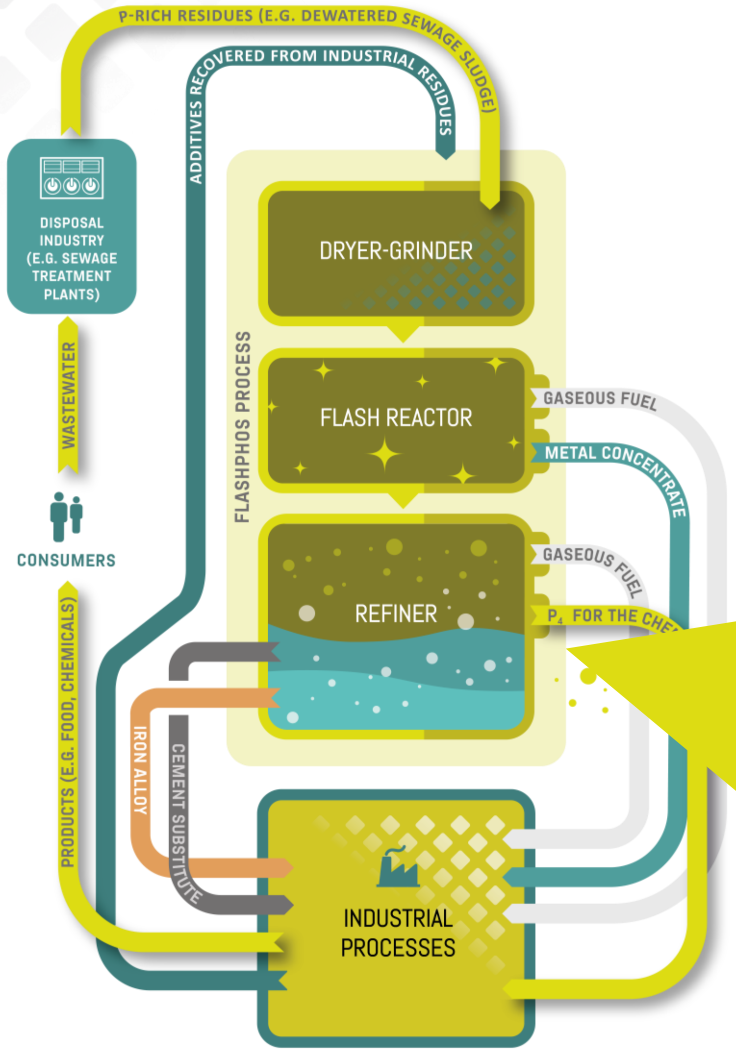

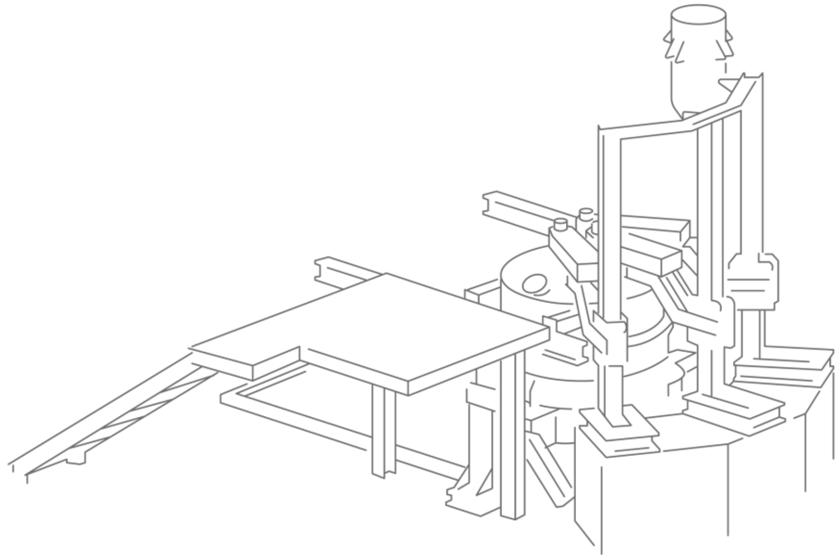

REFINER

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The Team

- Luigi Di Rienzo
- Valentin Mally
- Christian Schmidberger
- Pilar Pizones
- Alexander Maurer
- Dietmar Zobel
- Willem Schipper

special thanks to:

Maurizio Fraschini
Matthias Rapf

And a thought to our beloved friend

Jelle Groenink

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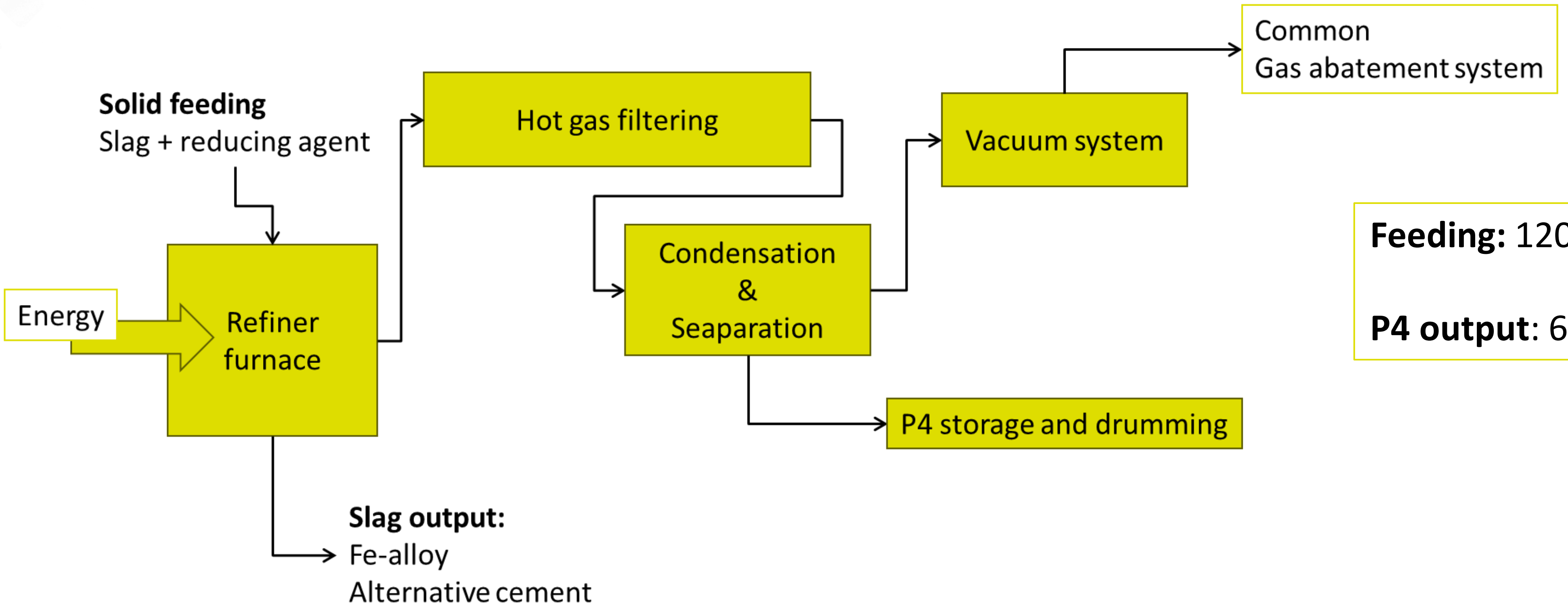
The concept



Feeding: 120kg/h

P4 output: 6-8 kg/h

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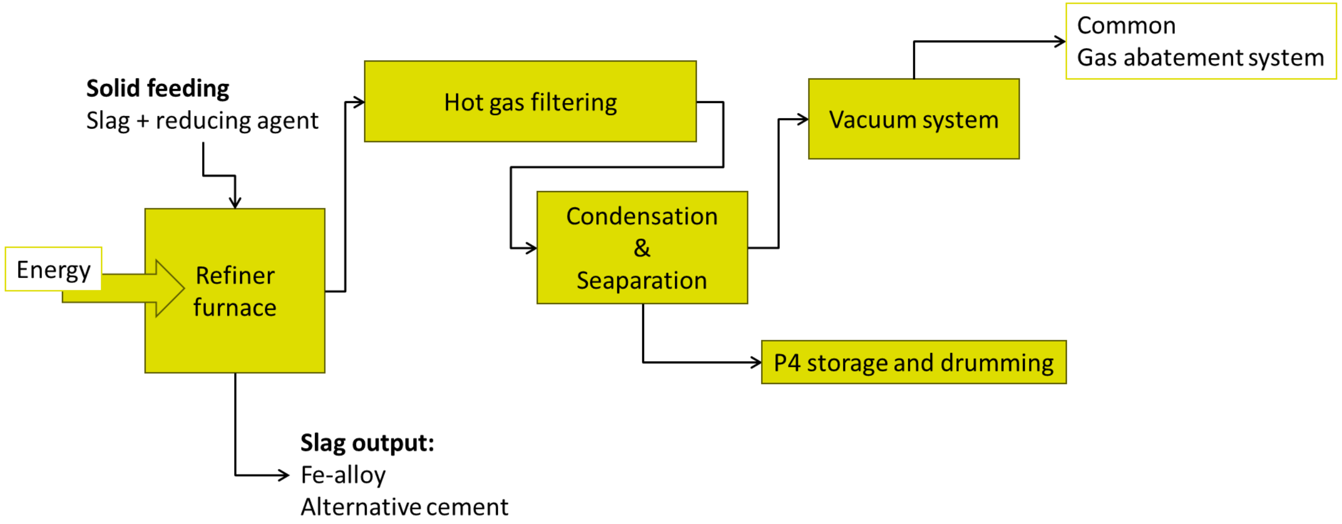
The numbers



- 1 Refiner furnace to be designed, adapting to the existing facility
- 20 other main items to be designed and purchased, with up to 12 months of delivery
- > 140 instruments & 200 signals to be managed
- > 30 suppliers involved in the procurement

> 1,5 M€ of equipment investment

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The Challenges

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From the process

Gas coming out from the furnace reaches 1700 °C

P_4 is flammable in contact with air and corrosive

CO is produced together with P_4

The furnace shall maintain its maintainability

From the project management

COVID and logistic crisis

Budget issues

Furnace design complexity

Suppliers delays and issues

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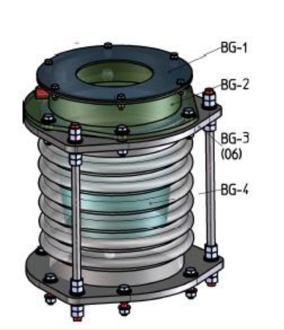
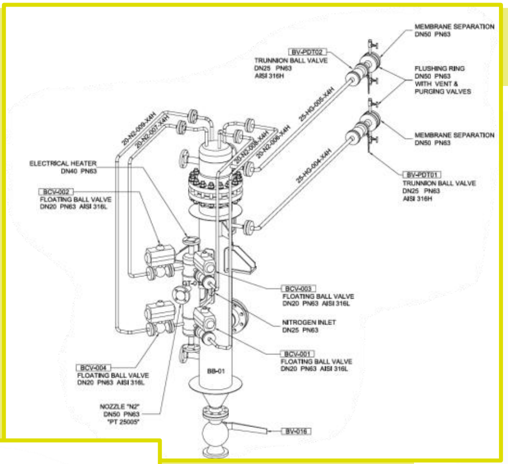
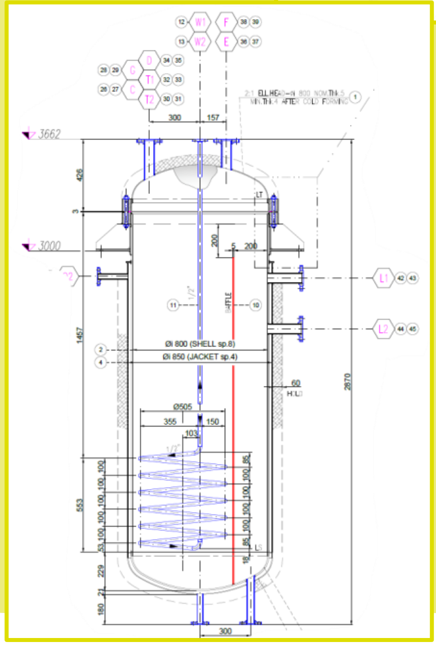
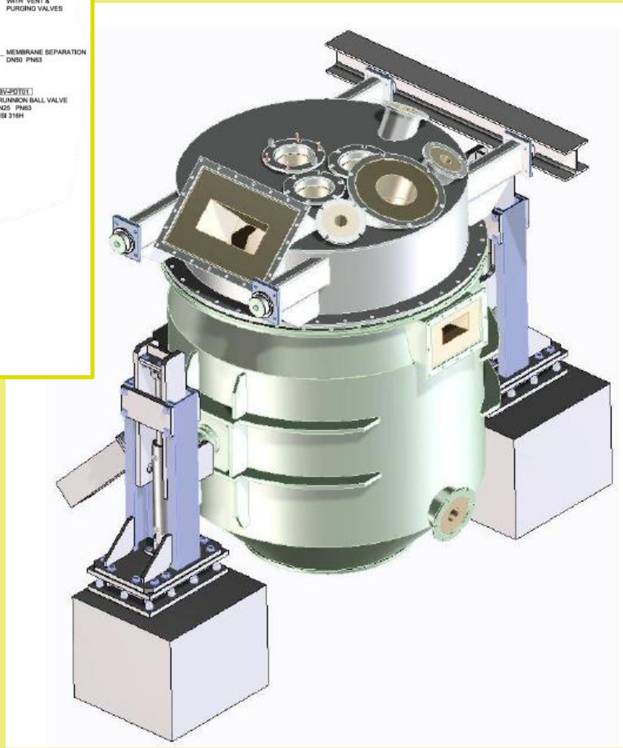
The Solutions

- Special sealing solutions for the furnace and the feeding system
- Special High T filtering system
- Fully designed furnace moving & tilting device
- Nitrogen inertization and special vacuum system
- Dedicated P4 storage system
- Special thermal camera









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The next Step

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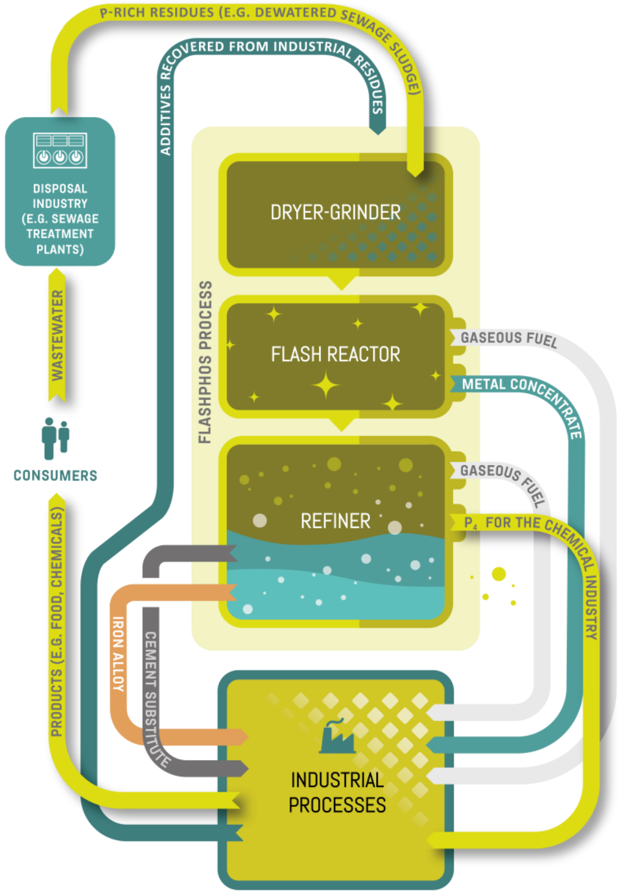
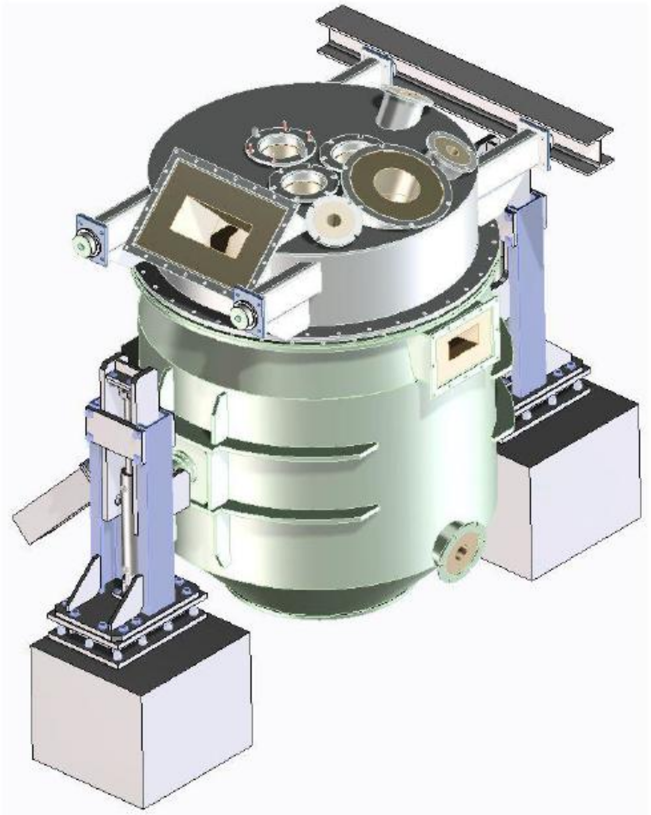
- Basic design
- Equipment procurement
- Layout and installation
- Piping & instrumental connection

Commissioning

Fully verify the process in the last step, doing the final extra mile





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FLASHPHOS

The complete thermochemical recycling of sewage sludge

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

Modelling and Simulation – 3D CFD Modelling

Benjamin Ortner

Graz University of Technology

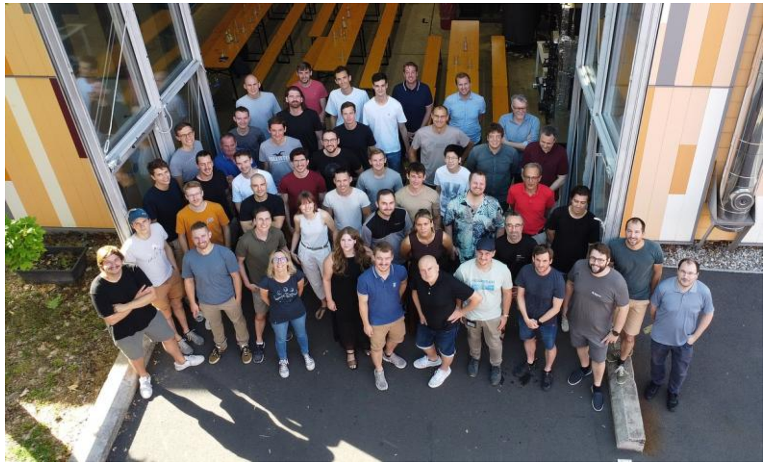
21.04.2026

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958267.

TU Graz Institute of Thermal Engineering

Content

- Our role in the project and the objectives
- What is multiphase CFD?
- Main simulation cases and major results
  - Validation experiments at USTUTT
  - Pilot plant Flash reactor simulations
- Summary and outlook



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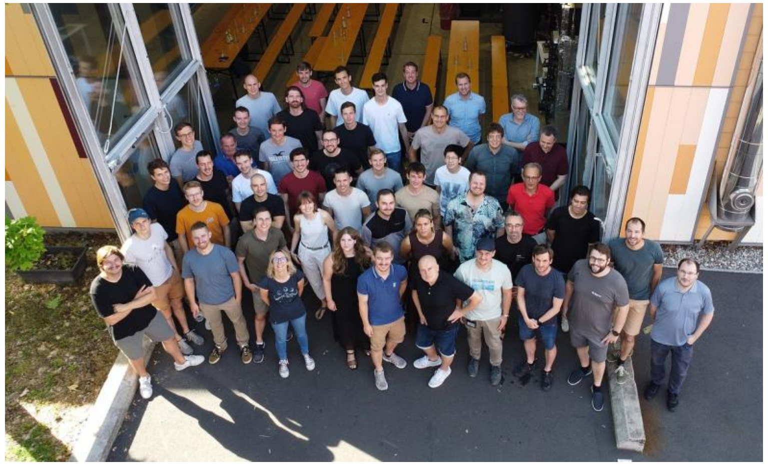
Institute of Thermal Engineering

Objectives

- Predict mass and energy balance of the Flash reactor and refiner
- Categorization of non-spherical particles and particle/fluid interaction
- Development of correlation equations for the drag coefficient and numerical models for the heat transfer and slag distribution in the refiner
- Application of the CFD model in the design and scale-up of the burner, Flash reactor and refiner of the FlashPhos pilot plant
- Simulations to support pilot design, scale-up and economic studies
- Provide data for WP3, WP4, WP6, WP8 and WP9



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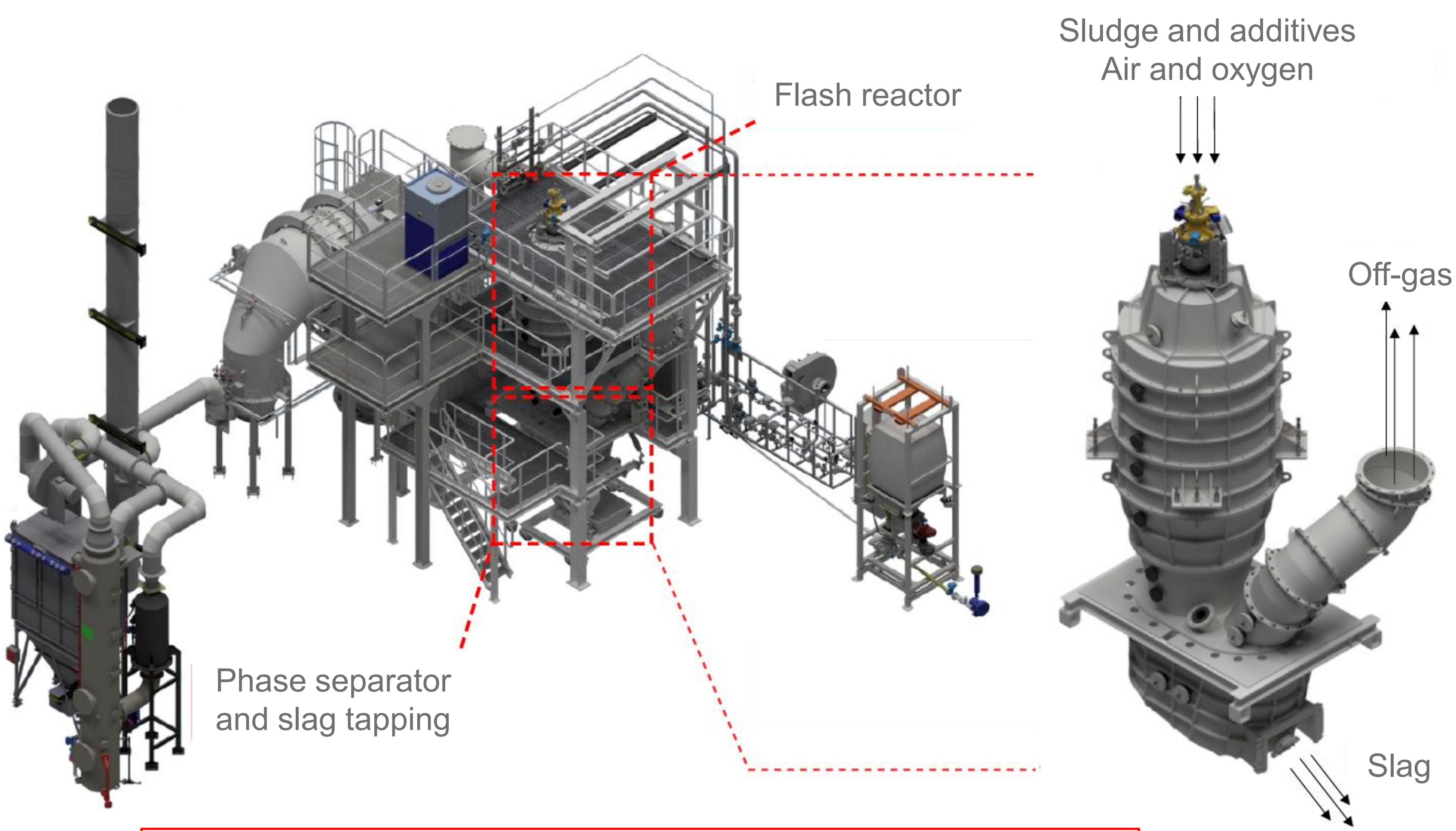
Multiphase CFD modelling

C → Computational
F → Fluid
D → Dynamics

Computer-based prediction of fluid flow, heat, and mass transfer by solving the mathematical equations for motion (Navier-Stokes), species transport, and chemical reactions…



The Flash reactor is a multiphase flow system!

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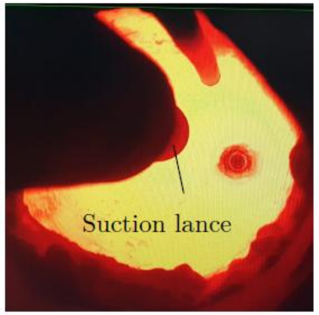
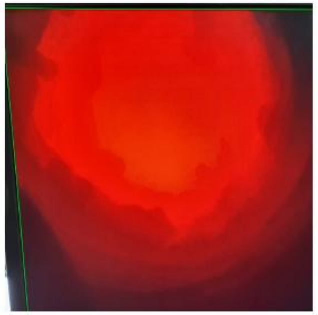
Main simulation cases:
Validation experiments for CFD

Experiments at USTUTT to obtain validation data for the CFD simulations

→ Variation of sludge type
→ Variation of additive
→ Different excess air ratios
→ Observe the process (ignition, slag deposition etc.)



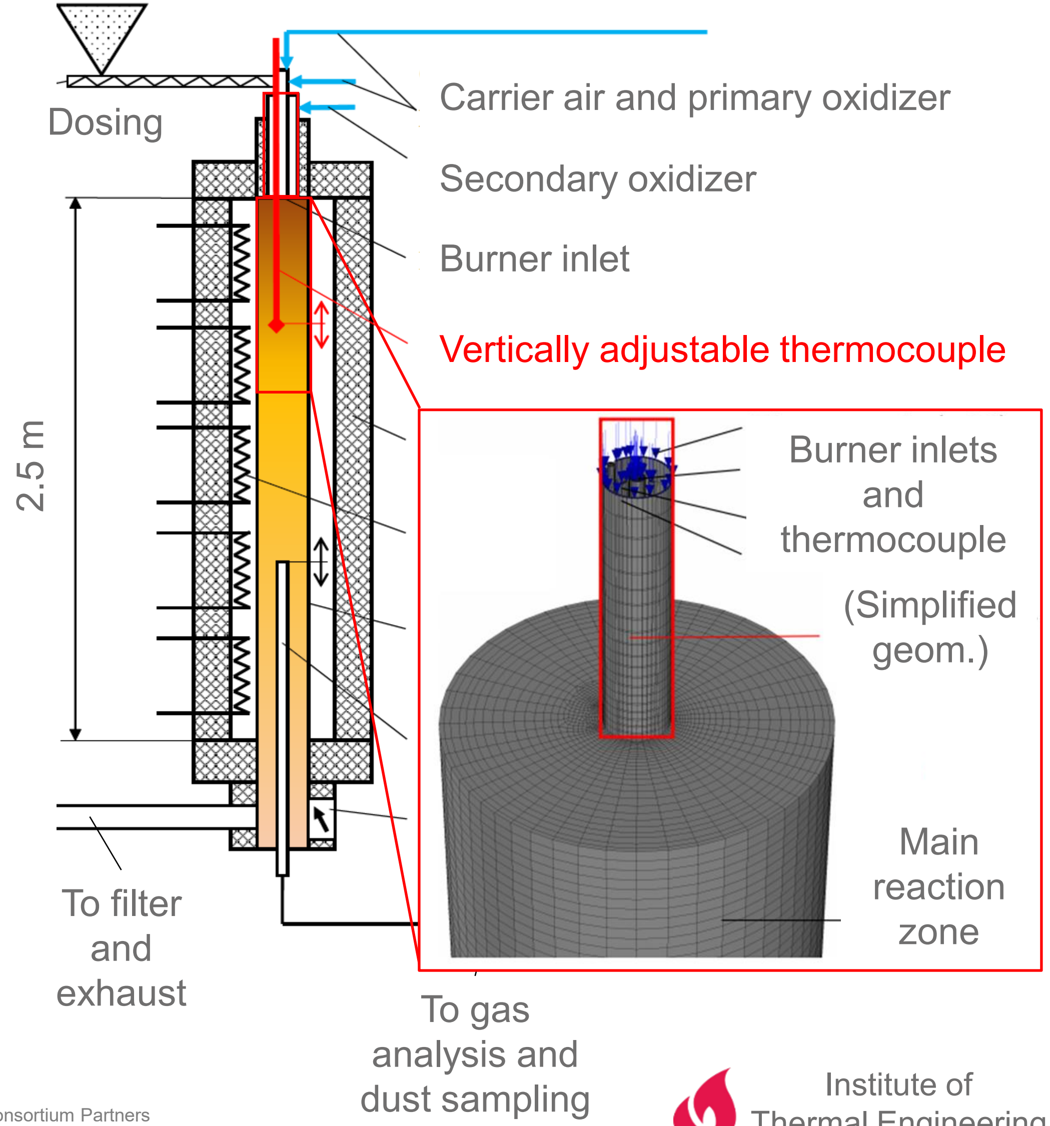
Before experiment



During experiment

After experiment

Slag is chemically aggressive
→ Highly relevant for refractory wear!
→ Must be considered in the models!



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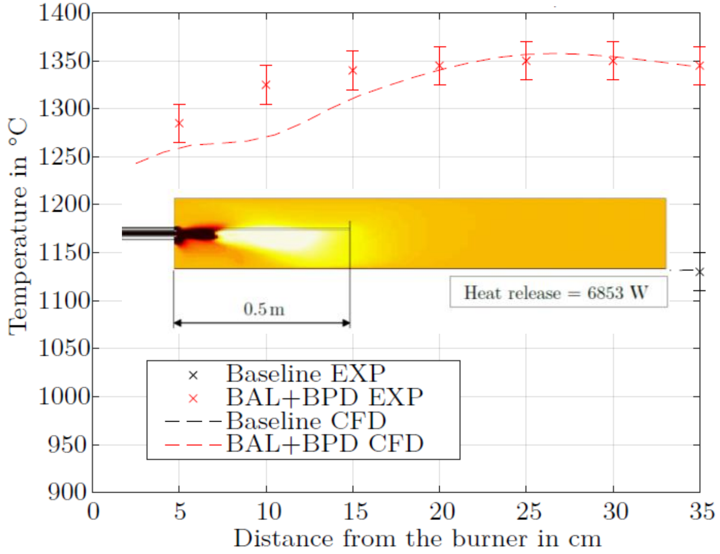
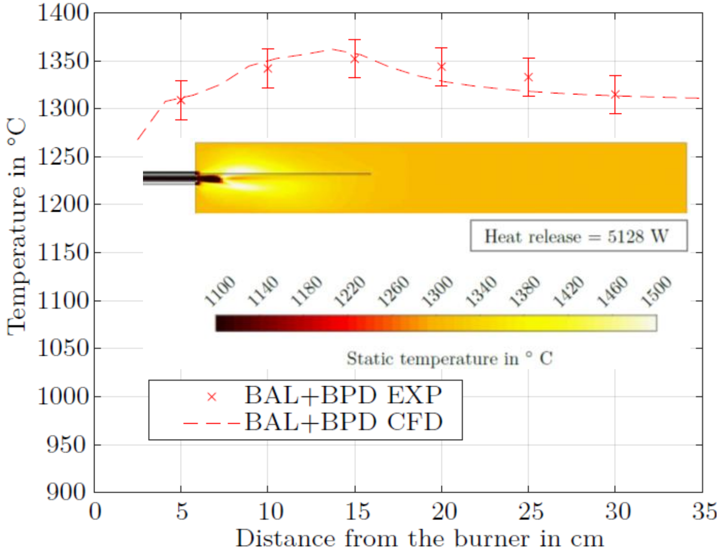
Main simulation cases:
Validation experiments for CFD

Combustion of 3 kg/h of
Sludge (BAL) **+ Additive (BPD)**

Case 1: Combustion
Case 2: Gasification

- Experimental and calculated temperature profiles align closely
- Max. temperature is reached close to the burner, even closer for subst. operation
- Gas composition measurements close to the burner were not feasible, but reaction appears complete about 0.5 m from the inlet





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Main simulation cases:
CFD simulation of the pilot Flash reactor

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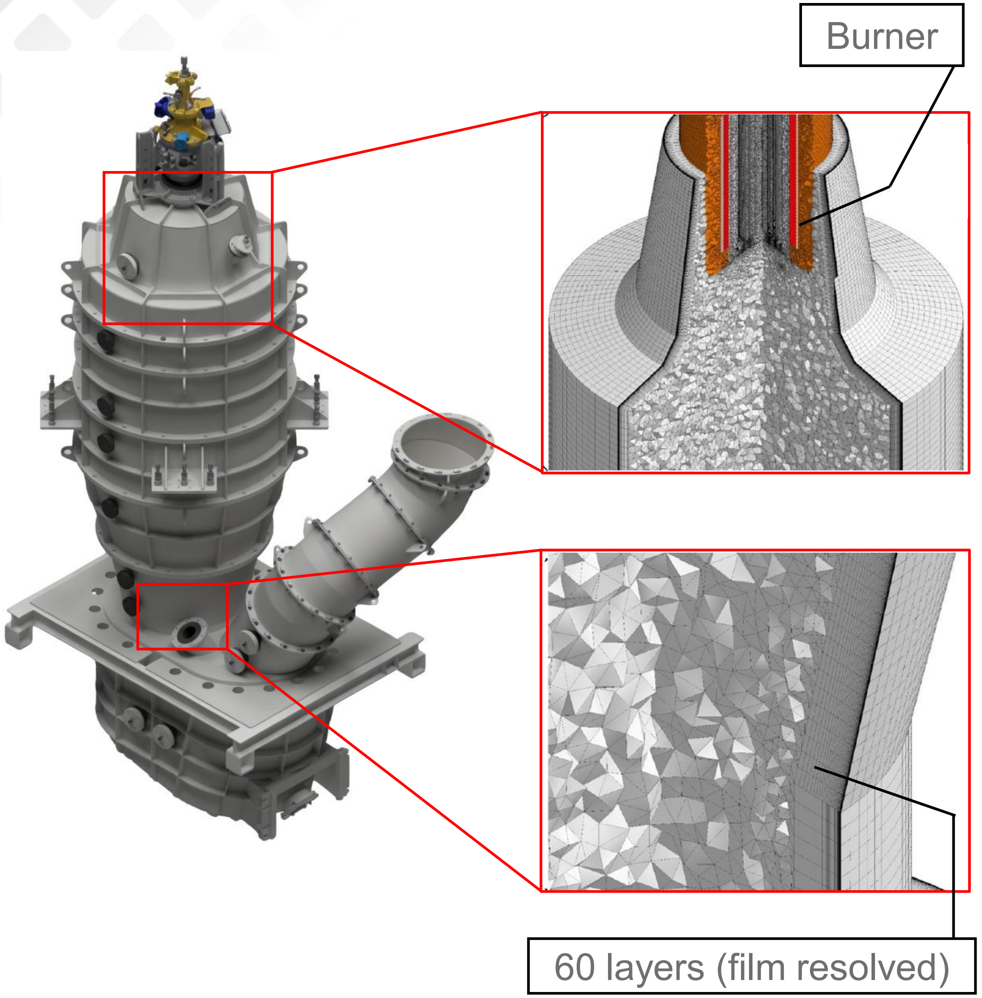

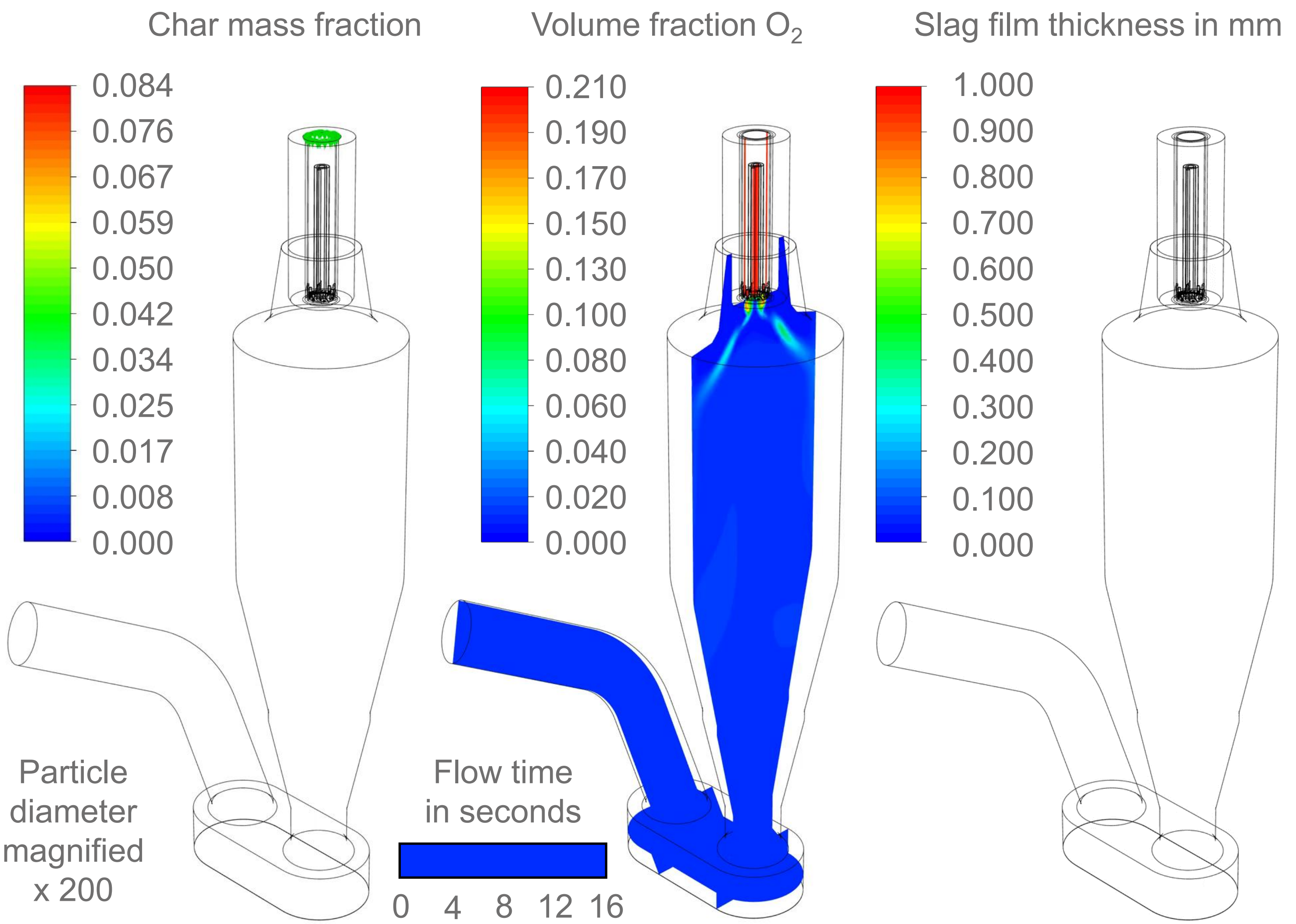

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Main simulation cases:
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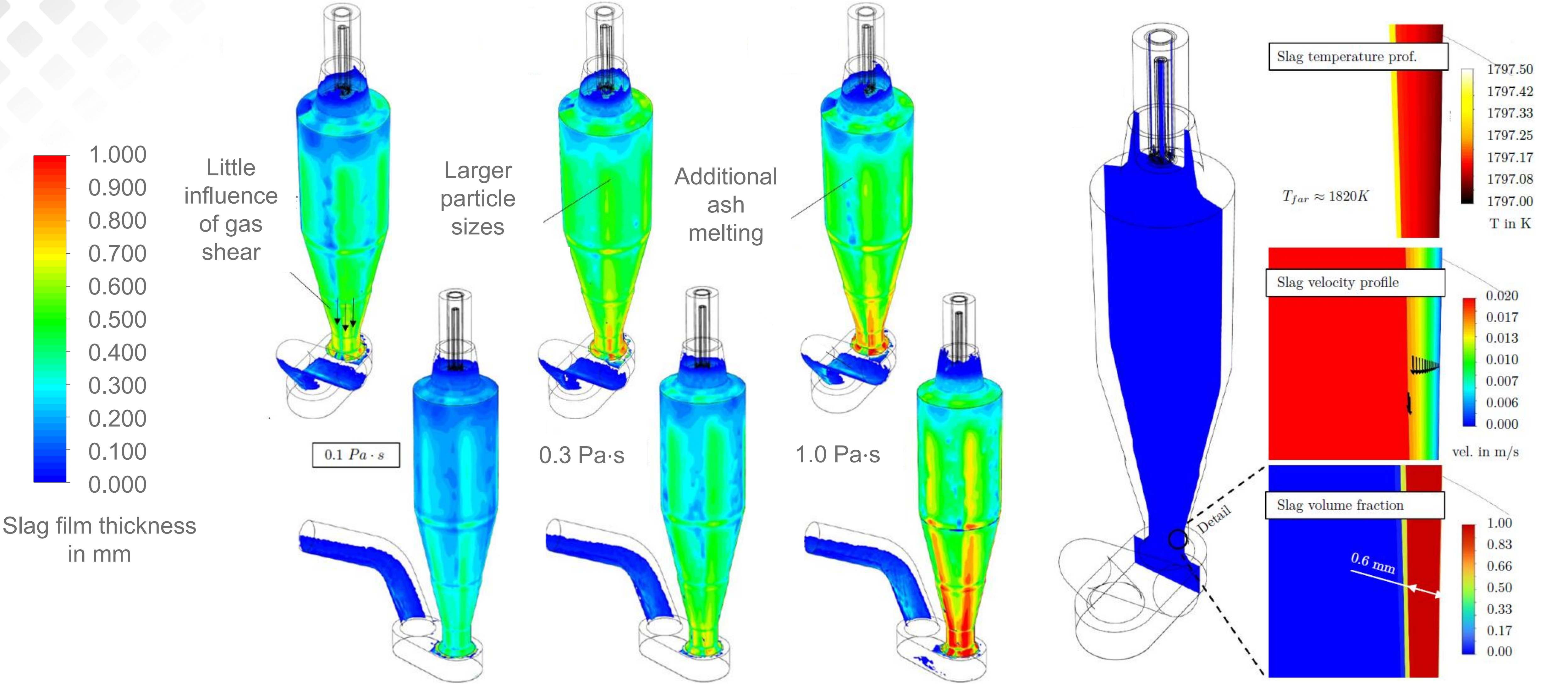

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Summary and outlook

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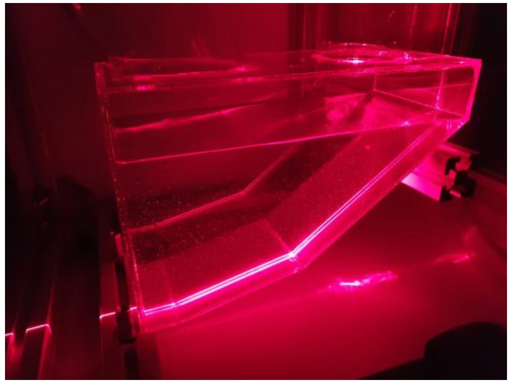
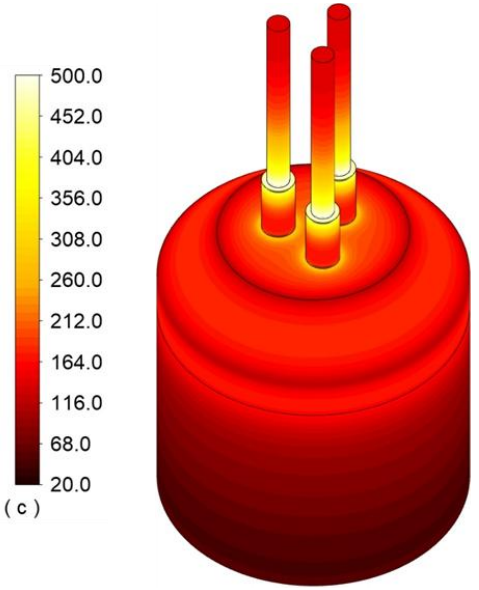
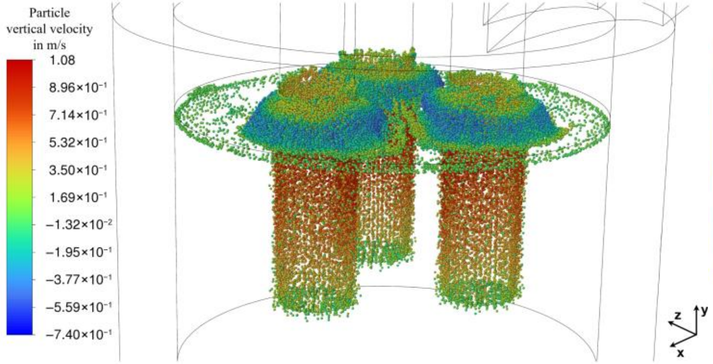
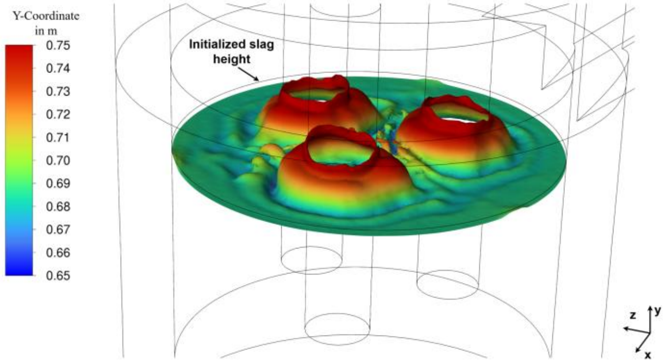
Not shown in this presentation:

- Multiphase flow model test rigs and model validations
- Other experimental campaigns at USTUTT
- Parametric studies (Geometries, sludge types, enhanced air settings, excess air ratios…)
- CFD simulations of the pilot plant refiner
- Various design studies and engineering support calculations









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Summary and outlook

- Predict mass and energy balance of the Flash reactor and refiner
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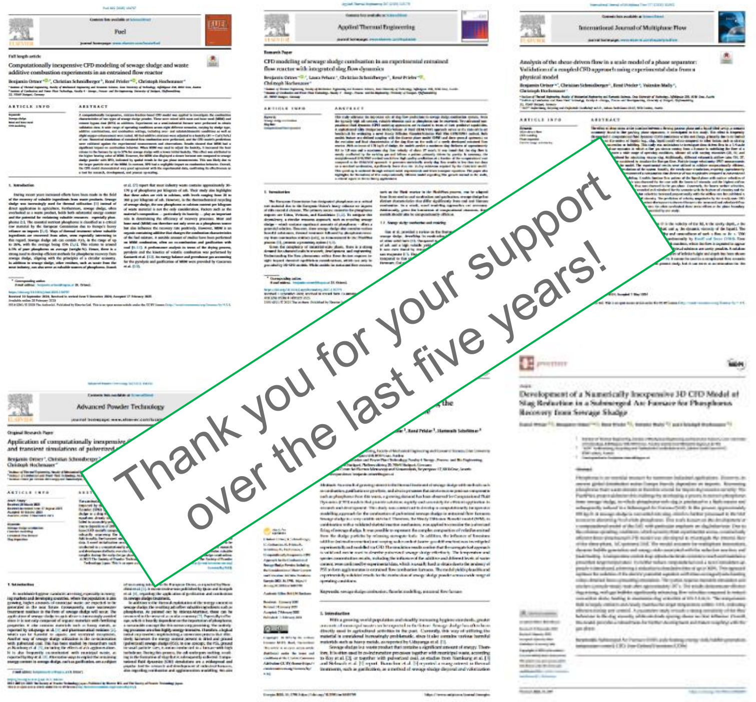

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The complete thermochemical recycling of sewage sludge

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The complete thermochemical recycling of sewage sludge

Digital twin
From concept to a useable tool

Els Nagels

InsPyro

21/04/2026

InsPyro

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958267.

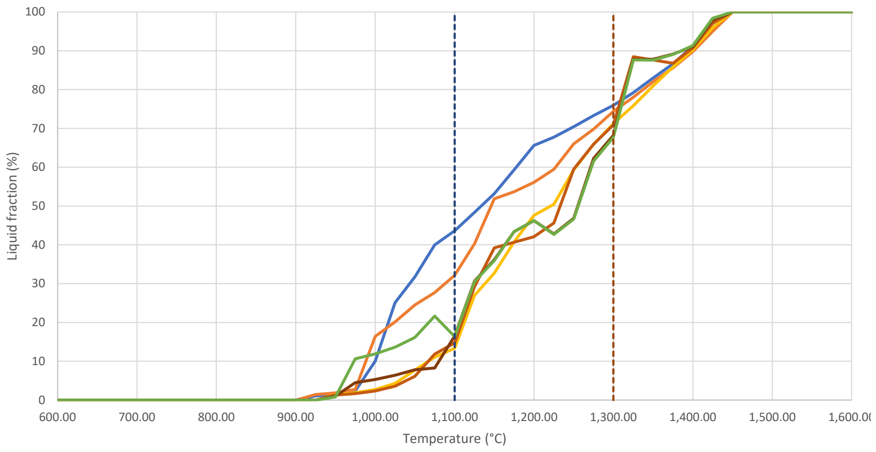
The model(s) behind the digital twin

FLASHPHOS

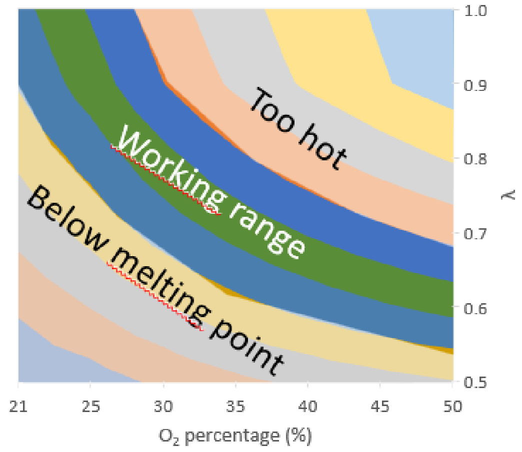
Building the knowledge base

- Thermodynamic models
- Experimental results
- Mapping the unknown
- Detailing the process flow diagram

Material behaviour (melting)



Operational window



2021 2022 2023 2024 2025 2026

Start

Building knowledge base

End

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958267.

InsPyro

The model behind the digital twin

FLASHPHOS

Building the knowledge base

- Thermodynamic models
- Experimental results
- Mapping the unknown
- Detailing the process flow diagram

2021	2022
Start: Building knowledge base	

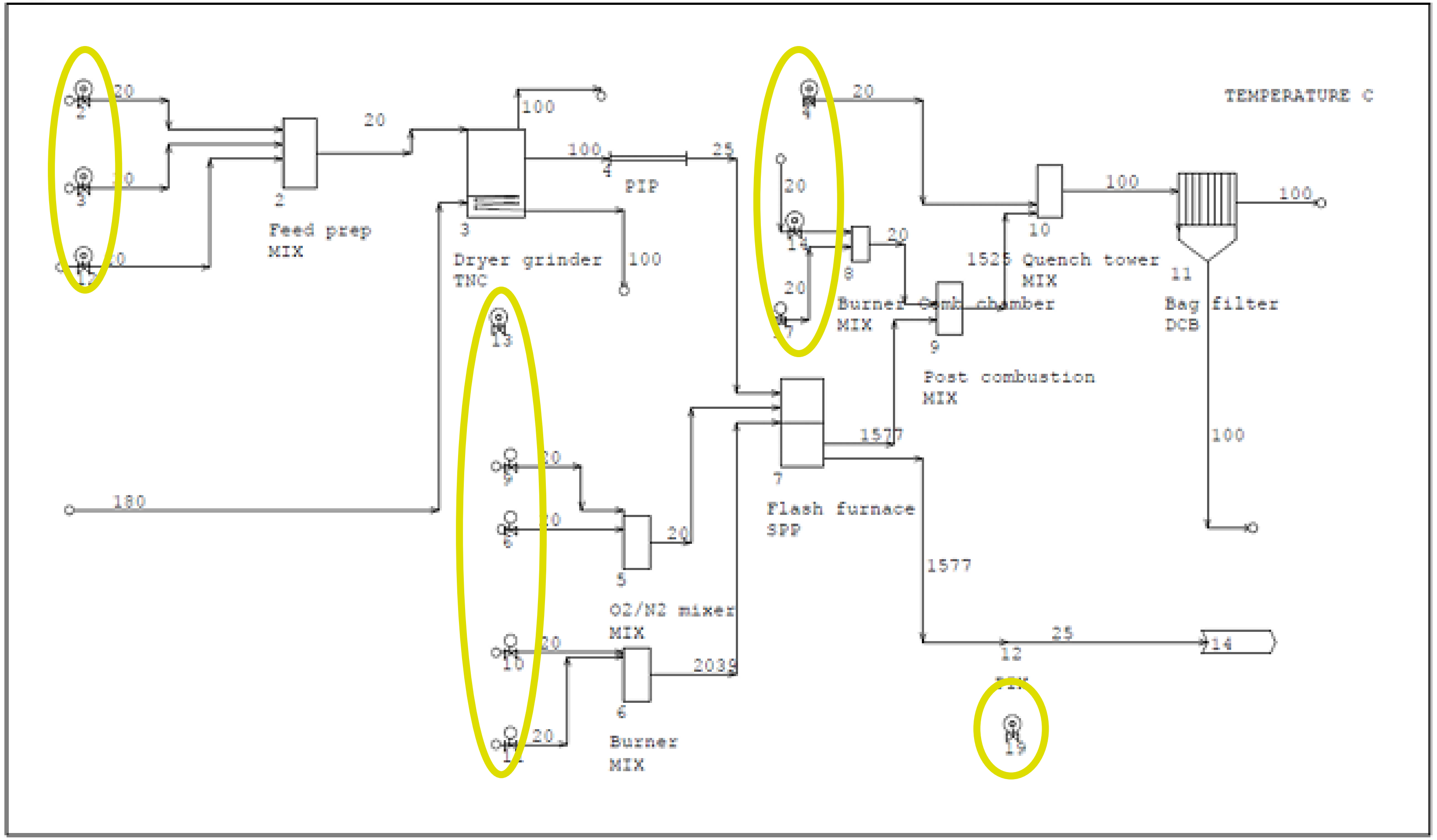


Figure 1: Flash furnace section in METSIM® with temperature (°C) on the streams

InsPyro

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Process controls

- Expectation: digital twin responds as the real process
- Controllers allow you to make a process model responsive
  - Flow rate controllers – set flowrate (as input or responding to other flow rates)
  - Feed back controllers – change setting to achieve a specific setpoint (fluxing strategies)
  - If then else loops – react to specific situations

- Stability of the model is very important for a digital twin
- Controller setpoints can be variable inputs (see later)

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The model behind the digital twin

FLASHPHOS

Filling in the gaps:

- Behaviour of minor elements?
- Kinetic constraints?
- Cp values of sewage sludge?
- Energy consumption of different units?
- Side equipment?

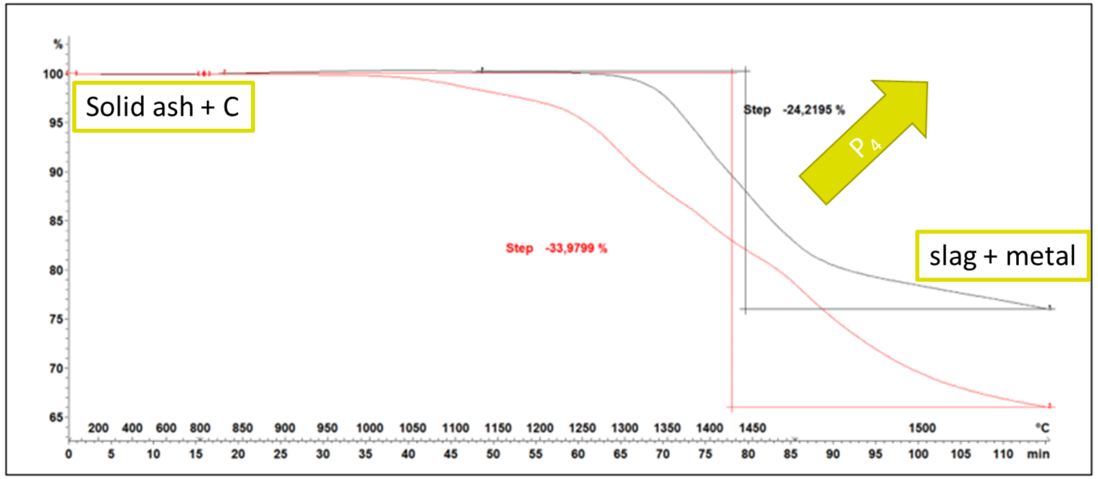

Figure 11: Carbon size comparison between fine (red) and coarser (black) carbon particles.

2021 2022 2023 2024 2025 2026

Start

Building knowledge base

Fill in the gaps
Data mapping

End

InsPyro

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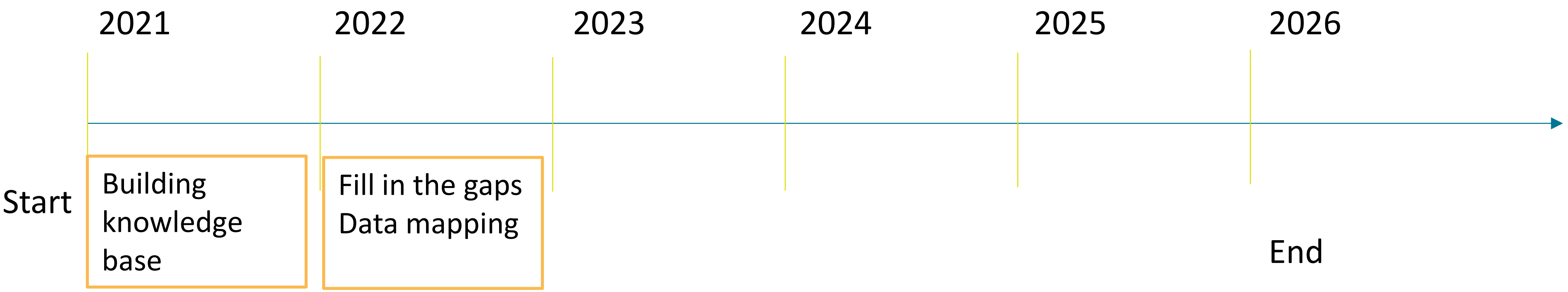
The model behind the digital twin

At the same time:

- Functional theoretical model
- Needs to become a digital twin
- Data mapping of required in-out
- Making lay-out of user interface



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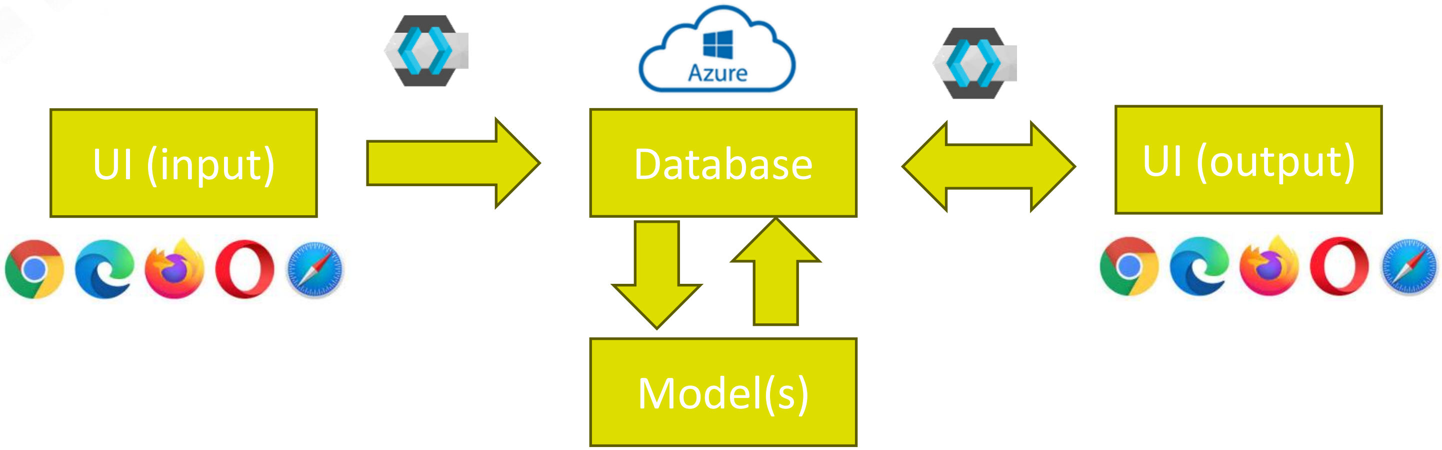
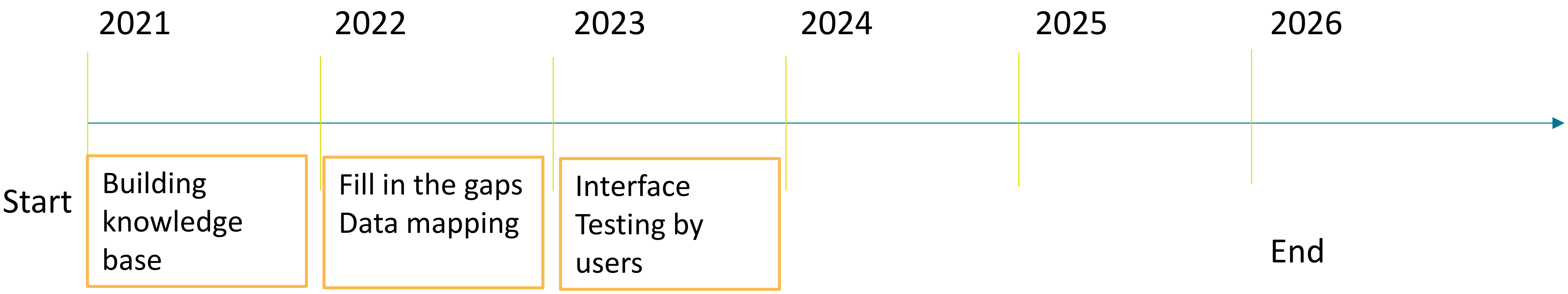
Digital twin scheme





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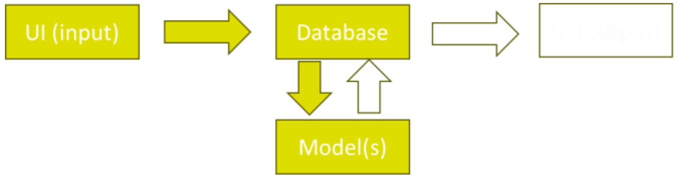
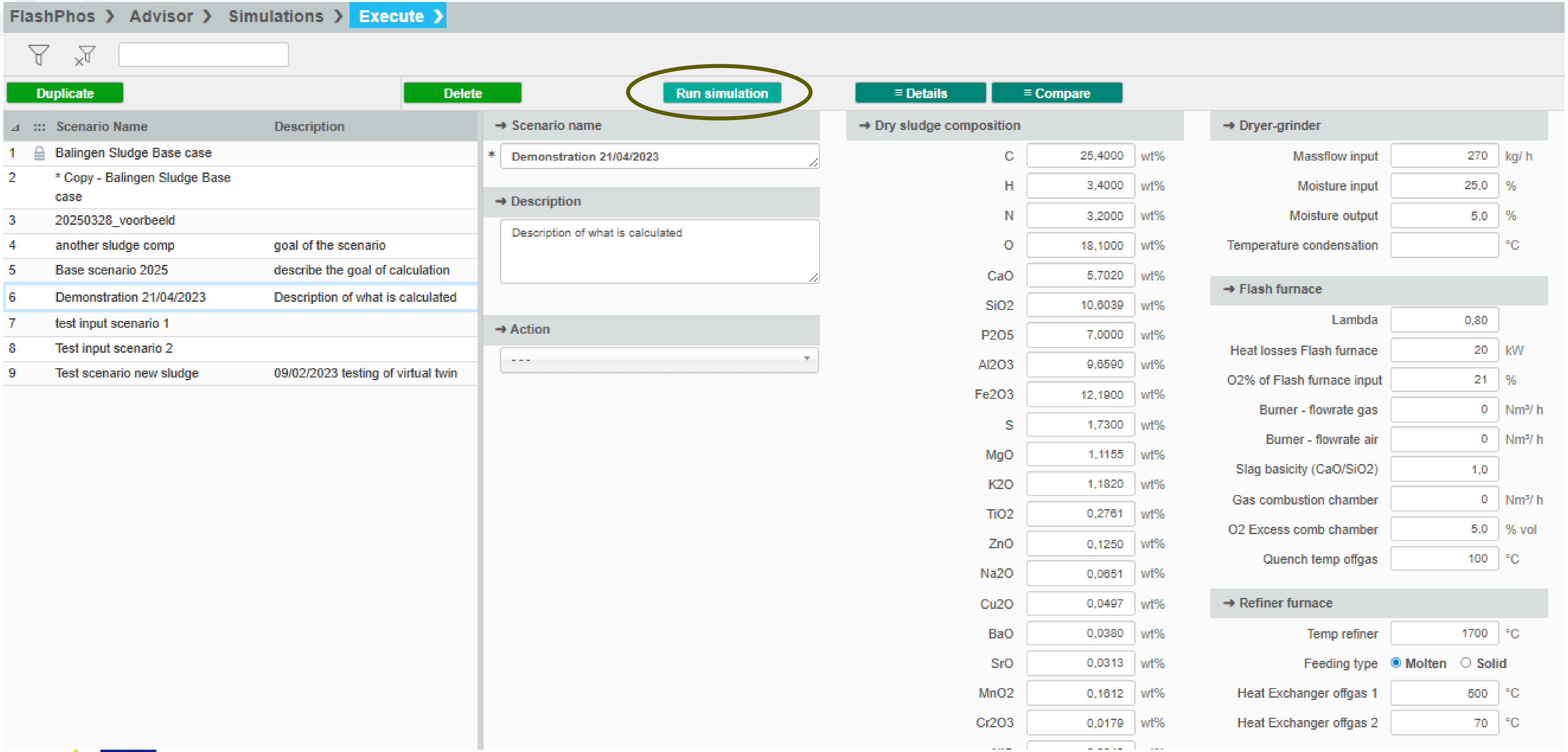
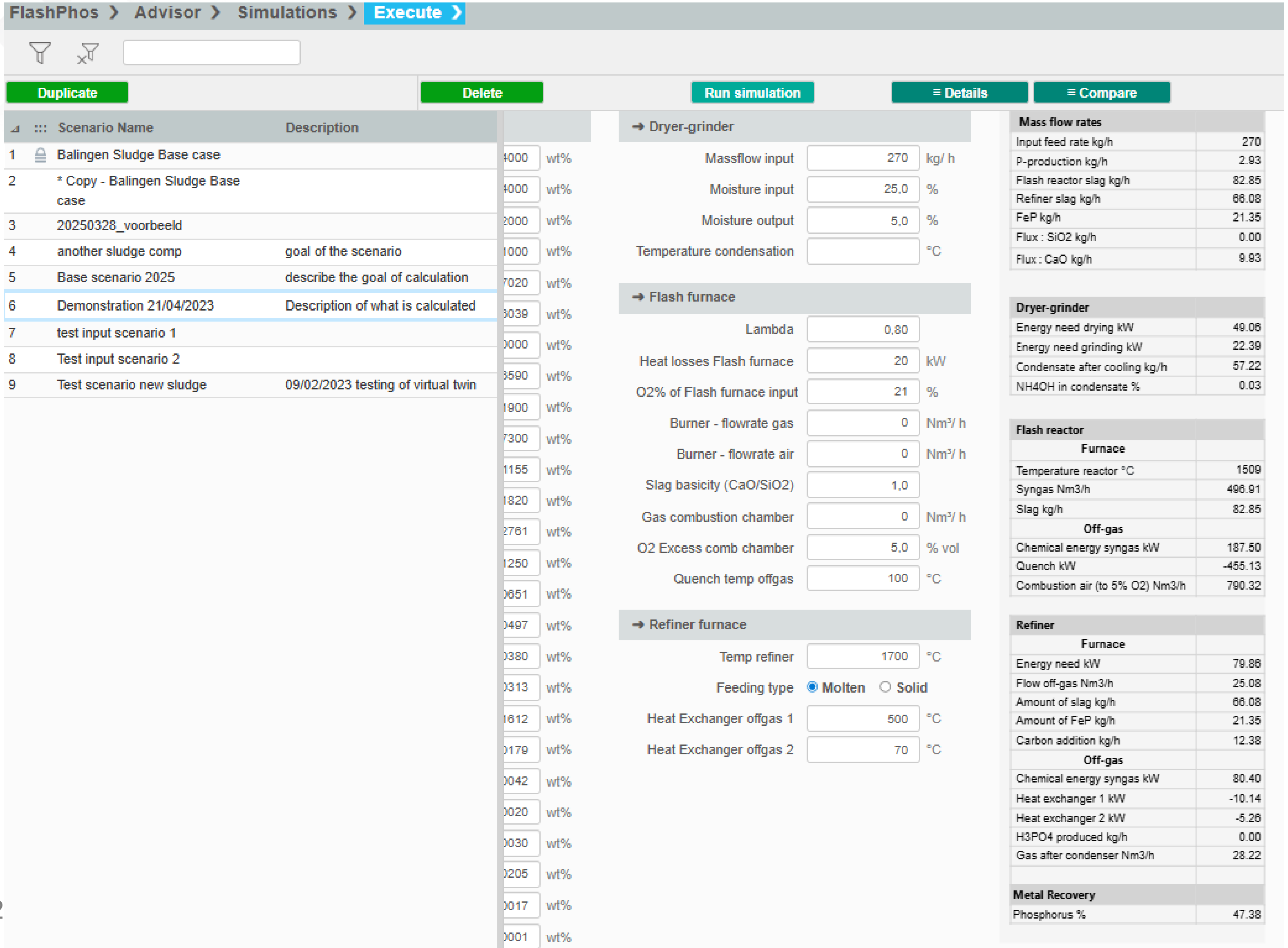
User interface (input)

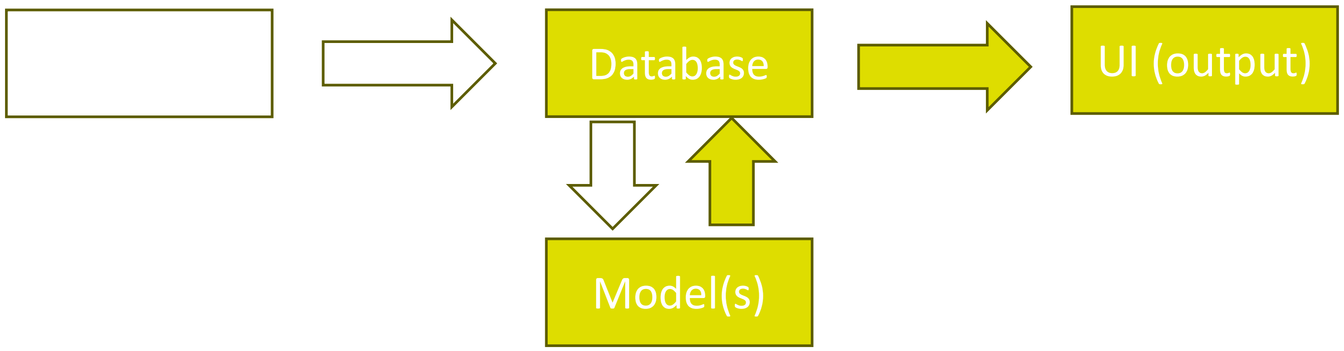


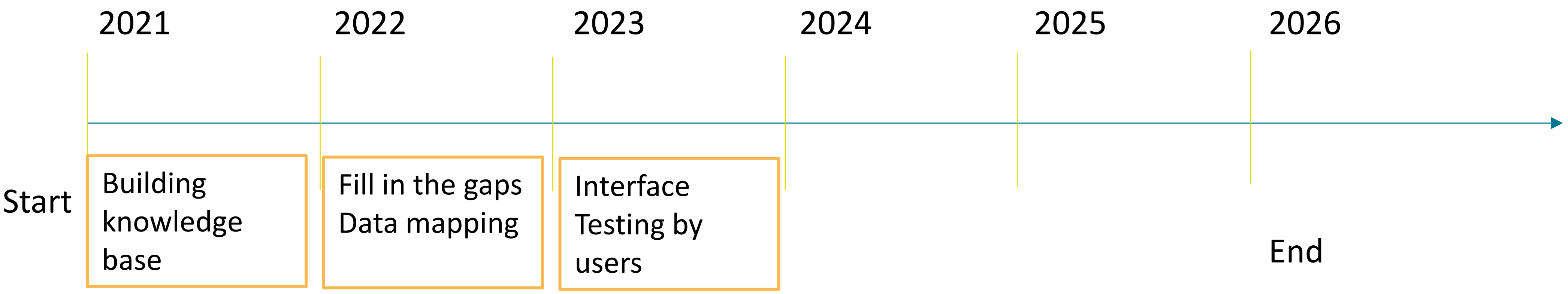


Summary of results



Digital twin scheme





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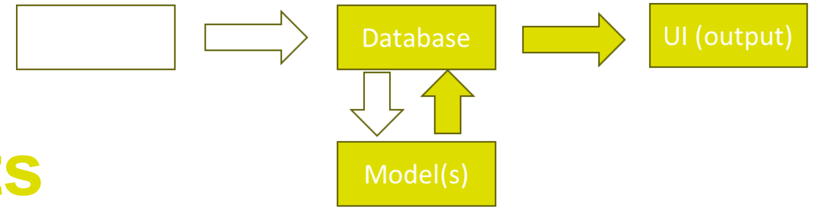
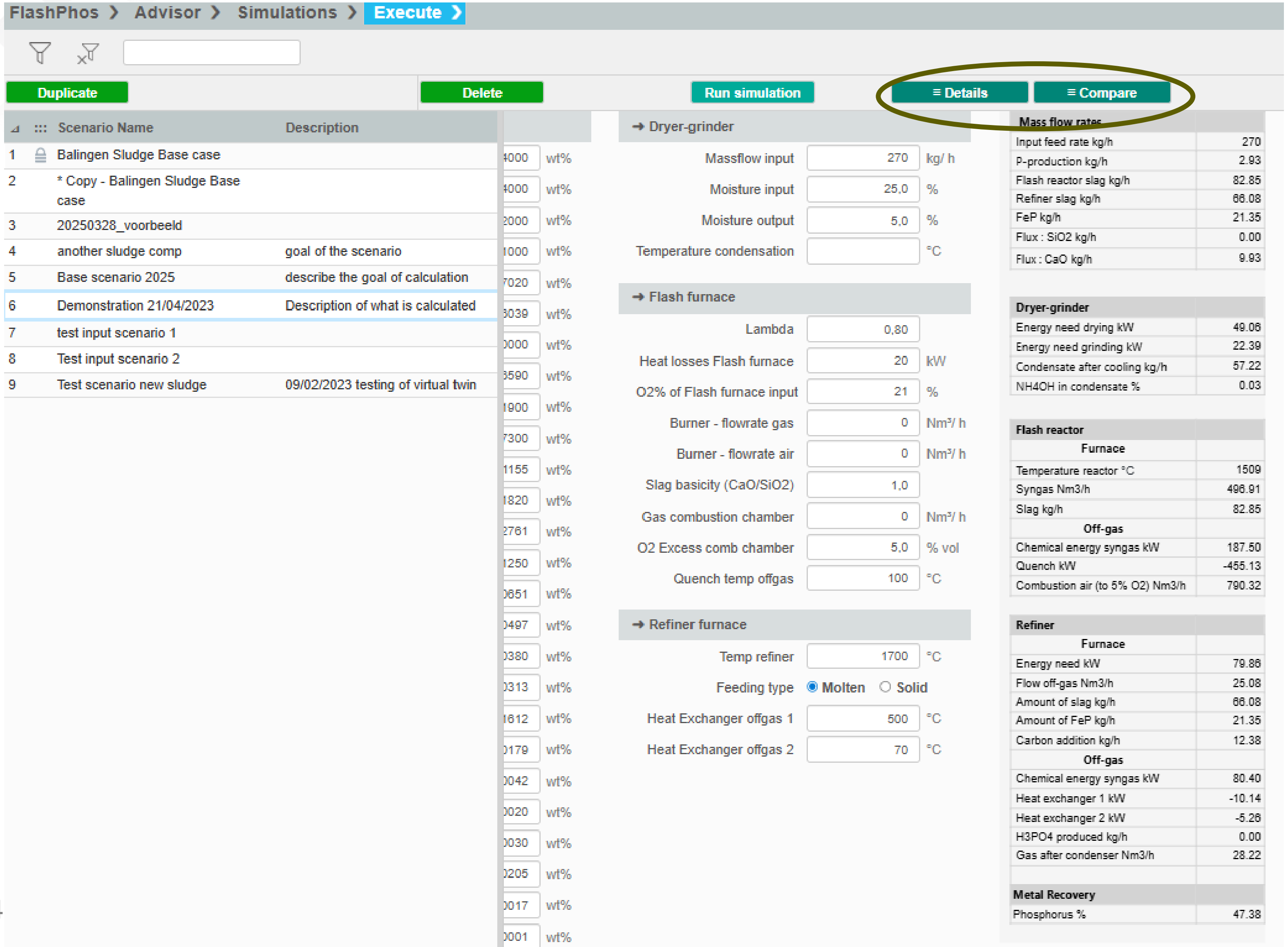
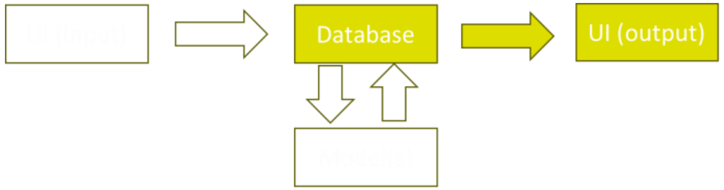


Summary of results

FLASHPHOS



- Detailed report generation
- Comparison tool with other scenarios



InsPyro

Use phase & Updating

- Model refinement
- Incorporate new knowledge
- Updating input/output

A digital twin is not a static entity; it is a tool which requires maintenance and updates

	2021	2022	2023	2024	2025	2026
Start	Building knowledge base	Fill in the gaps Data mapping	Interface Testing by users	Use phase Updating	Use phase Updating	End

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Thank you for your attention

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

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EU Project FlashPhos @FlashPhos

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

FEED Study & Integration into the Cement Industry

Sabrina Frühauf

A TEC Production & Services GmbH

21/04/2026

A TEC GROUP
A Member of LOESCHE Family

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Agenda

- FEED-Study Overview
  - What is a FEED-Study
  - Objectives at the FlashPhos project

- Tasks & Results
  - Basic Engineering
  - Integration into the cement industy
  - Cost estimation

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FEED Study Overview – FlashPhos Integration

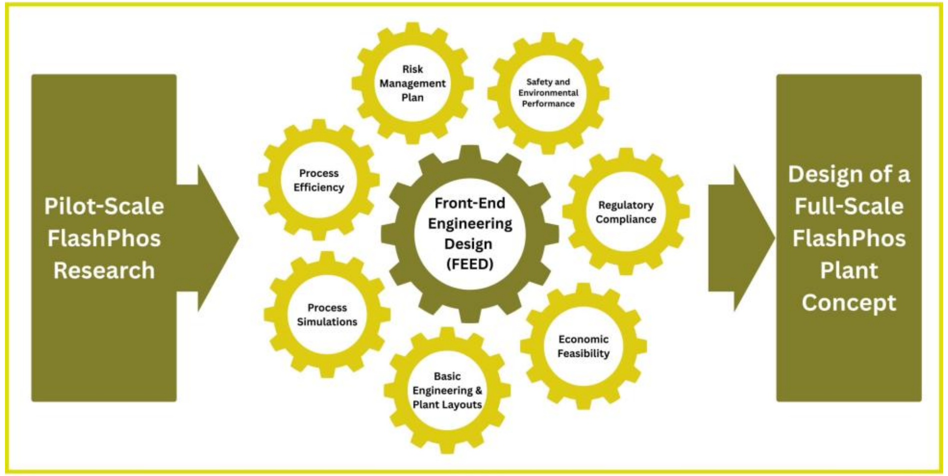
Front-**E**nd **E**ngineering **D**esign: Early phase engineering step that defines how a project will be built, technically and economically, before the final investment decisions are made.

FEED Scope at FlashPhos:
- Scale Up – Pilot to Industry plant size
- Process design & key equipment definition
- Plant layout and system integration

Engineering Level (FEL-2):
- ~10–40% design maturity
- Identifies risks & technical feasibility
- Basis for next phase (detailed engineering)

Cost Estimate:
- According to AACE 18R-97 - Class 3 estimate
- Accuracy: approx. –20% to +30%

Outcome:
✓ Validated concept
✓ Reliable cost range
✓ Decision basis for investment



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FlashPhos Feed Study Objectives – From Research to Industrial Design

FLASHPHOS

- Bringing together **lab research, simulations, engineering & industry experience**
- **Scaling FlashPhos from pilot to industry size ->** considering the results and outcomes of Pilot plant design, process development, resources management and pilot plant demonstration tests
- **Basic engineering of an industrial sized FlashPhos** for integration in a reference cement plant
- **Study/modelling of the influence by the impurities** delivered by the industrial sized FlashPhos process **on the cement reference process**.
- **FEED study** of FlashPhos integrated in cement plant with cost estimation according to AACE No. 18R-97, **cost estimate** class 3

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FlashPhos Scale-Up Process – Basic Engineering

- From Pilot -> industrial plant design
- Based on simulations and digital twin models
- Defined mass & energy balance, PFD & P&ID´s, equipment specification, 2D/3D layouts
- Scaled-up key equipment:
  - Dryer/Grinder Units
  - Burner system
  - FlashReactor
  - Refiner
  - Phosphorus recovery system
  - Product storage areas & equipment
  - Pipelines

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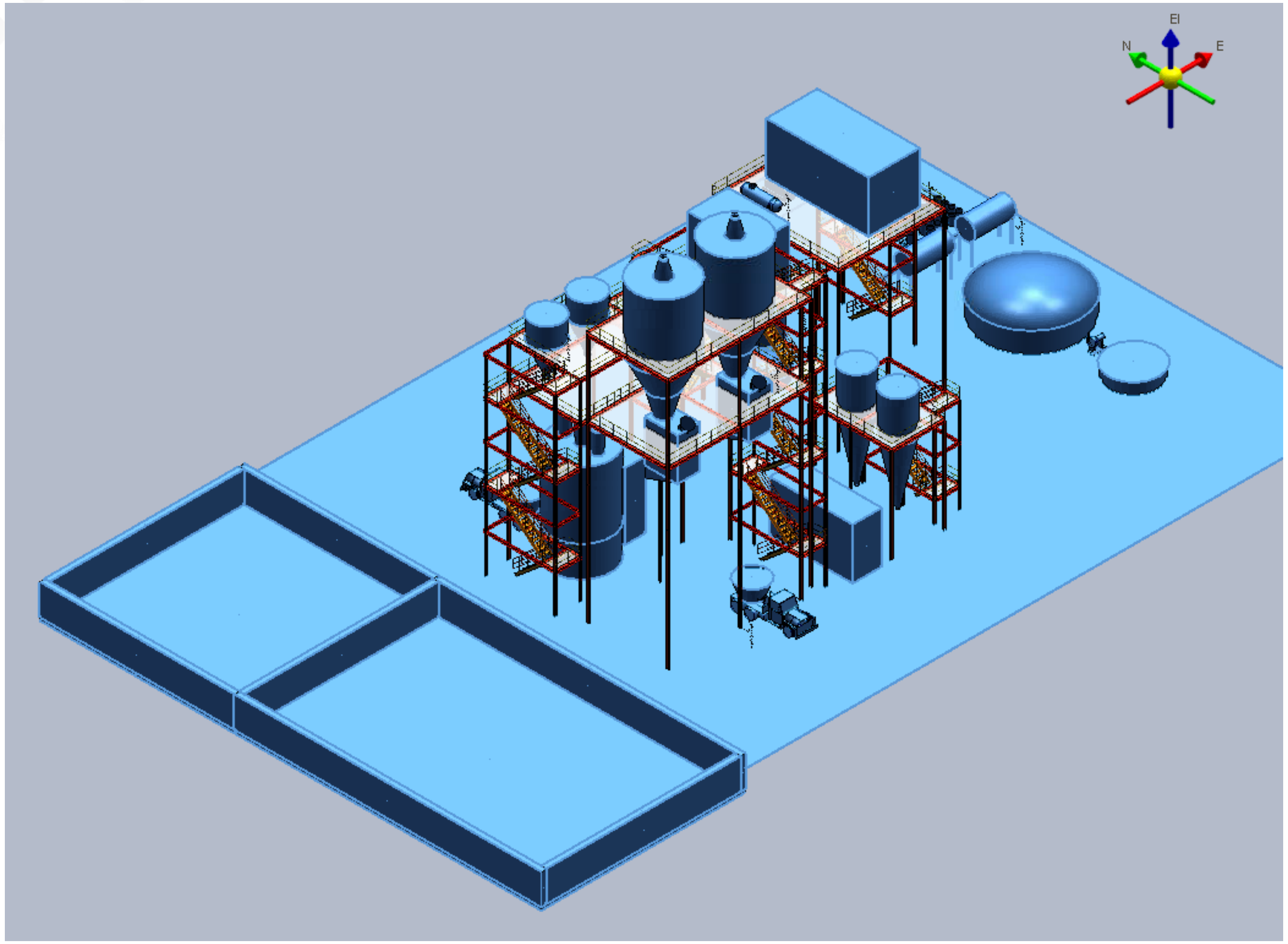
Layout of FlashPhos Core Components

FLASHPHOS



Basic Engineering – Scale-Up FlashPhos Process

Key Design Criteria:

- **Capacity: 5.000 t/a P**
- **Feed:** 30 t/h dried sewage sludge + kiln dust
- **Annual running time**: 8,000 h/a
- **Syngas:** ~ 98.000 Nm^3/h
- **Slag Production:** ~ 9,8 t/h
- **Proven Technology**: Based on conventional, reliable industrial systems.
- **Operational Safety**: Stable, safe performance across all components.
- **Instrumentation**: Full monitoring and modeling capabilities.
- **Flexibility**: Designed for start-up, shutdown, and stress testing.

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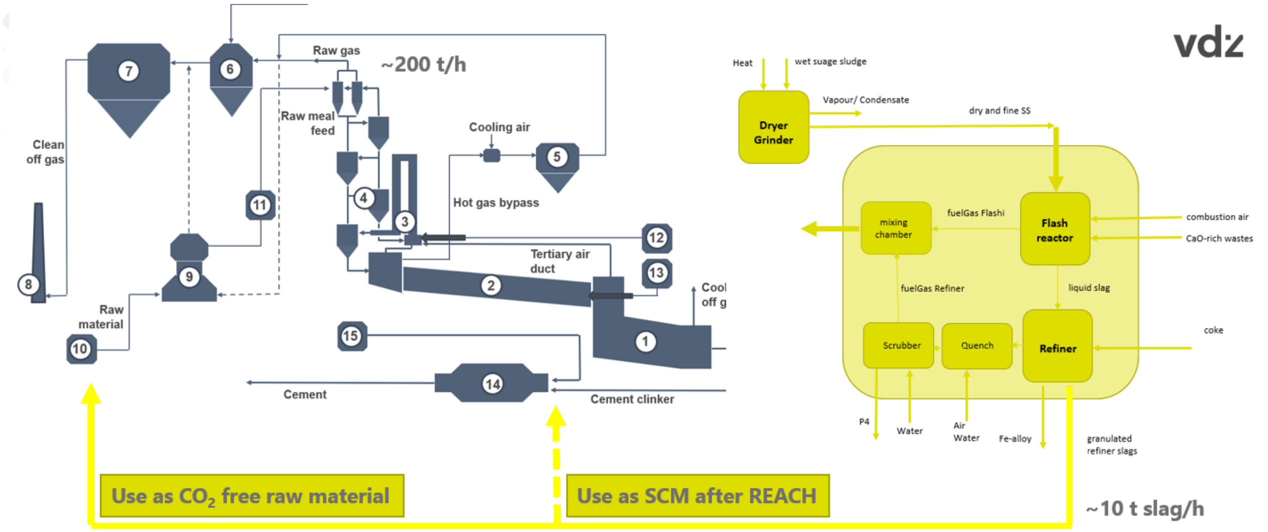
Integrating FlashPhos into Cement Industry

- Integration of FlashPhos Process into an existing Cement plant
  - Integration of:
    - Heat
    - Gas flows
    - Material flows
- Simulation & Integration Study by VDZ
- Close collaboration with industry
  - Workshop
  - Cement plant site visit
- Development of plant layout
- Dryer/Grinder Logistics & Location Assessment
- Safety & Environmental analysis (HAZOP, SIL)



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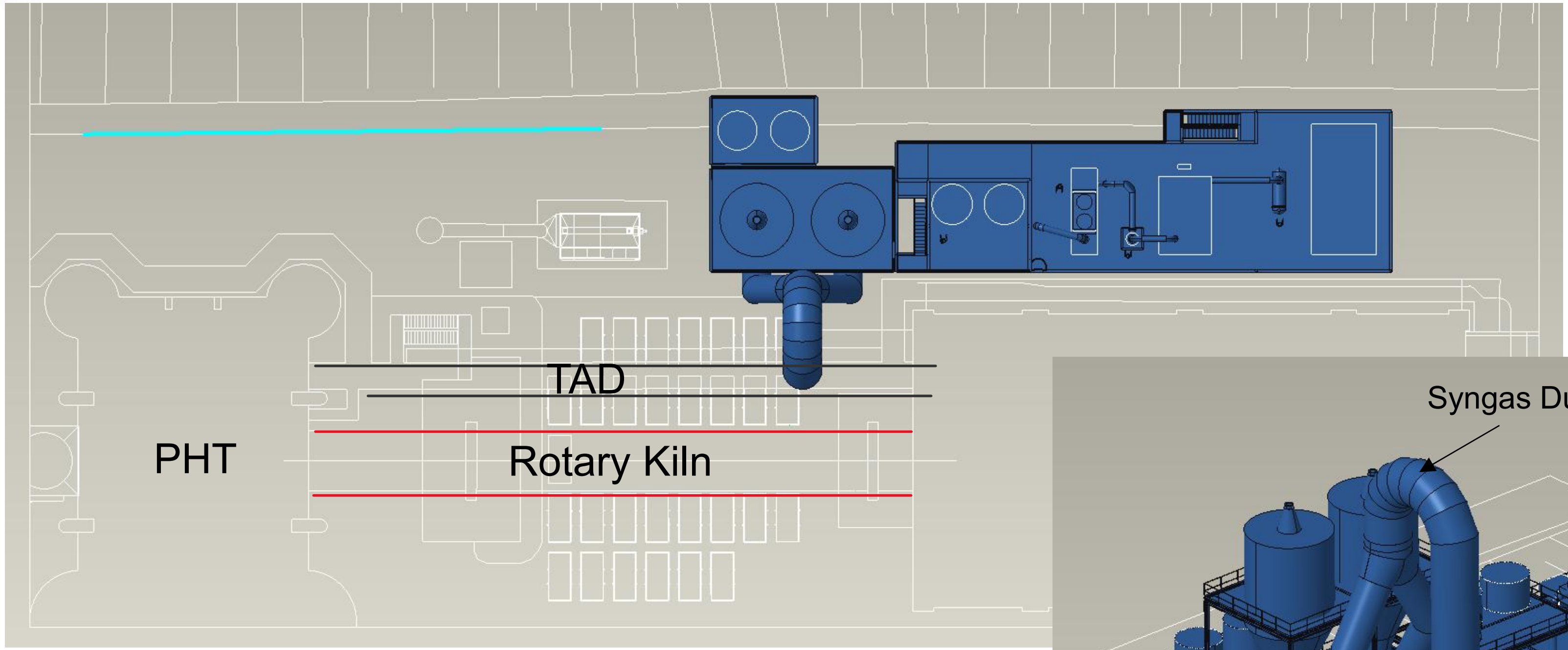
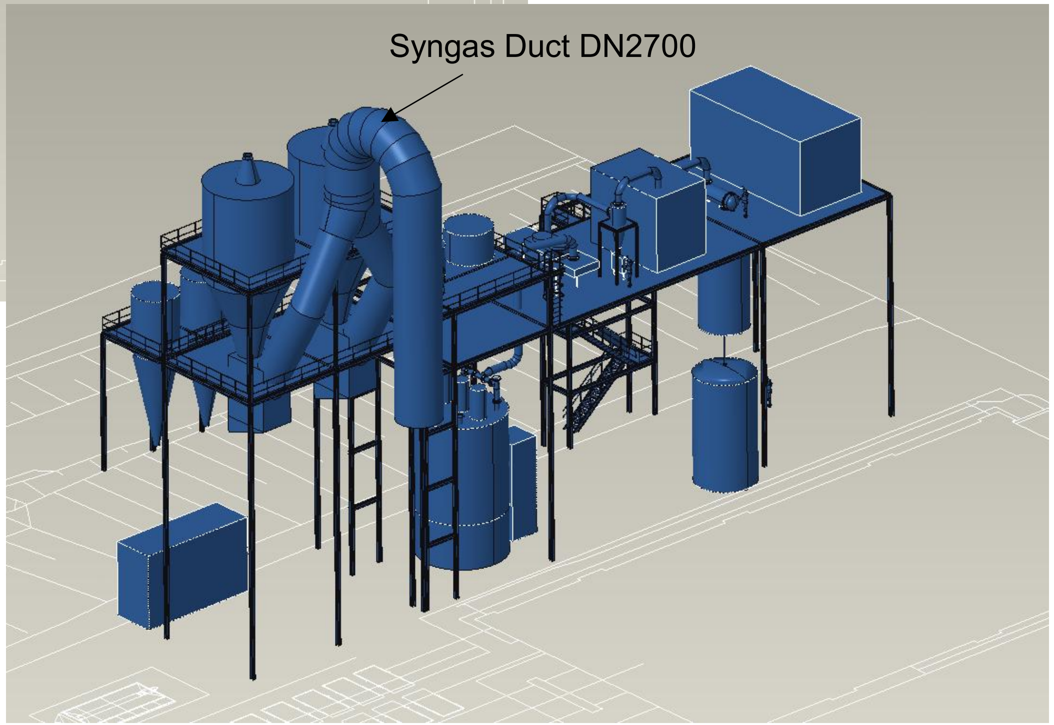
FlashPhos Scale-Up Design Integration





Integration of an industrial-scale FlashPhos process into a reference cement plant with a clinker capacity of 3.000 t/d.

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FEED-Study Cost Estimation - CAPEX

$

CAPEX Split – Dryer/Grinder Units

CAPEX 2 – Dryer-Grinder (~930.000 t/a wet sewage sludge)	
Cost Categories	CAPEX [€]
Dryer incl. periphery (18 Units)	
Integration dryer in host plant (heat, vapour)	
Commissioning	
Permission & Documentation	
Structural Steel	
Transport Costs	
Contingency (15 %, Class 3)	
Sum Cost Estimation (CAPEX 2, Class3):	**45 – 65 Mio**

- Conservative Cost Estimate
- Costs reflect the current full-scale concept
- Future optimisation and alternative configurations may improve economic performance

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FEED-Study Cost Estimation – CAPEX

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CAPEX Split – FlashPhos Process

CAPEX 1 – FlashPhos Process (~240.000 t/a dry sewage sludge)	
Cost Categories	**CAPEX [€]**
FlashPhos Process Equipment	
EMSR (electrical, measurement, control & regulation)	
Engineering	
Commissioning	
Permission & Documentation	
Building, site development	
Instrumentation	
Refractory	
Structural Steel	
Transport Costs	
Contingency (15 %, Class 3)	
Sum Cost Estimation (CAPEX 1, Class3):	**55 – 75 Mio**

- Conservative Cost Estimate
- The numbers are in line with recent on going industrial projects based on traditional process

CAPEX Split – Possible modifications on host plant: up to 50 Mio. €

- Host plant specific (e.g. plant infrastructure, equipment)
- This scenario must be studied in detail as well as other combinations incl. installing of FlashPhos in alternative industry host

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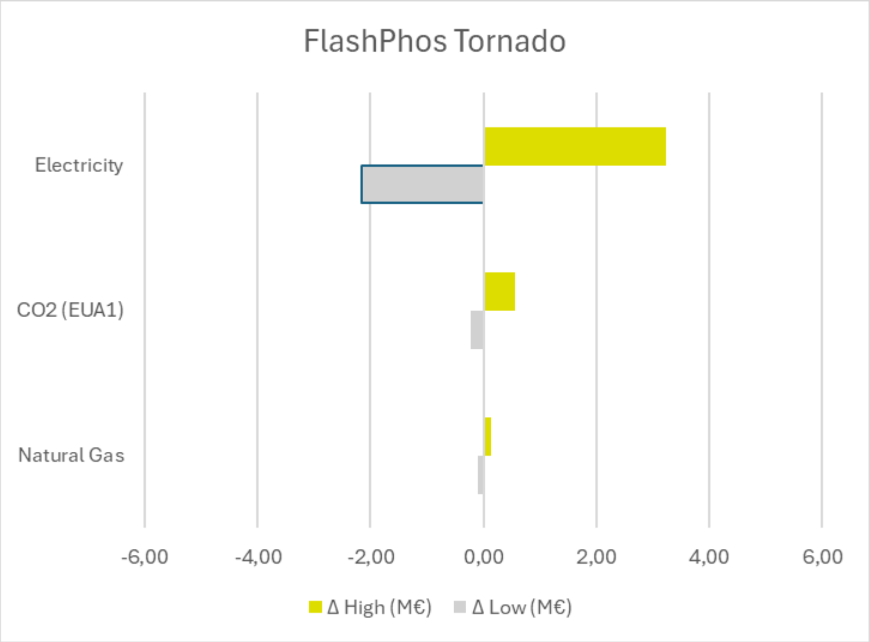
FEED-Study Cost Estimation – OPEX FlashPhos Process

OPEX FlashPhos Process (Base Case SCENARIO)*1			
Category	Unit costs		OPEX [€/a]
Natural Gas	30.00	€/MWh	
CO_2 Costs Natural Gas	100.00	€/t CO_2	
Sewage Sludge (dry) on site handling	3.00	€/t	
Pet-Coke	200.00	€/a	
Pet-Coke, on-site handling	3.00	€/t	
CO_2 costs Pet-Coke	100.00	€/t CO_2	
Transport Pet-Coke	1.50	€/km	
Electricity	0.11	€/kWh	
Water	1.00	€/m³	
Instrument Air	0.10	€/kWh	
Refractory Lining	-	-	
Operators (9 in 4 shifts)	60,000	€/a	
Maintenance (3% of CAPEX)	-	-	
Product quality control (1% of CAPEX)	-	-	
Insurance (0,9% of CAPEX)	-	-	
Depreciation costs (10 years)	-	-	
Administration (3,5% of OPEX)	-	-	
			~ 30 Mio

1*: without Dryer/Grinder and sewage sludge transport



- Multiple scenarios evaluated since project start (2021)
- Different technical and operational options identified
- Strong dependency on energy prices (electricity & gas)

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FEED-Study Cost Estimation - Revenue

$

REVENUE LASHPHOS SCALE-UP			
Parameter	Unit	Unit Price	Value [€]
Fee for sewage sludge acceptance	€/ton WM	€ 35.00	
Good sold	t/a		
Iron Alloy	t/a	€ 160.00	
P4	t/a	**€ 3,300,00**	
Alternative binder before milling	t/a	€ 40.00	
Compensation for EUA1 emission allowances - cement binder	tCO_2 avoided/a	€ 100.00	
Compensation for EUA1 emission allowances, Syngas	tCO_2 avoided/a	€ 100.00	
Combustible Gas	MWh/a	€ 20.00	
		Total Revenue	**~ 80 Mio**

- Sewage sludge acceptance on wet base
- Limited revenue potential for iron alloy due to mixed metal composition, with possible additional handling or disposal requirements
- Conservative P_4 unit price – considerable higher price level based on better quality of final product

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FEED-Study: Partners involved

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Integration of FlashPhos into the cement Industry

Stefan Papkalla

- Opportunities of the FlashPhos integration into the cement plant
- Integration concept and challanges
- Overall FEED Study Results

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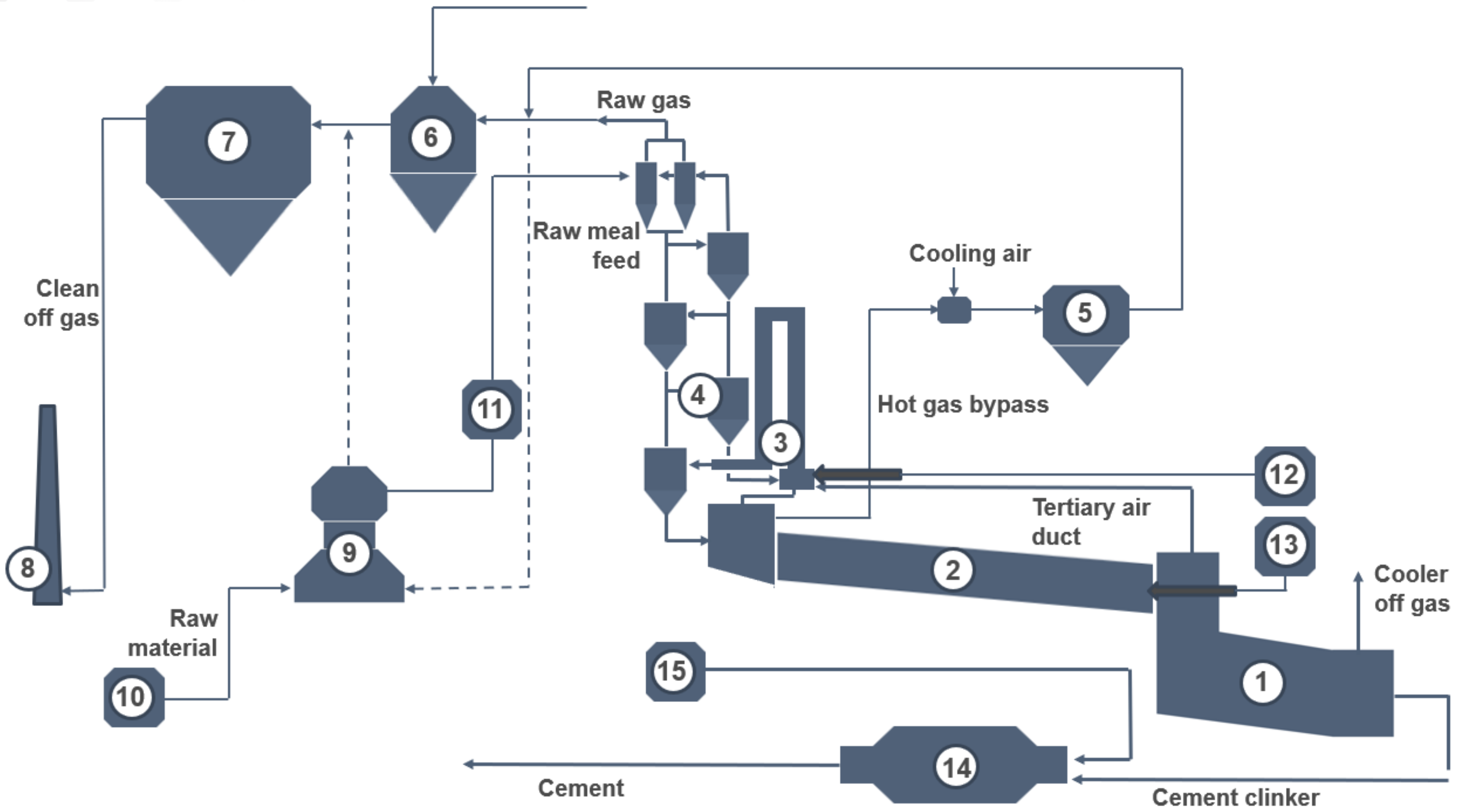
Cement Plant as a Host Plant



1	Clinker cooler
2	Rotary kiln
3	Calciner
4	5- stage cyclone preheater
5	Dedusting hot gas bypass
6	Evaporative cooler
7	Kiln dedusting
8	Stack
9	Raw mill
10	Raw material system
11	Raw meal silo and feeding
12	Kiln burner system
13	Calciner burner system
14	Cement mill
15	Cement additives system

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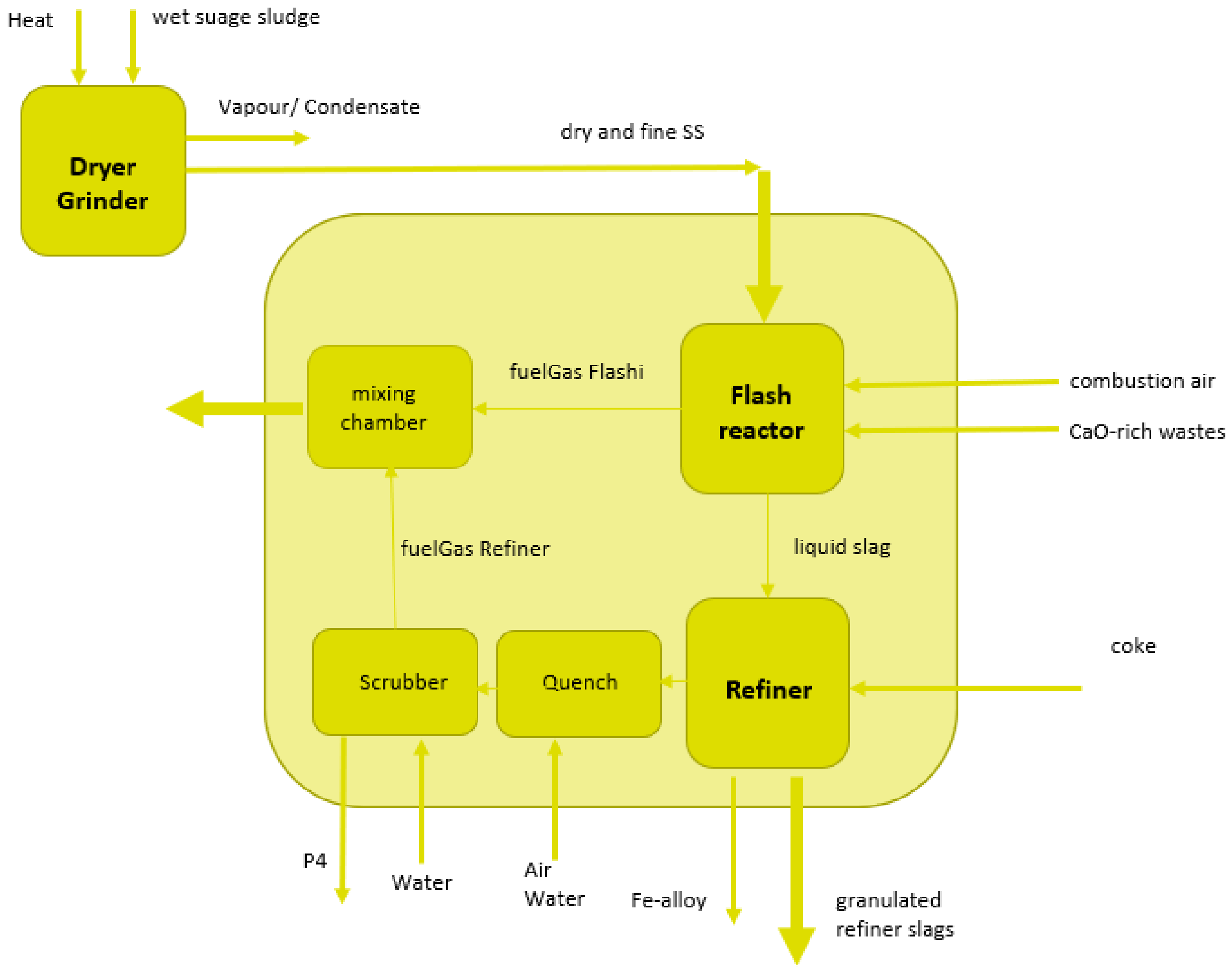
FlashPhos Process Flow

FLASHPHOS



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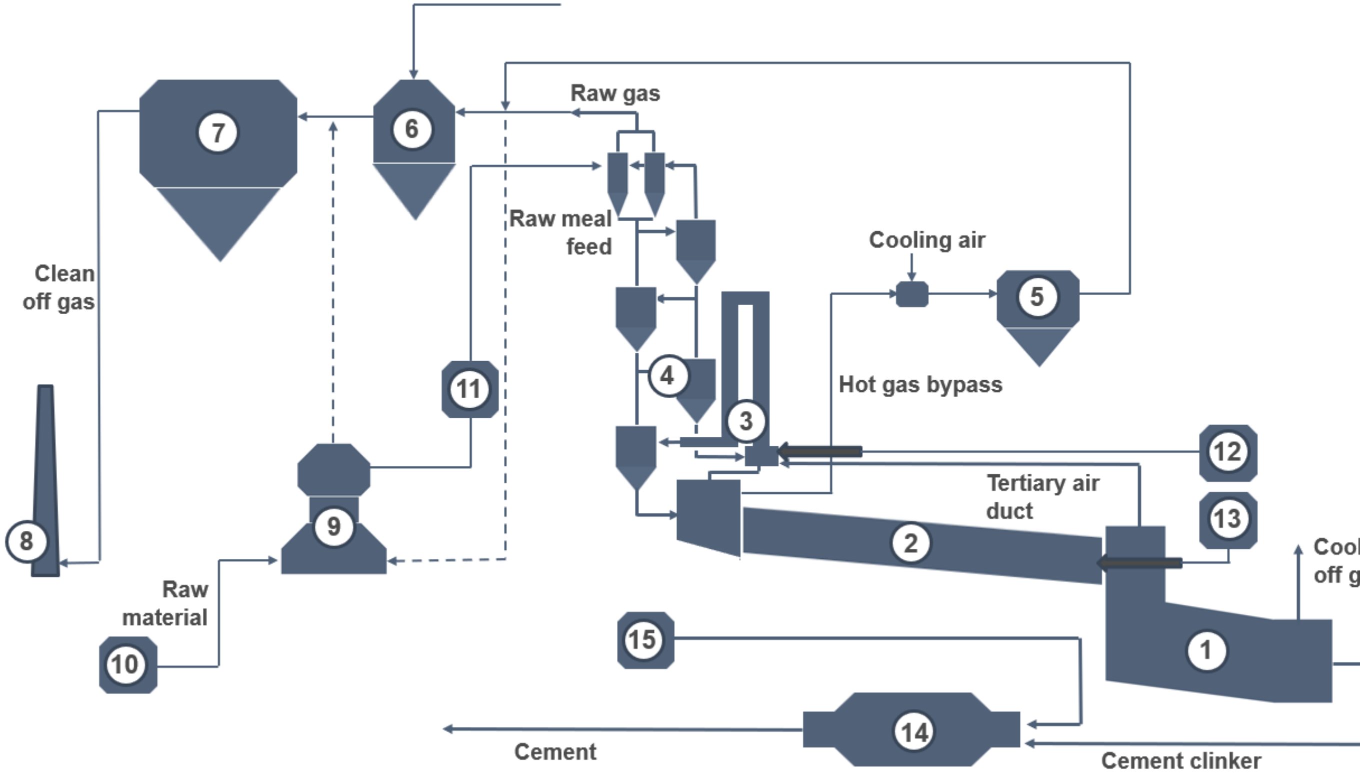
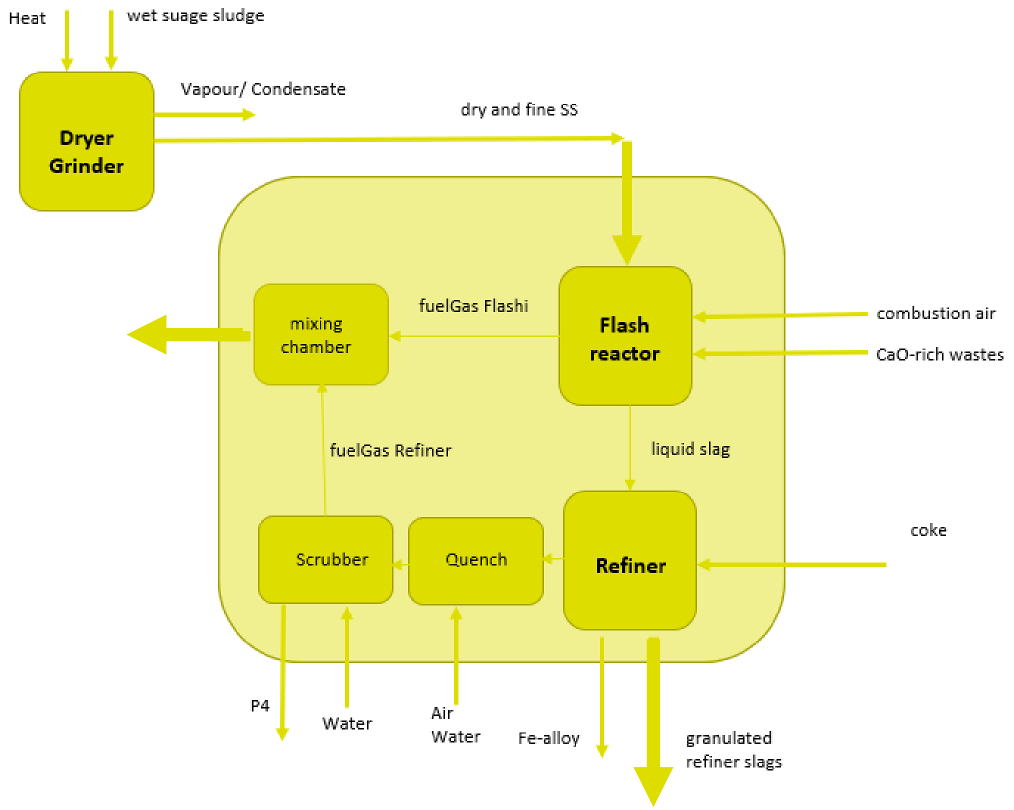
vdz

Expected Synergy Effects





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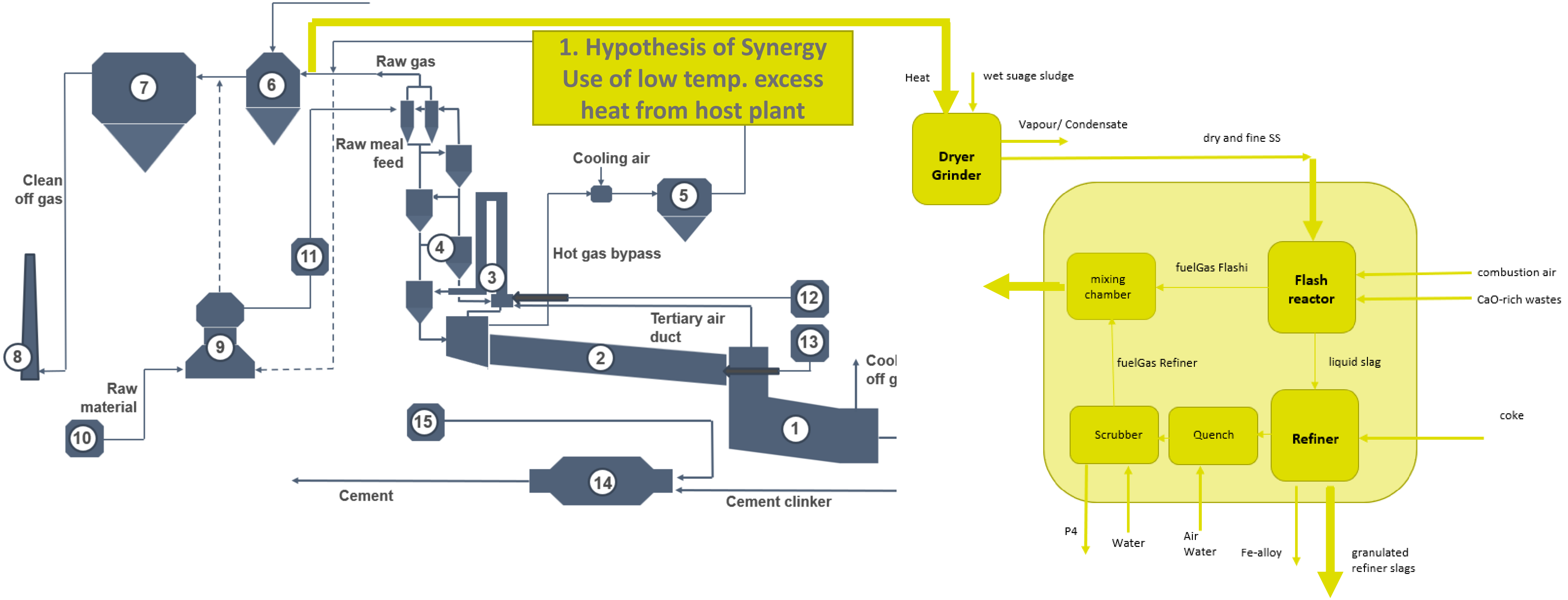

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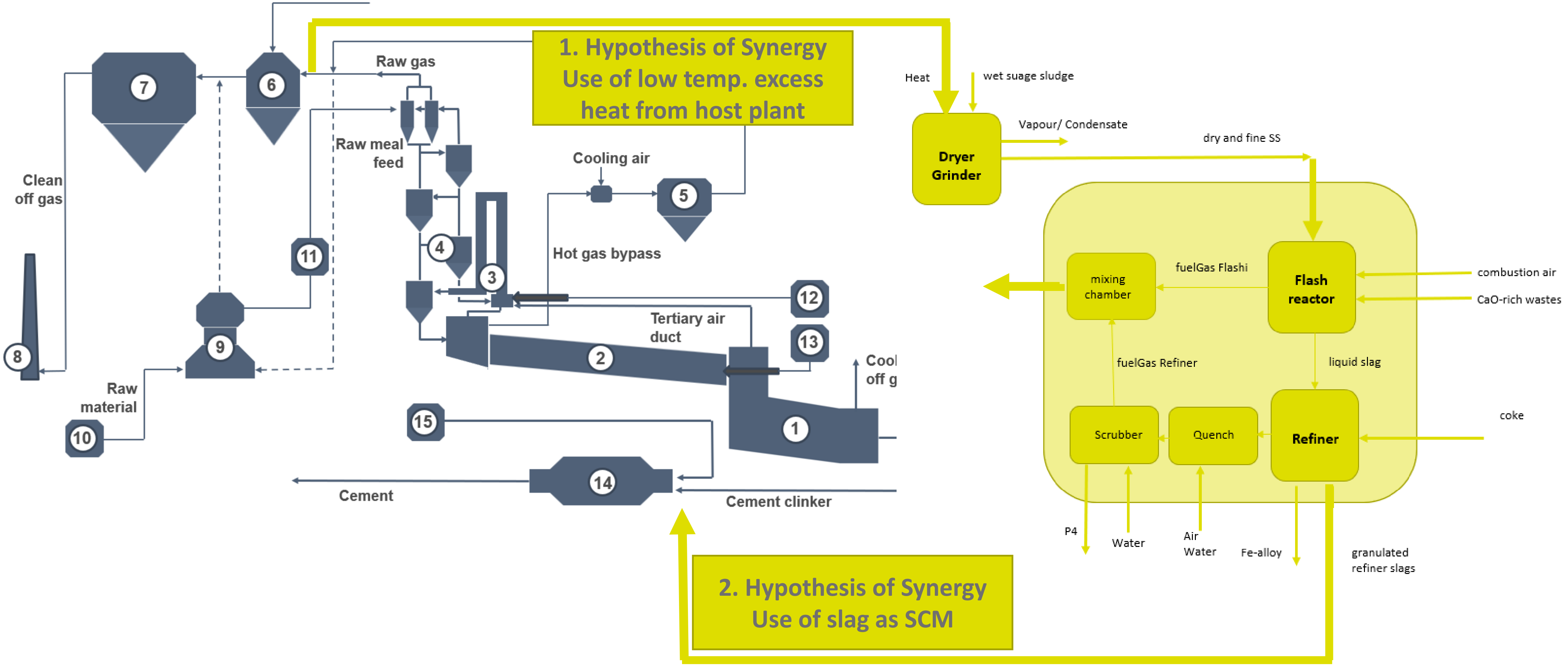

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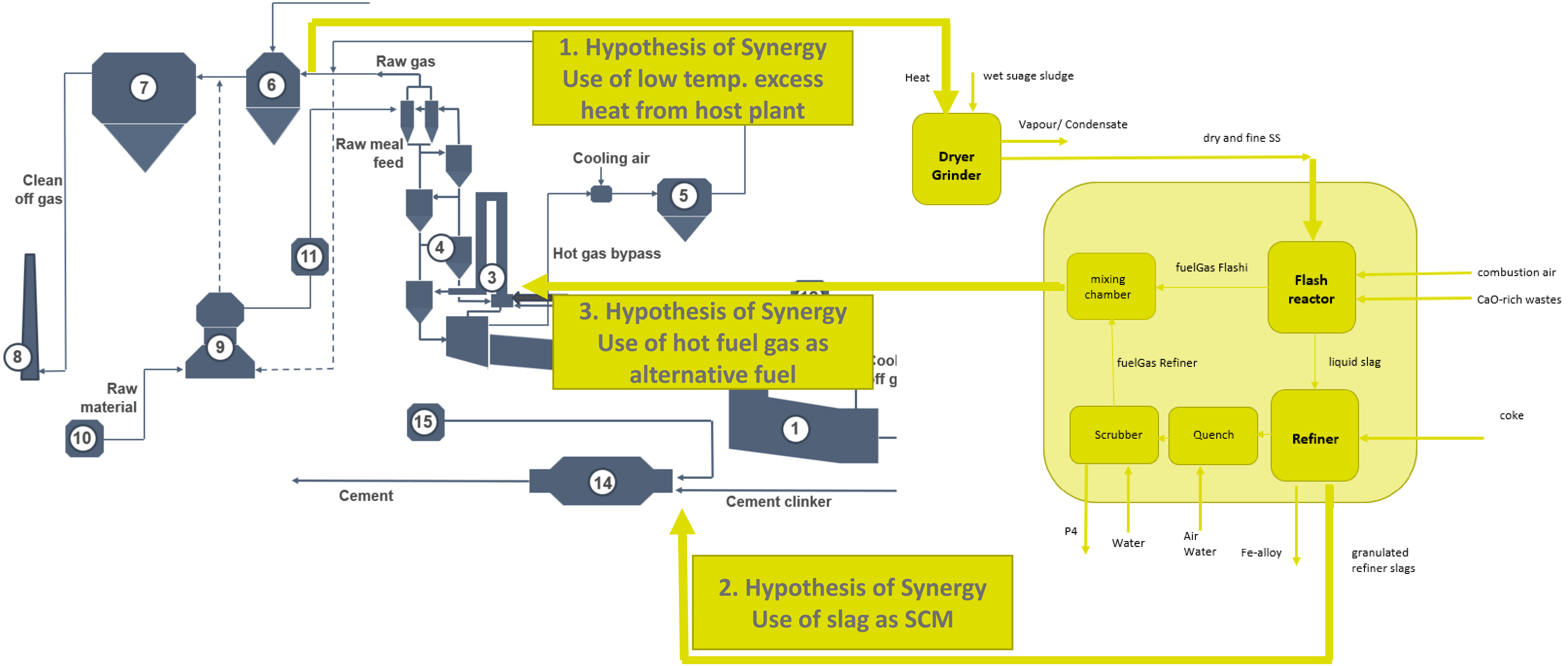

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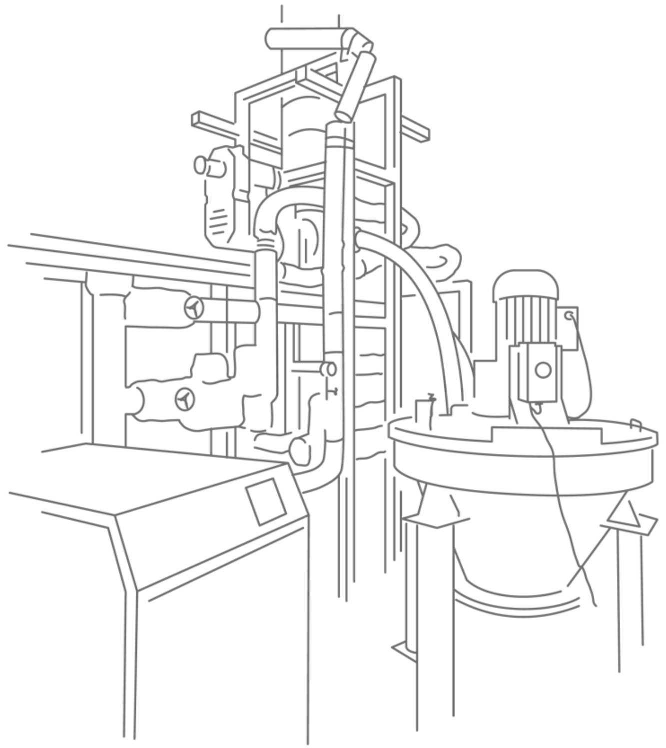
1. Hypothesis of Synergy

“Utilisation of low temperature excess heat to dry sewage sludge”

- Drying wet sewage sludge centrally at a host plant faces big challenges
  - High shipping effort due to 75 wt. % of water in the SS
  - Sludge drying and storage requires a lot of space in a host plant
  - The excess heat is not sufficient to dry all the required sewage sludge
  - Treatment of contaminated vapor or condensate necessary



Drying is recommended to be carried out on a hybrid drying concept in smaller units, e.g. some at the sewage treatment plants and some at the host plant

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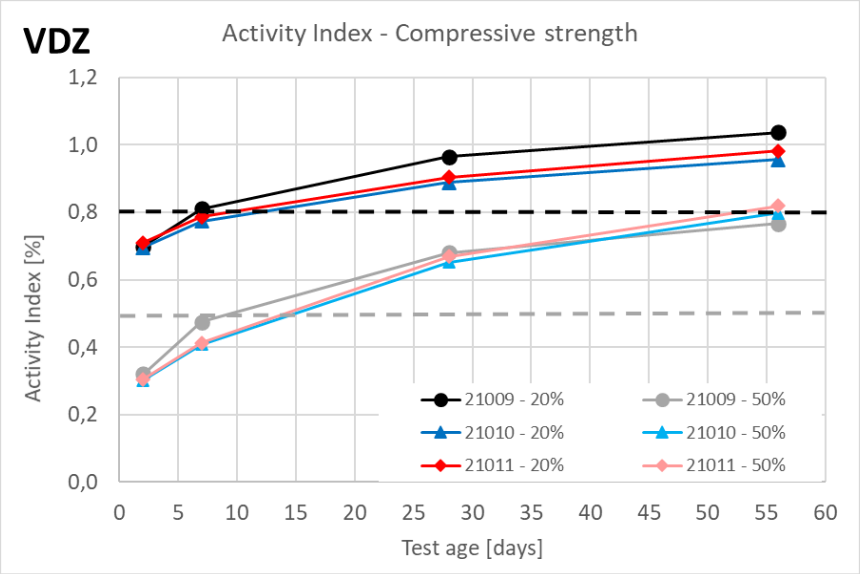
2. Hypothesis of Synergy

FLASHPHOS

“FlashPhos slags can be used as SCM in cement production”

- Investigations on cementitious properties of FlashPhos slag in WP3.4 show that it is likely to be suitable for use as SCM. Its grindability, reactivity an strength development in mortars are **comparable to GGBS**
- Using FlashPhos slags as SCM, **requires REACH** registration at the European Chemical Agency. This is very time-consuming and expensive.
- The use of slag as an alternative and **CO_2-free raw material** is not subject to any strict conditions



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2. Hypothesis of Synergy

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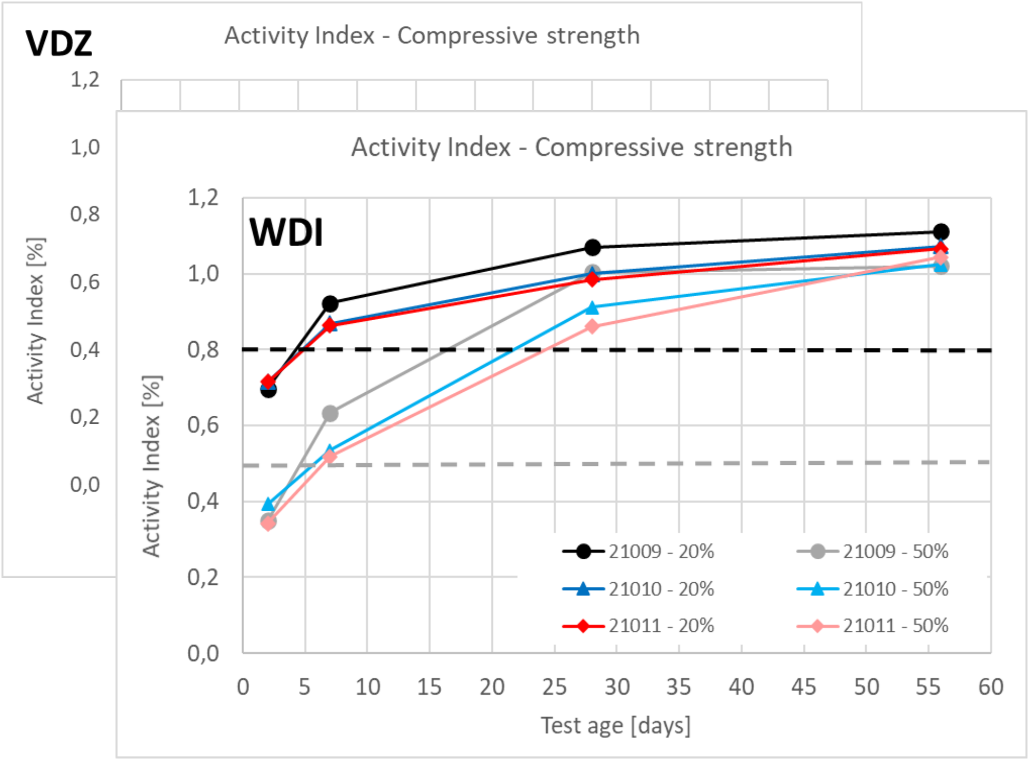

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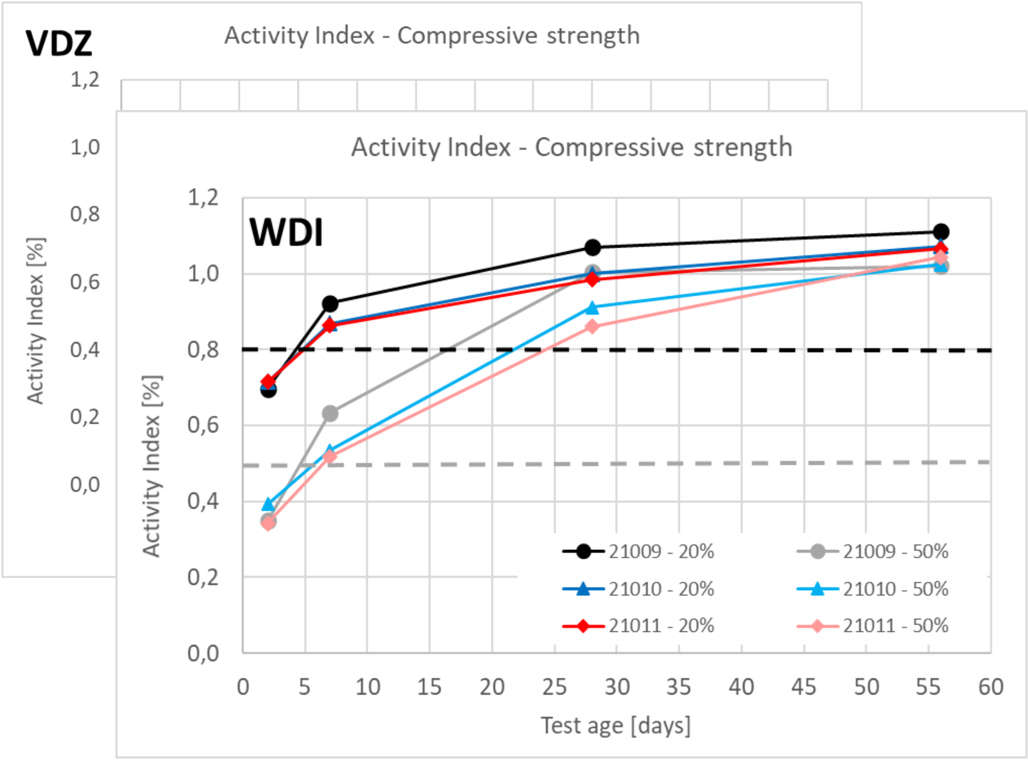
FlashPhos slags show great potential to be suitable as a SCM in slag cements to reduce clinker faktor



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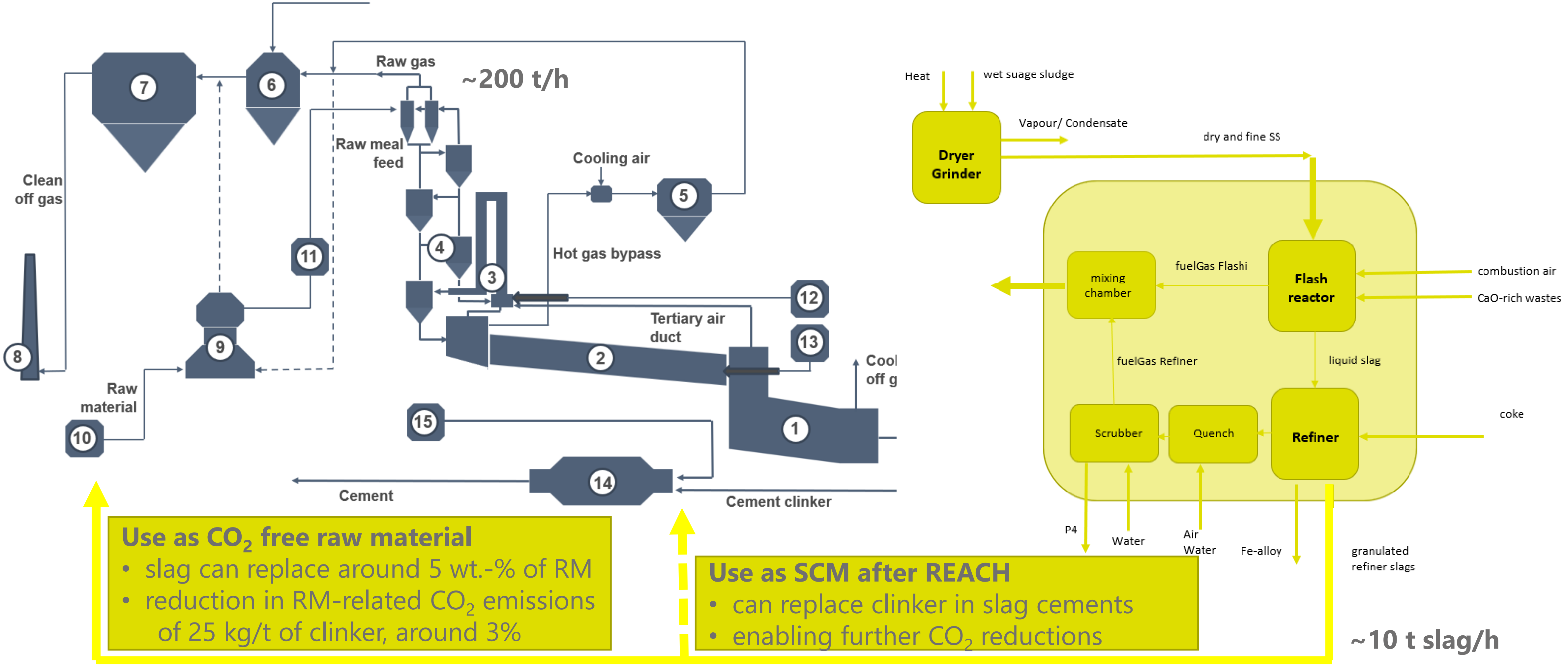
2. Hypothesis of Synergy

FLASHPHOS



Use as CO_2 free raw material
- slag can replace around 5 wt.-% of RM
- reduction in RM-related CO_2 emissions of 25 kg/t of clinker, around 3%

Use as SCM after REACH
- can replace clinker in slag cements
- enabling further CO_2 reductions

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vdz

3. Hypothesis of Synergy

“FlashPhos fuel gas can substitute conventional fuels”

- Feeding FlashPhos fuel gases into the calciner can substitute conventional calciner fuels
- The larger the FlashPhos system, the greater the volume of fuel gases
  - Higher gas volumes, higher gas velocities, less heat exchange, higher energy loss
  - Higher energy demand means more fuel consumption and an increase of CO_2 emissions
- Increase of critical materials input into the cement plant (Cl, S, Hg)

FlashPhos Business Case		
P-Production	5000	t/a
	⇩	
Volumeflow fuel gases	~100.000	Nm³/h
Engery fuel gas	330-410 92-114	GJ/h MW
Massflow Slag (SCM)	~10	t/h

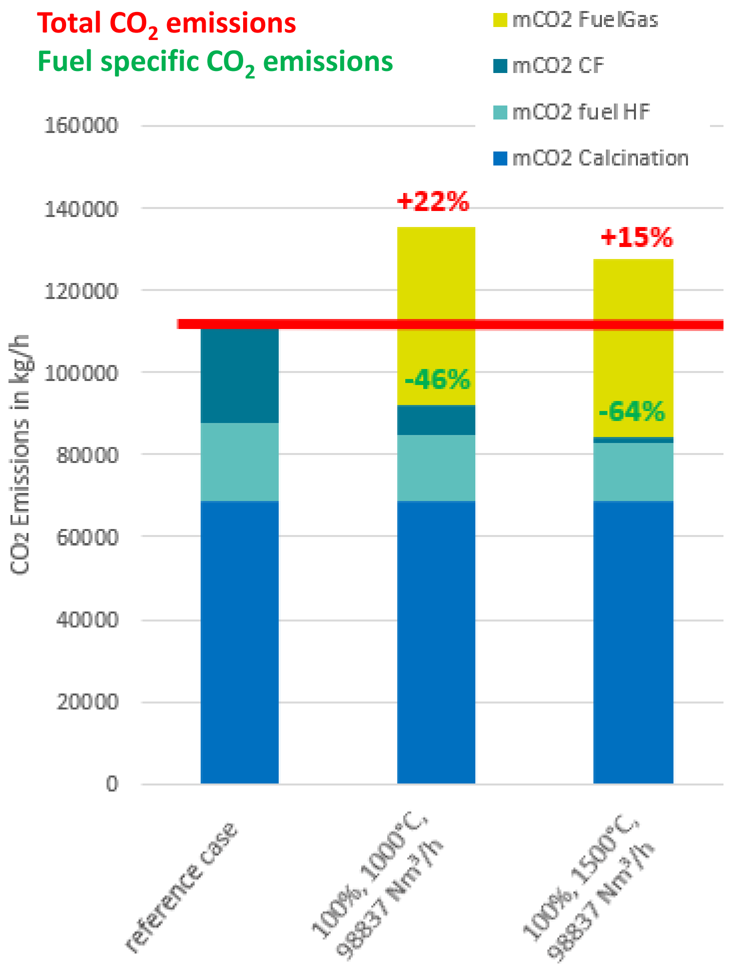
Integration can be technically successful, but
adjustments to the gas pathways and additional exhaust gas cleaning stages are required in the host plant

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958267.

3. Hypothesis of Synergy

- The thermal efficiency of process integration depends on the quality and quantity of the fuel gas to be integrated
- Increase in energy demand means more fuel consumption and an increase of CO_2 emissions.
- If the fuel gases from the FlashPhos process are considered renewable, the fuel-specific CO_2 emissions can be reduced significantly

The economic feasibility of FlashPhos integration therefore depends on the regulatory classification of energy generated from sewage sludge within the EU Emissions Trading System (EU ETS)



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FEED FlashPhos Scale-up – Impacts & Benefits

FLASHPHOS

Circular Economy

- Recovers phosphorus from sewage sludge
- Produces:
  - White phosphorus
  - CO_2-neutral slag (usable in cement)

→Turning waste into valuable resources

CO_2 Reduction Potential

- Process syngas replaces fossil fuels
- Reduction of fossil fuel CO_2 emissions
- Slag can substitute clinker (SCM)

→Supports decarbonisation of industrial process

Innovative Industrial Concept

- Combination of waste recycling, energy integration & material reuse
- Cross-industry potential

→Strong technical synergies with industrial proceses

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958267.

FEED FlashPhos Scale-up – Results, Challenges & Outlook

FLASHPHOS

Key Results

- FEED study of full scale-up FlashPhos plant
- Confirmation of technical feasibility
- Integration into cement process demonstrated
- Business case developed (AACE Class 3)

Key Challenges

- Integration into existing plants is complex
- Full-scale integration is very plant specific – adaptations to specific sites needed

Path Forward:

- Alternative Modular & flexible plant concepts
- Optimisation and adaptation of drying & grinding concepts
- Further optimisation of energy demand
- Exploration of different host industries

Promising circular & low-carbon technology

Clear pathway torwards industrial deployment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958267.

The complete thermochemical
recycling of sewage sludge

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EU Project FlashPhos @FlashPhos

A Member of LOESCHE Family

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

Building Applications of By-Products

Elise François

ResourceFull

21/04/2026

RESOURCEFULL

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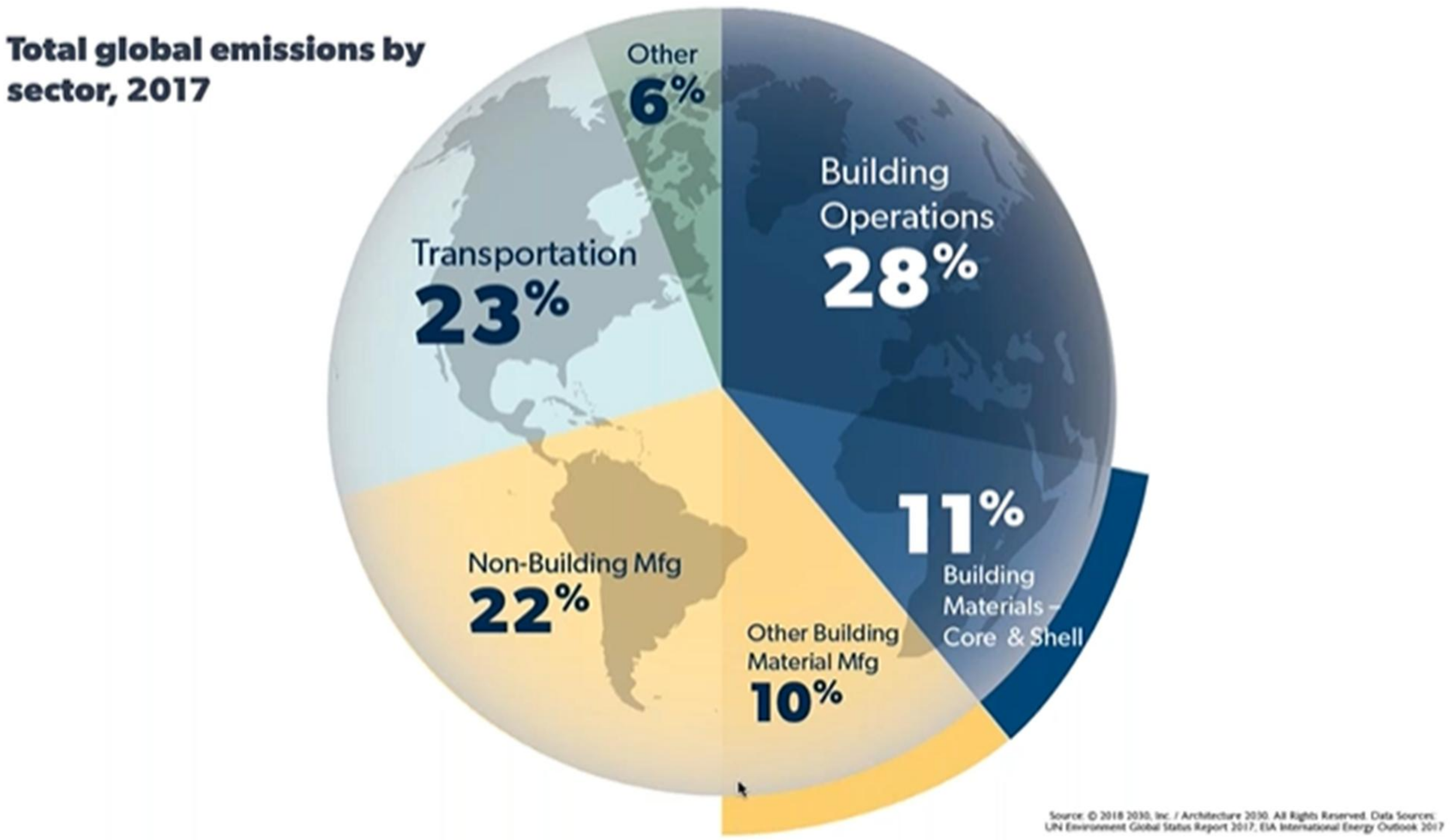
Introduction



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RESOURCEFULL

Introduction

Most used man-made material in the world

12.500.000.000 m^3 per year

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Most used man-made material in the world

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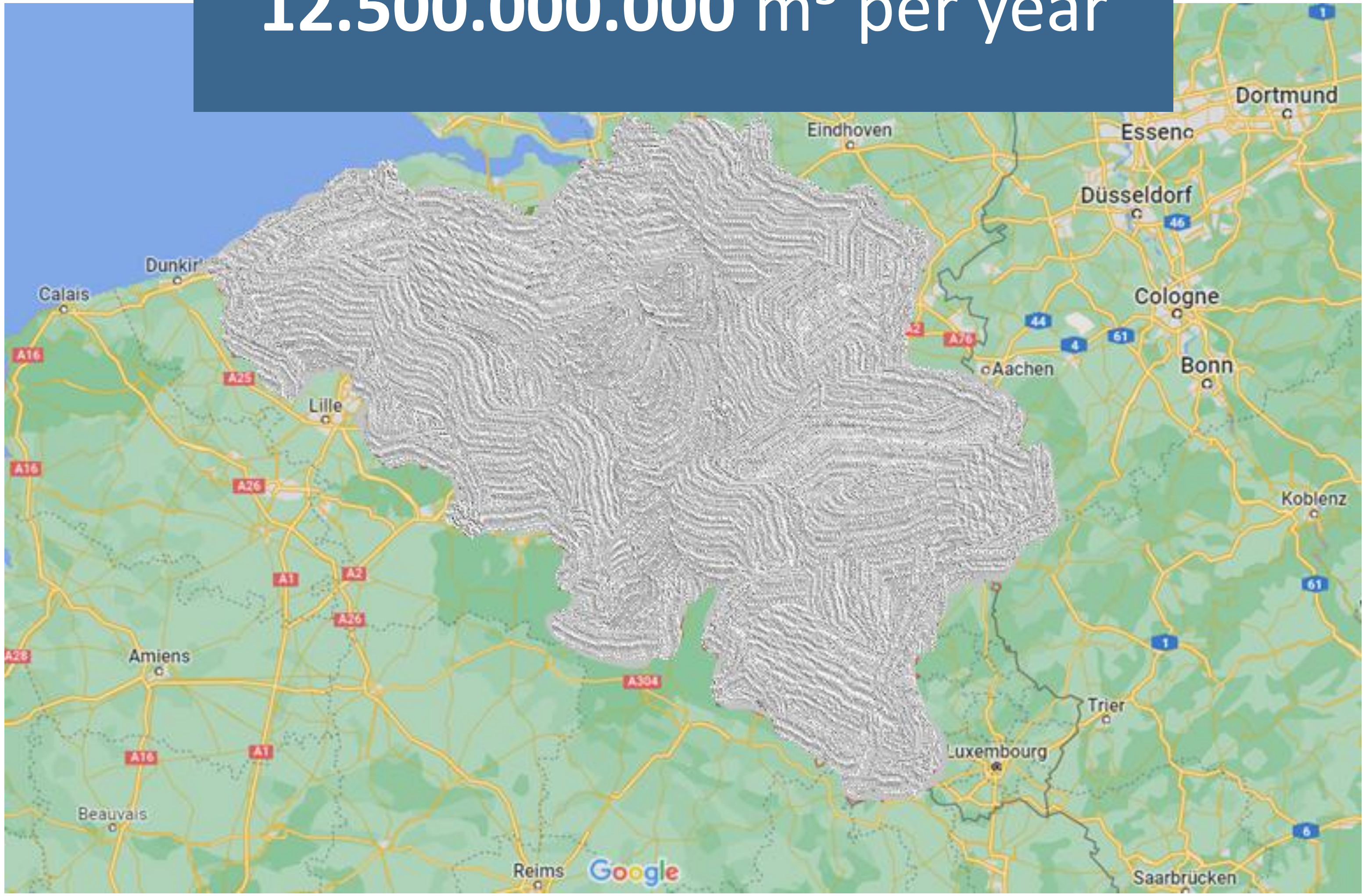

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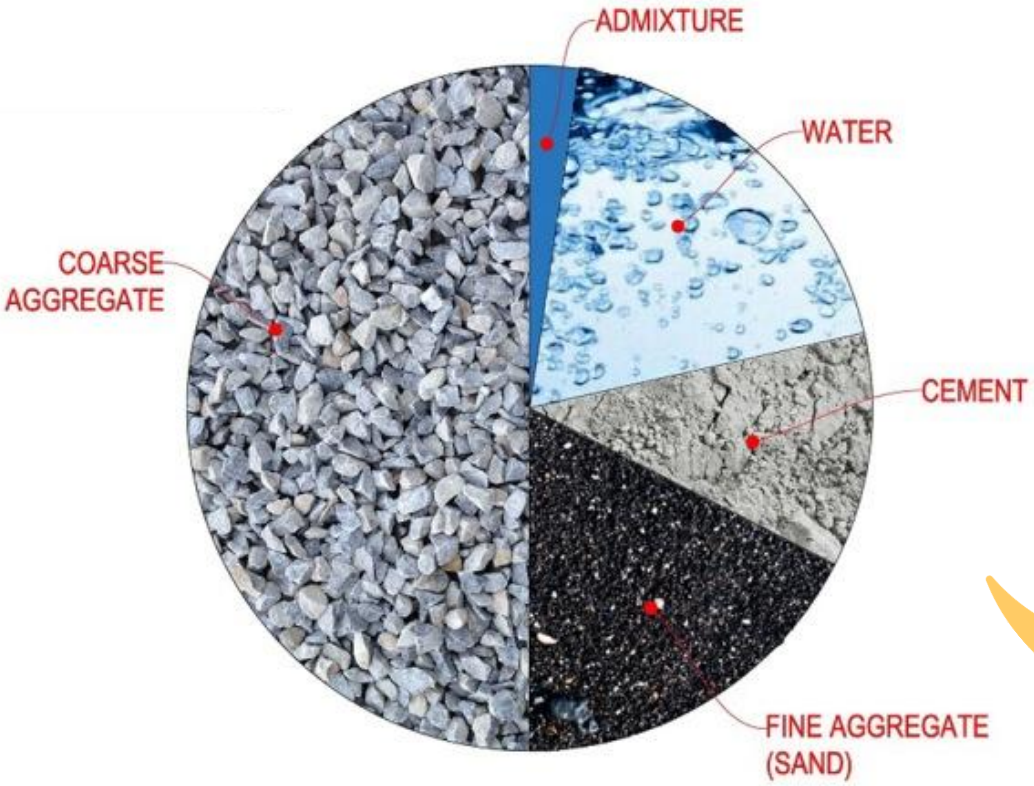
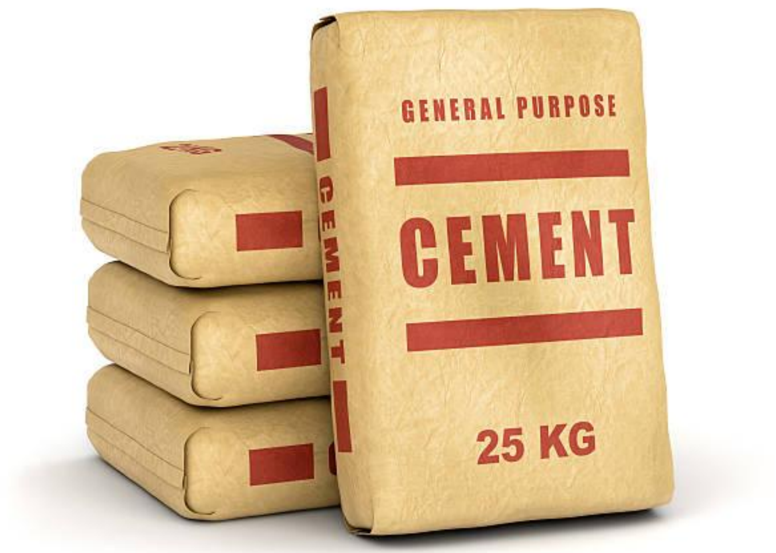
Introduction

Concrete ⟷ Cement





8 % of global CO_2 emissions

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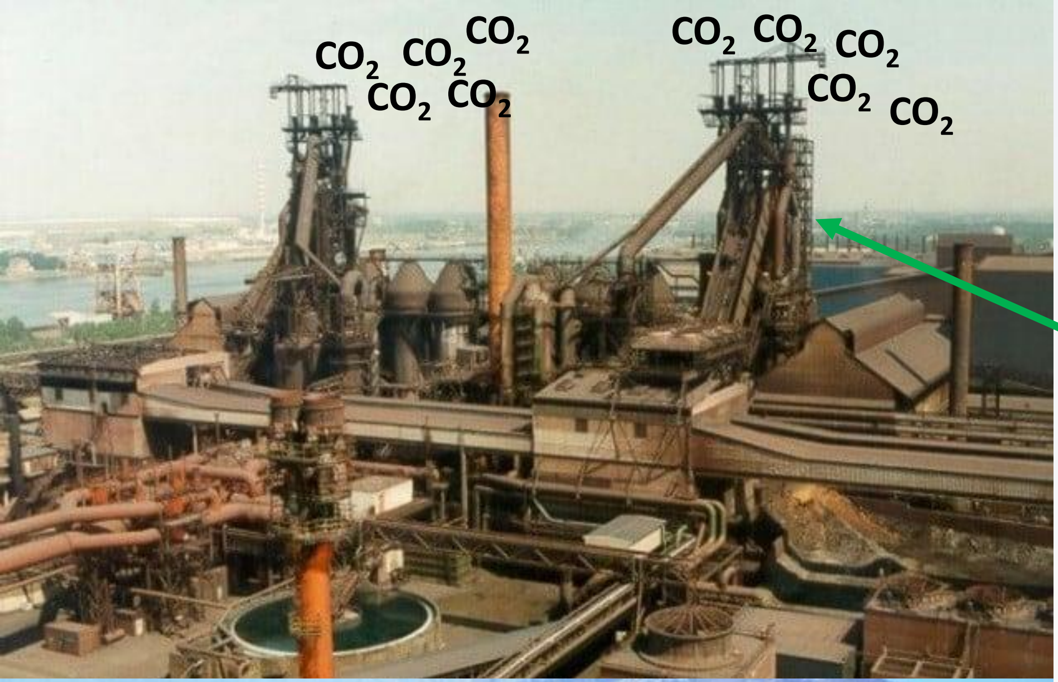
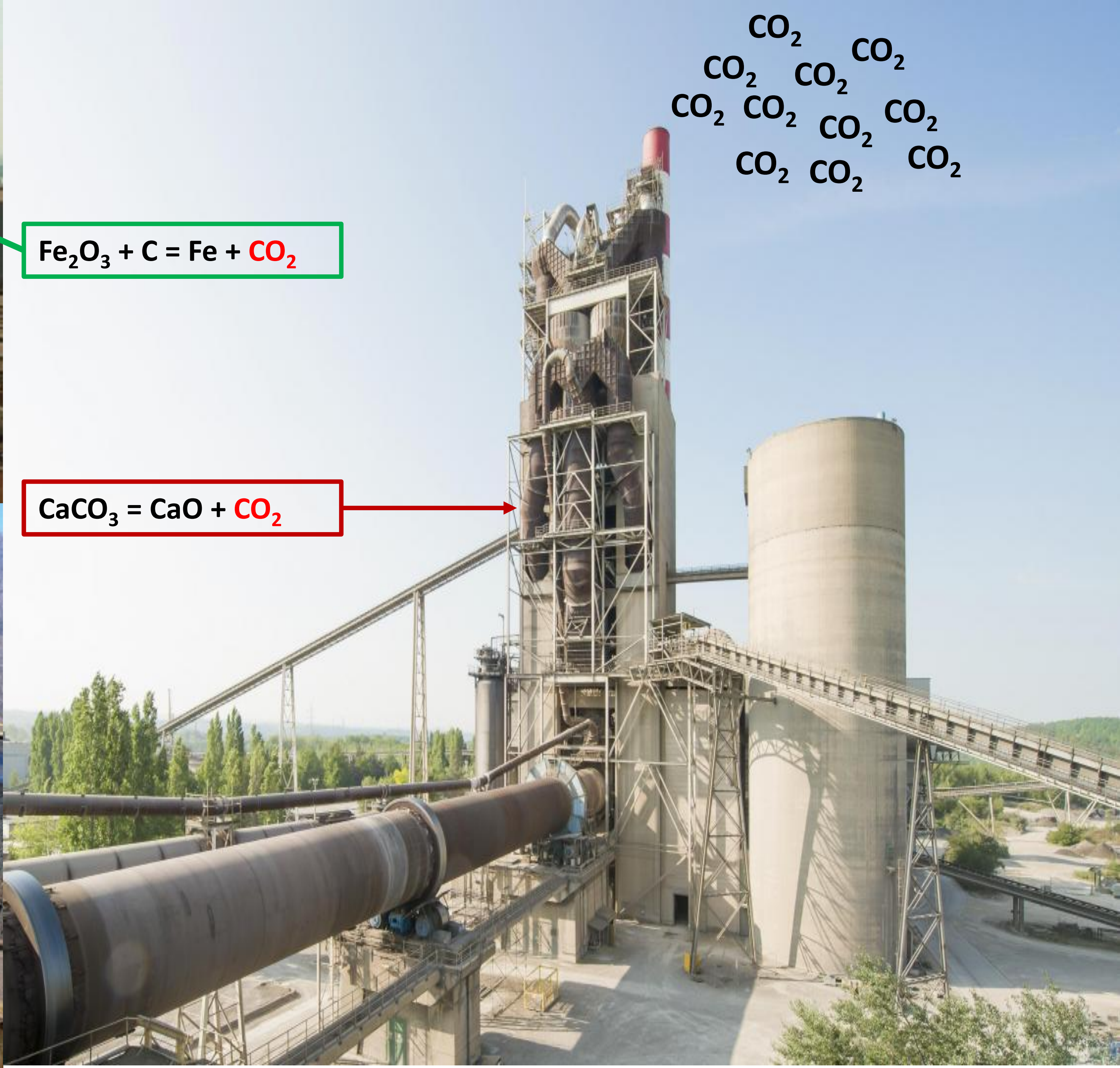


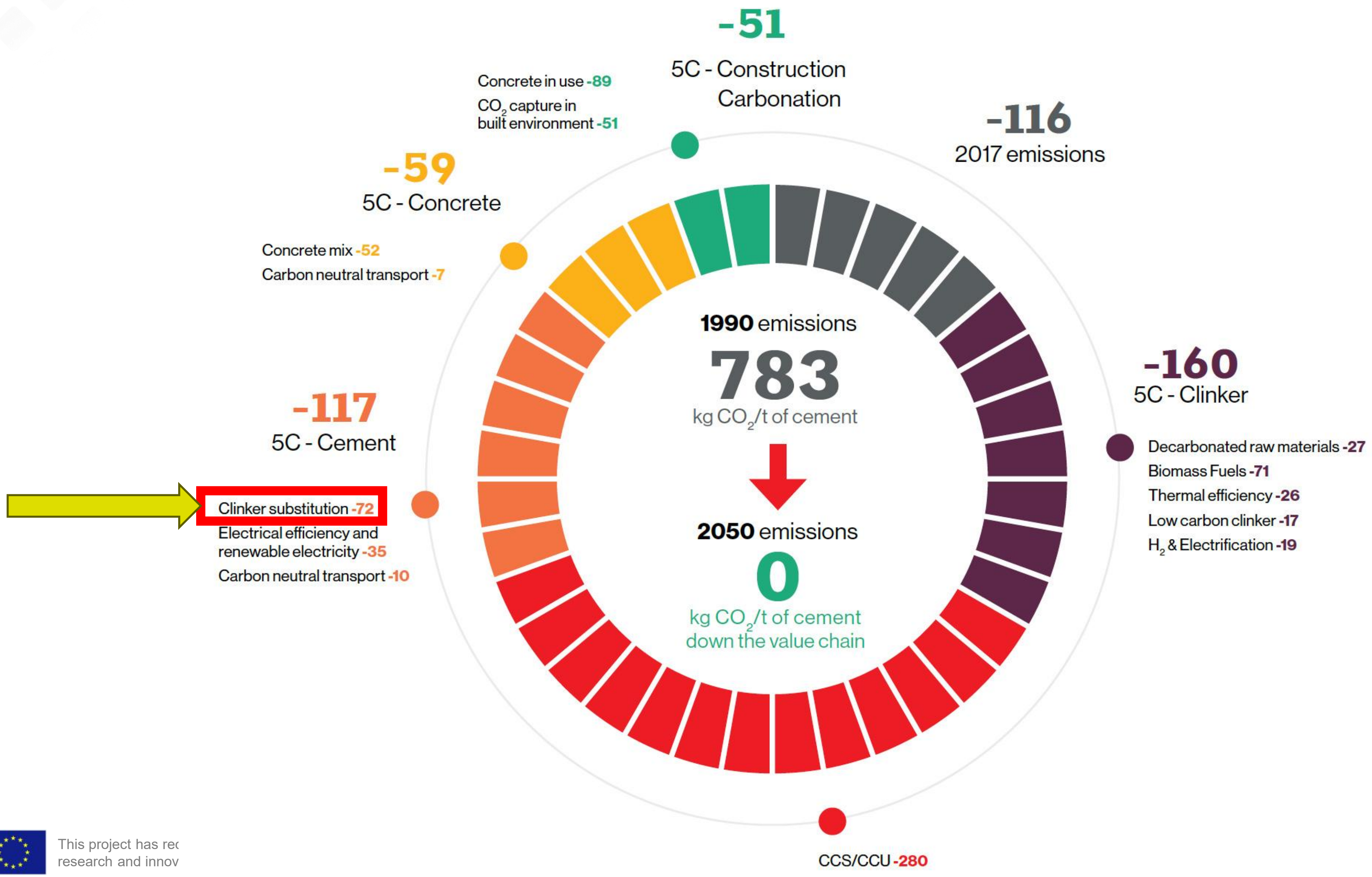
$Fe_2O_3 + C = Fe + CO_2$

$CaCO_3 = CaO + CO_2$



Introduction

FLASHPHOS



This project has rec
research and innov

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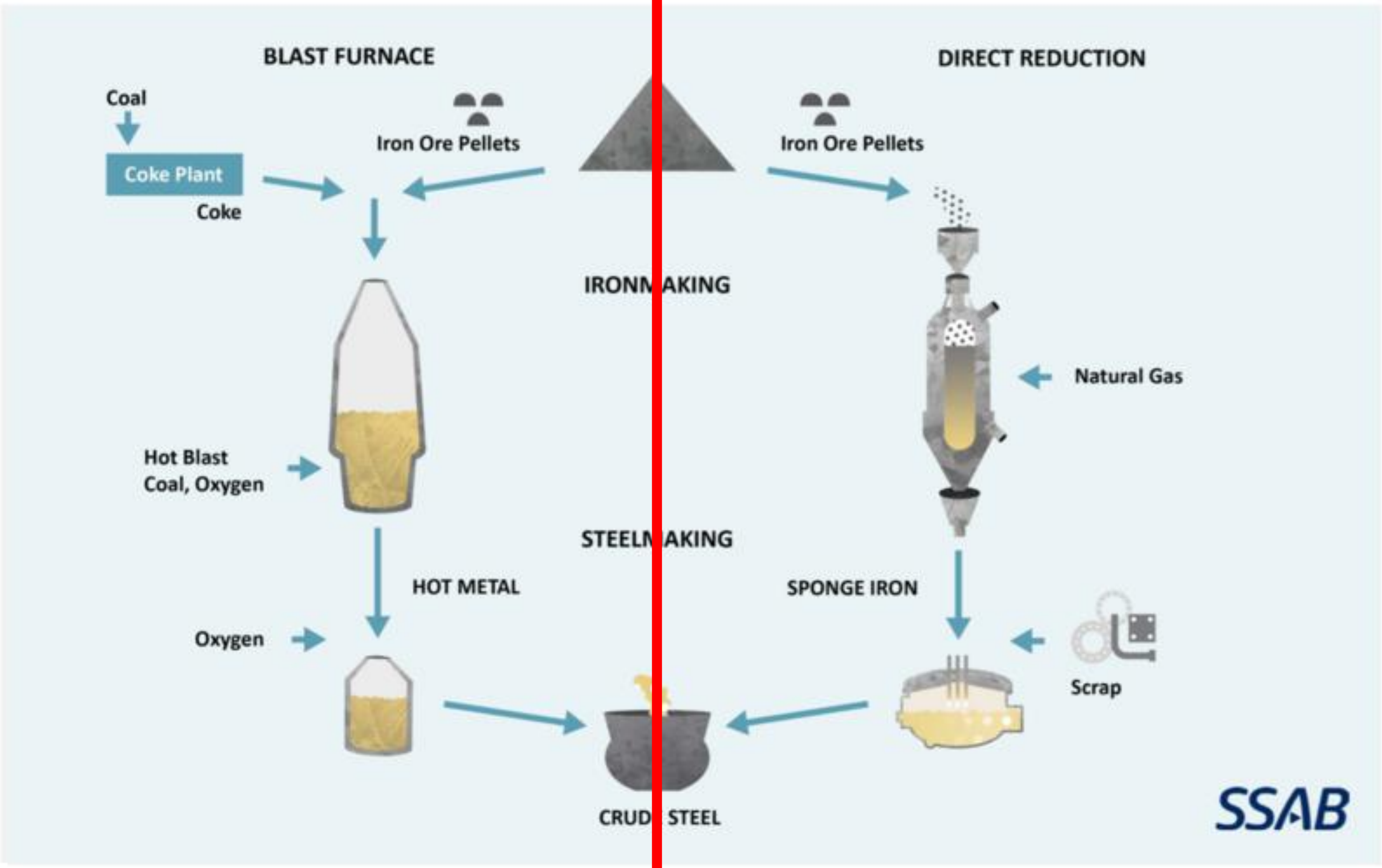
Introduction

$Fe_2O_3 + C = Fe + CO_2$

current flowsheet | **Future flowsheet**

$Fe_2O_3 + H_2 = Fe + H_2O$



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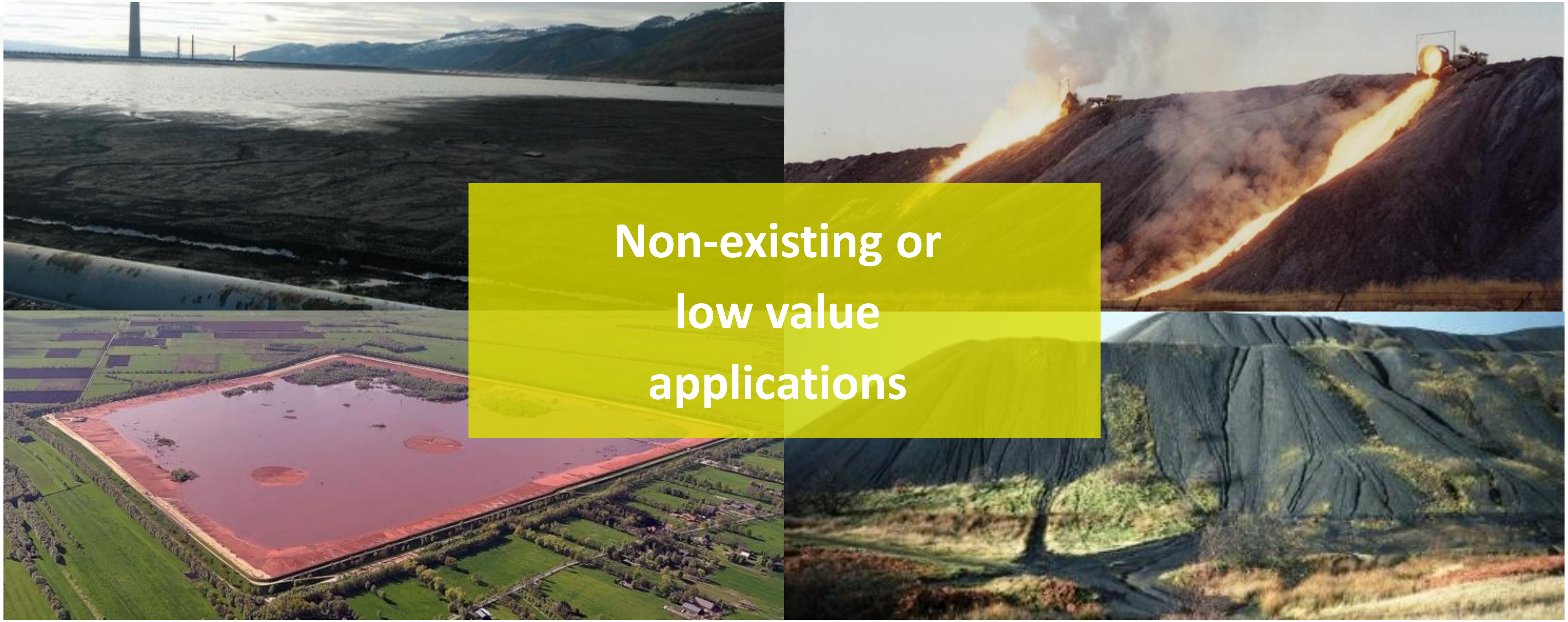
Metallurgical residue waste piles



Non-existing or low value applications

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Supplementary cementitious materials

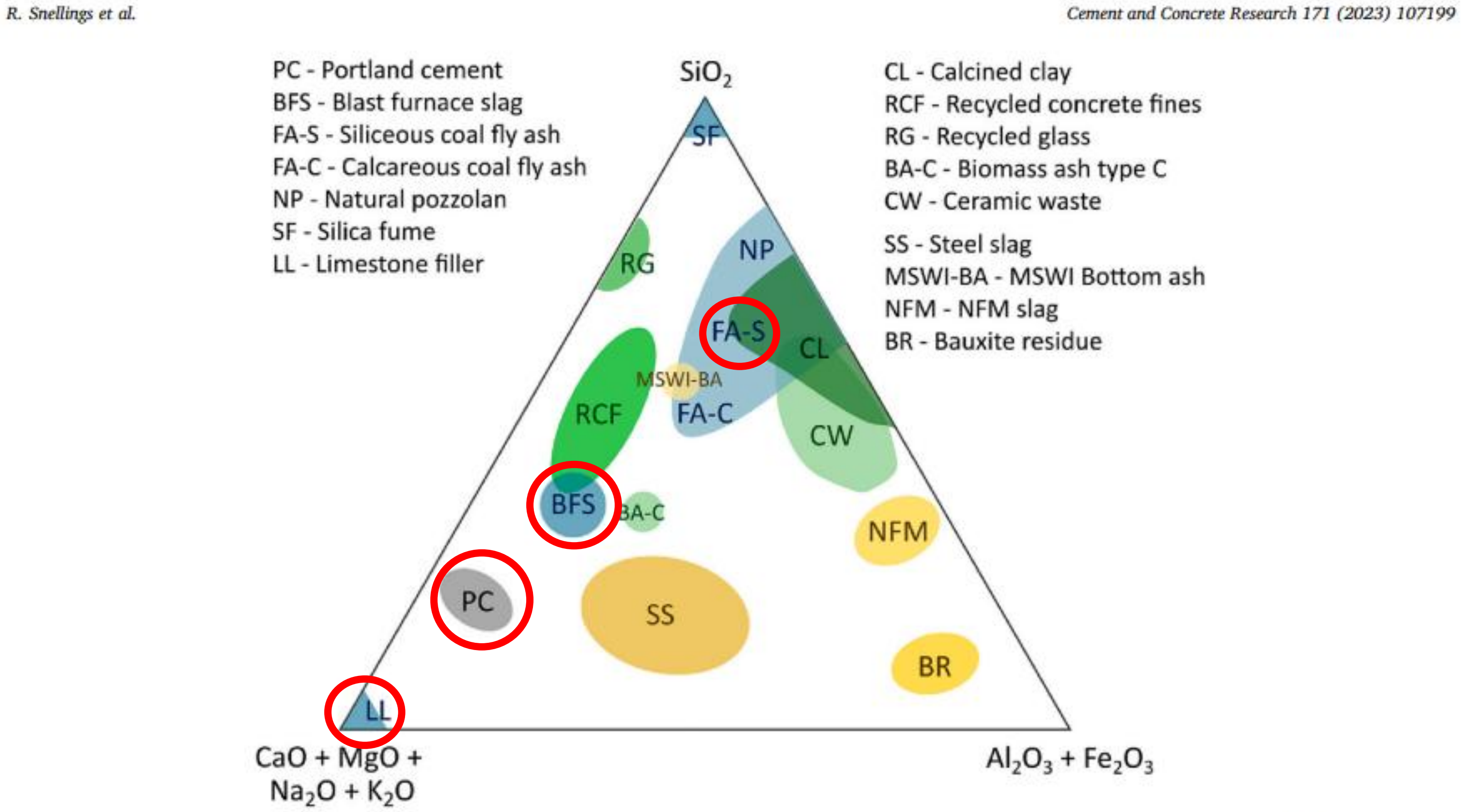

Fig. 1. The chemical composition ranges of common, emerging and future SCMs in a ternary diagram of (earth)alkalis–silica–alumina/iron oxide (in wt%). NFM stands for "non-ferrous metallurgical", MSWI for "municipal solid waste incineration". Commonly used SCMs and fillers are in green shades and emerging SCM sources are in yellow shades. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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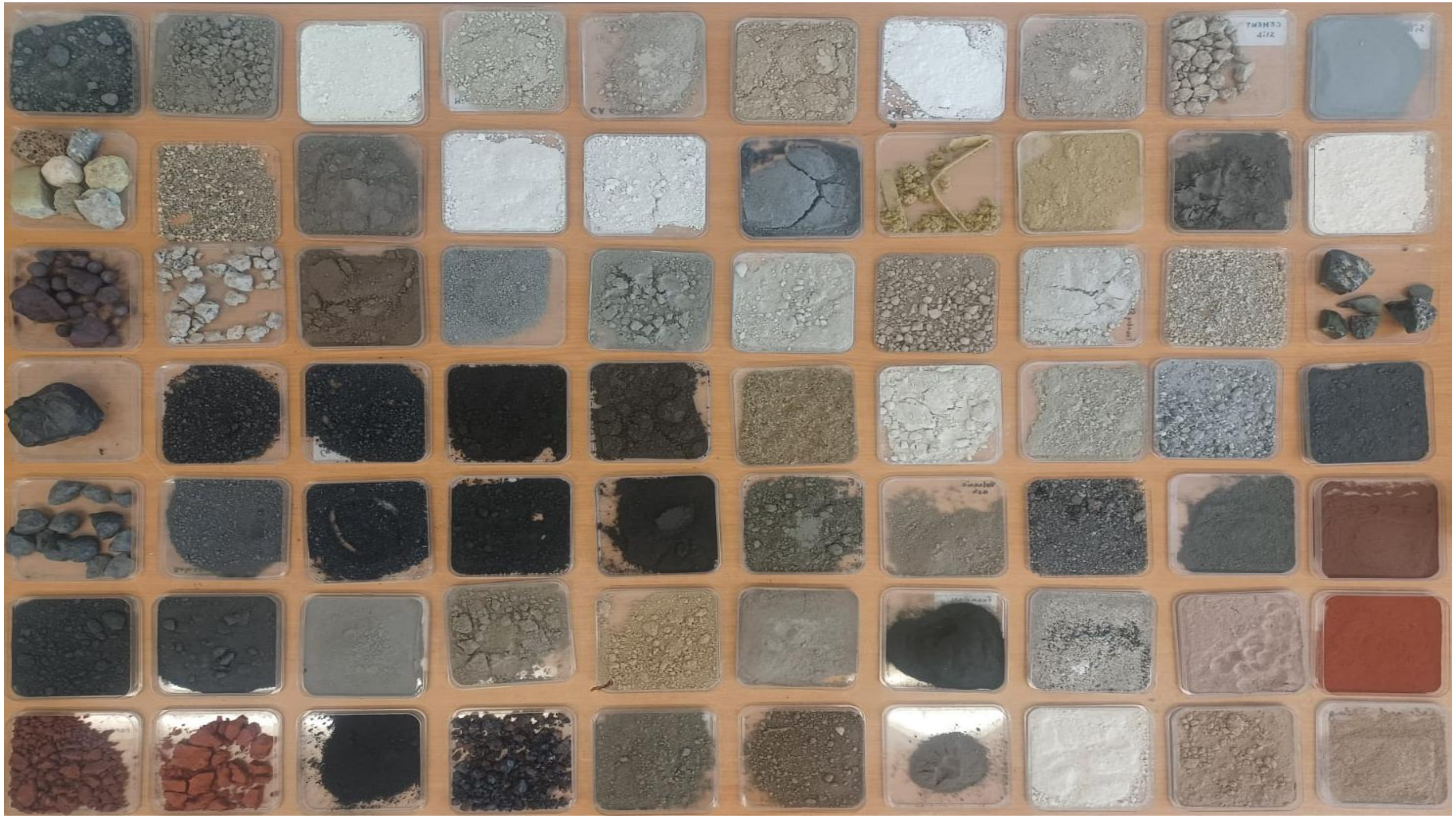
Secondary streams



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Your engineering partner for low carbon concrete

1

Pre-treatment and analysis

Chemical analysis
Mineral analysis
Crushing/grinding
Sizing and seperation
Thermal processing

2

Binder development

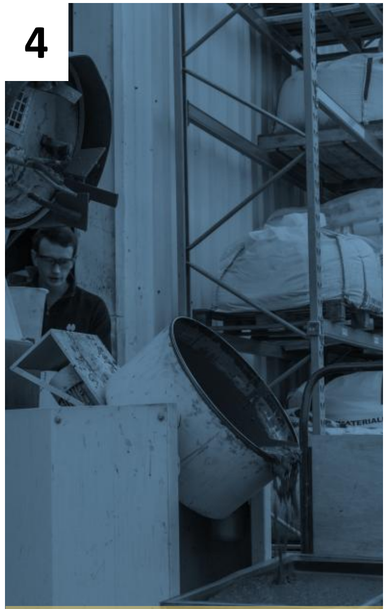
Alkali activation
Cement replacement
Acid activation
Carbonatation
Mg-cement
Ceramics

3

Product development

3D-printing mortar
Acid resistant mortar
Floor screed
Ready-mix concrete
UHPC
Bricks

4



Performance testing

Aggregate testing
Workability
Strength testing
Freeze-Thaw
Carbonatation

5

Scale - up

Industrial implementation
LCA
Waste legislation
Building legislation

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FlashPhos slag

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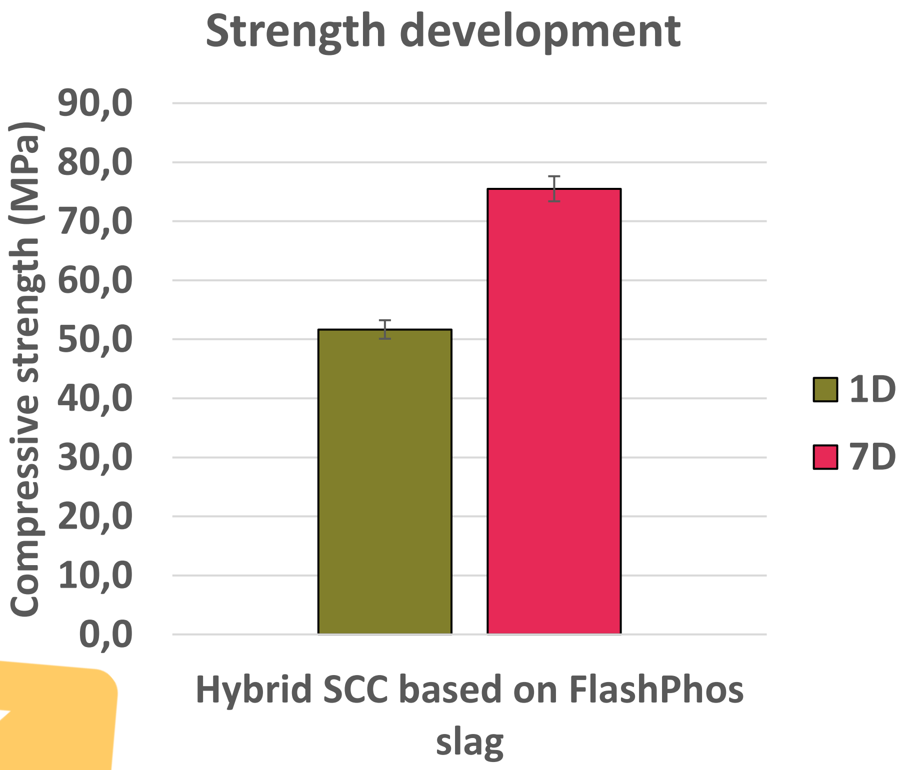
research and innovation programme under grant agreement No
rtners

Concrete development

- Hybrid self-compacting concrete based on FlashPhos slag with excellent strength development



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Concrete development

- Supersulfated masonry bricks based on FlashPhos slag with excellent strength development (> 15 MPa at 7D)

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Future of FlashPhos slag → Hybrid structural staircase

research and innovation programme under grant agreement No 958267.

Future of FlashPhos slag → supersulfated vibro-pressed industrial plates

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Future of FlashPhos slag → Geopolymer products

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67.

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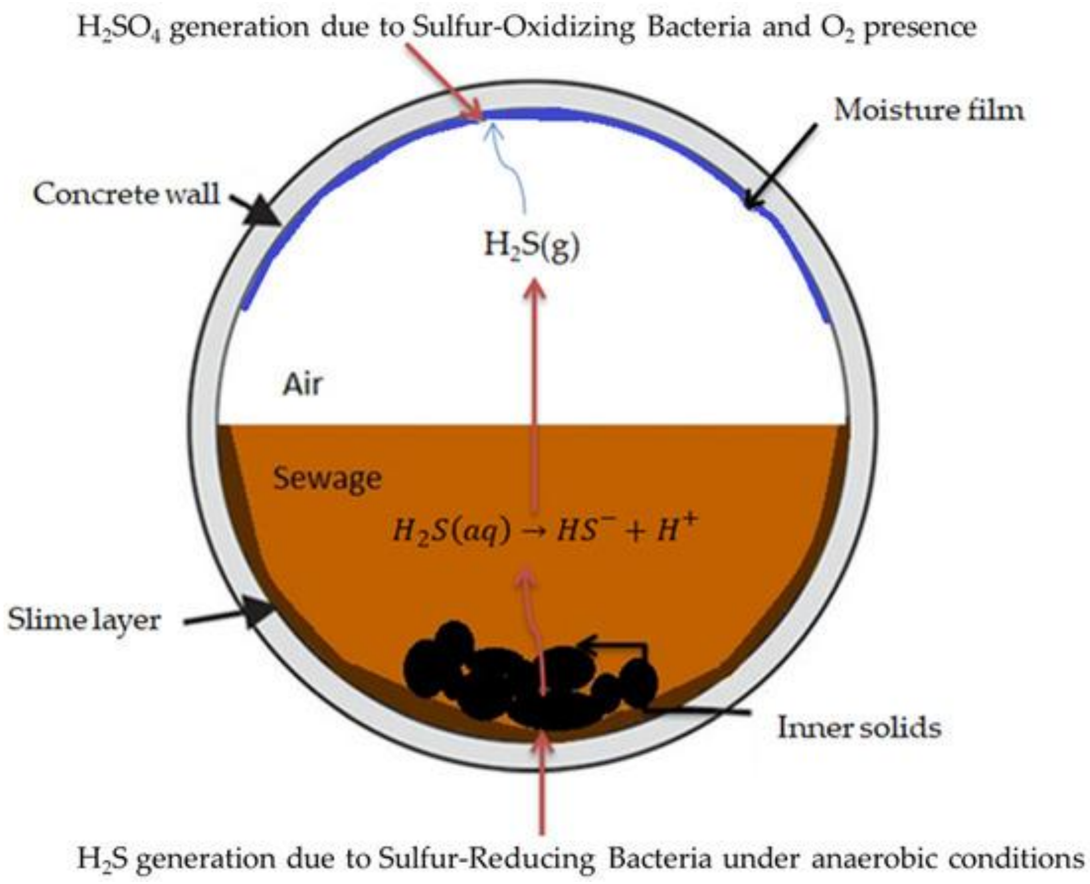
Future of FlashPhos slag → Geopolymer products
Acid resistant sewage pipes



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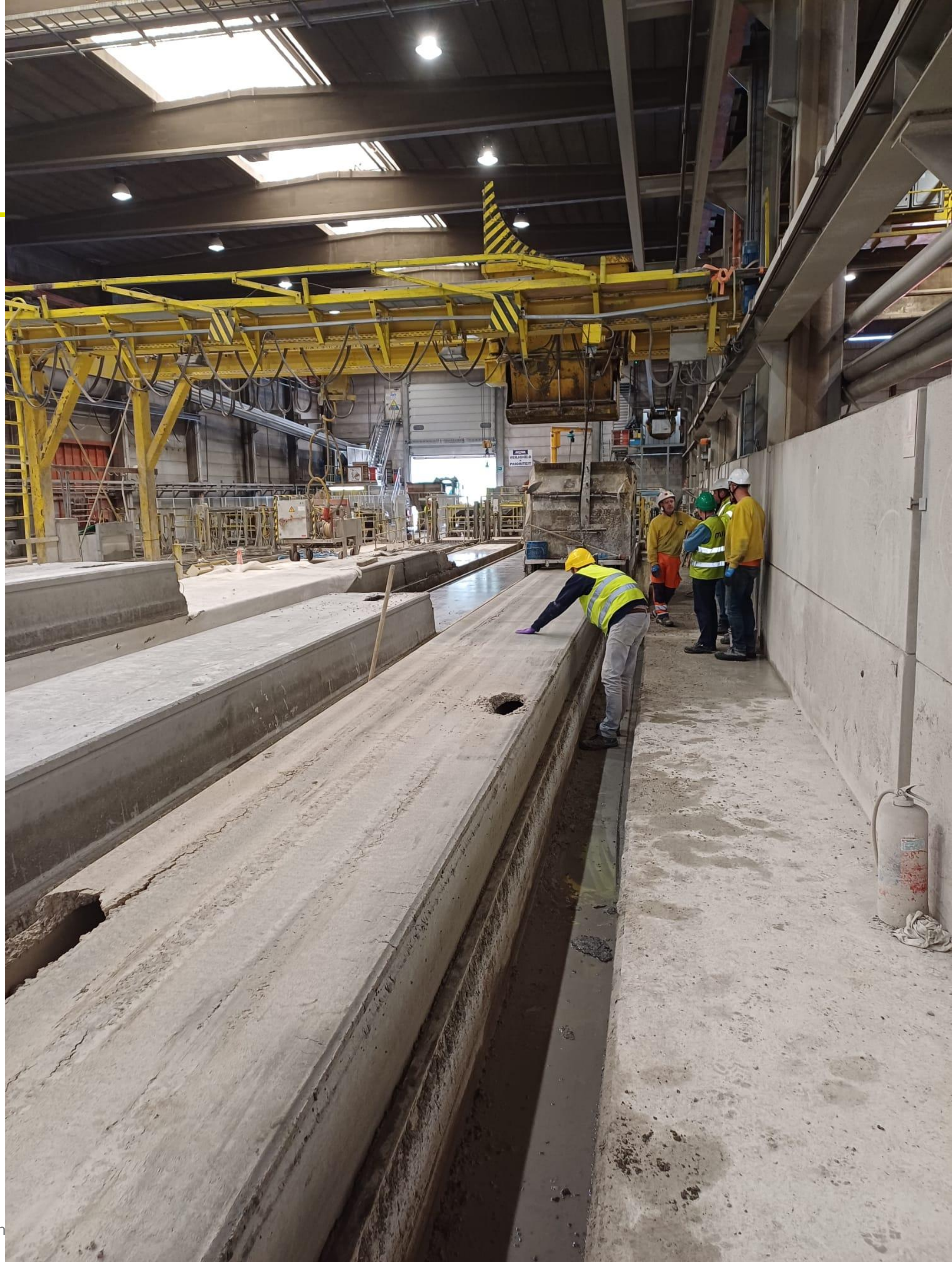
Future of FlashPhos slag → Geopolymer products
Hollow cores



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Conclusion and prospective

- We believe that the slag coming from the FlashPhos process is a versatile and high-performing material, suitable for use across a broad spectrum of cement types and applications
  - The chemistry and fineness allow for **high reactivity** and the incorporation of lower-value by-products or fillers
  - Due to the **white colour** and reactivity, the slag will experience greater acceptance by the market than other secondary raw materials
  - The slag shows a **significantly lower environmental impact** than Ordinary Portland Cement with similar performance, making it attractive for further endeavors to reduce the ecological footprint of building products

- More to come…

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FLASHPHOS

The complete thermochemical
recycling of sewage sludge

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EU Project FlashPhos

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

FlashPhos Life Cycle Assessment

Encarni Muñoz

INERCO Engineering, Technology and Consultancy, S.A.

April 21st, 2026

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TABLE OF CONTENT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958267.

1. OBJECTIVES OF THE LCA IN THE FLASHPHOS PROJECT

FLASHPHOS

Demonstrate the environmental benefits of FlashPhos against existing solutions for production of phosphorus

OBJECTIVES

Optimizing the FlashPhos project design from an environmental perspective using the concept of Life Cycle Thinking (LCT) approach

ACTIONS TO ACHIEVED THE OBJECTIVES

1. Identification of key environmental impacts (initial screening)
2. LCA for FlashPhos
3. Comparison to conventional production process

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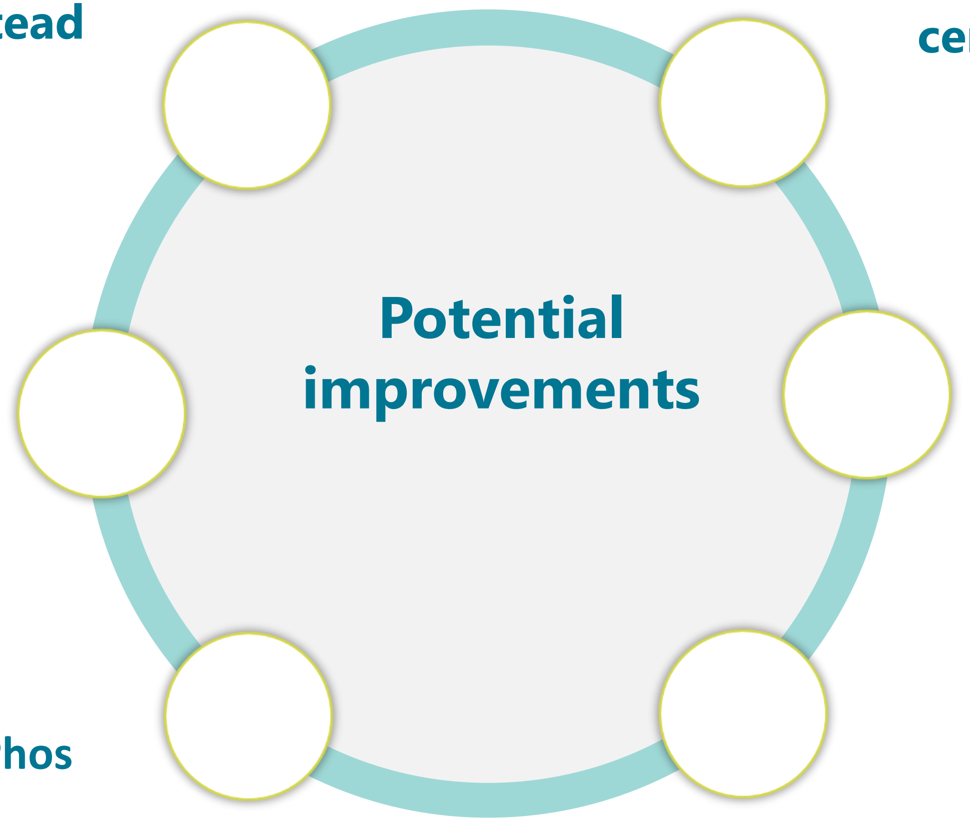
2. OPTIMISING THE PROCESS FROM THE ENVIRONMENTAL POINT OF VIEW

Use of alternative reducing agent instead of coke in refiner

Use of refiner slag in cement plant



Heat recovery from Waste Water Treatment Plant (WWTP)

Impact of syngas use in cement plant

Alignment of FlashPhos concept with EU environmental policies

Future improvements due to technology developments

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3. SCENARIOS ANALYSED AND WHY

Scenario 1

FlashPhos process
No integration

Scenario 2

FlashPhos process
Integrated into a cement plant

Scenario 3

FlashPhos process
Integrated and dryer grinder decarbonisation

Scenario 4

FlashPhos process
Integrated, dryer grinder decarbonisation and renewable electricity

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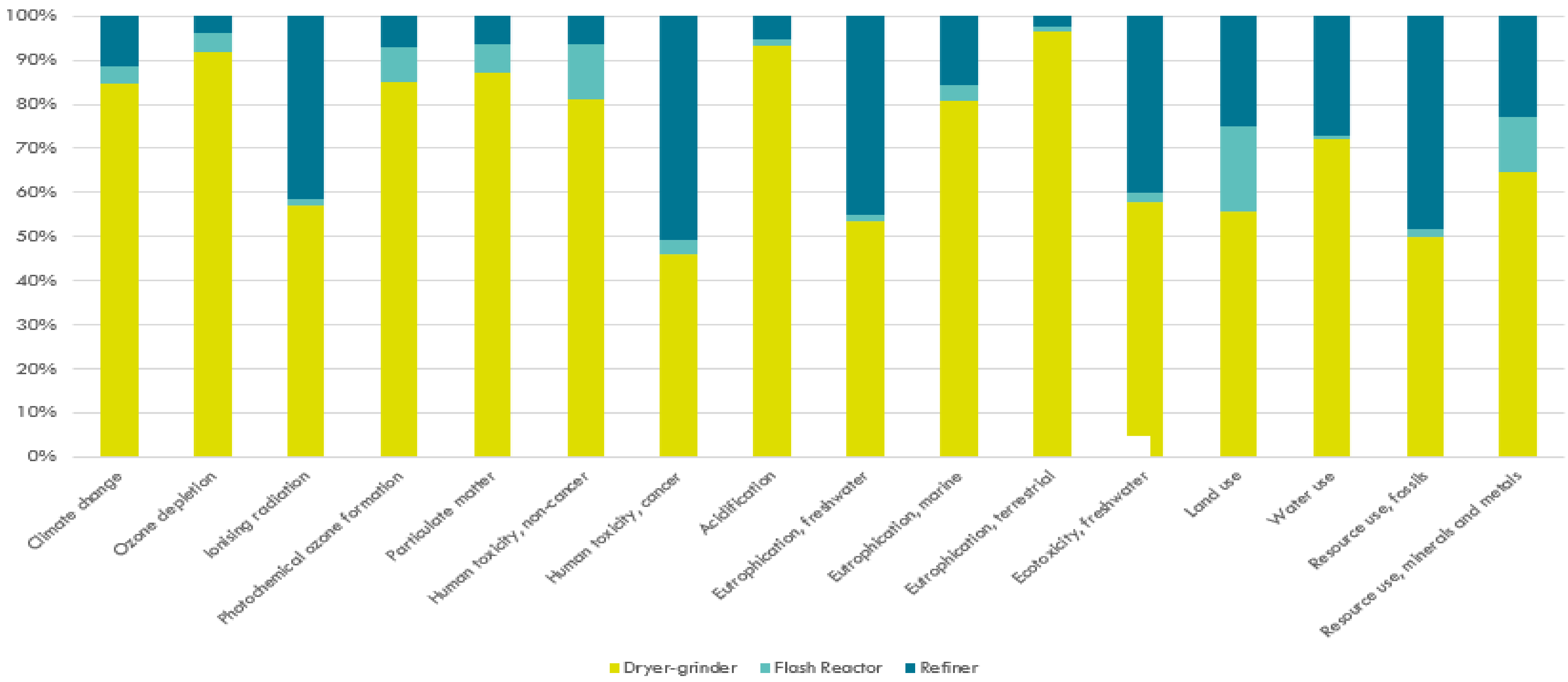
4. RESULTS OF THE LCA



FlashPhos LCA results scenario 1 (%)

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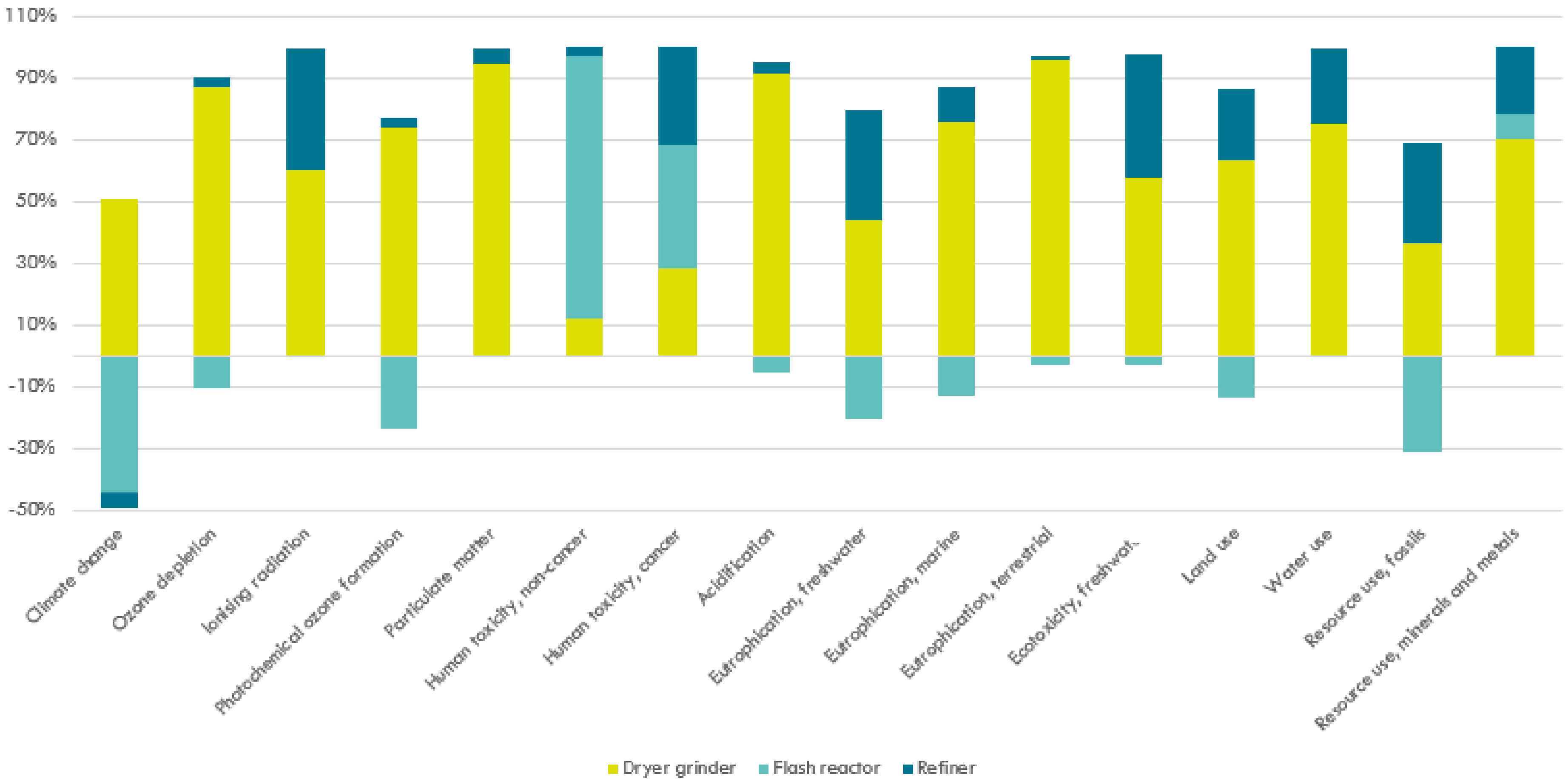

Figure 7. FlashPhos scenario 2 (%)

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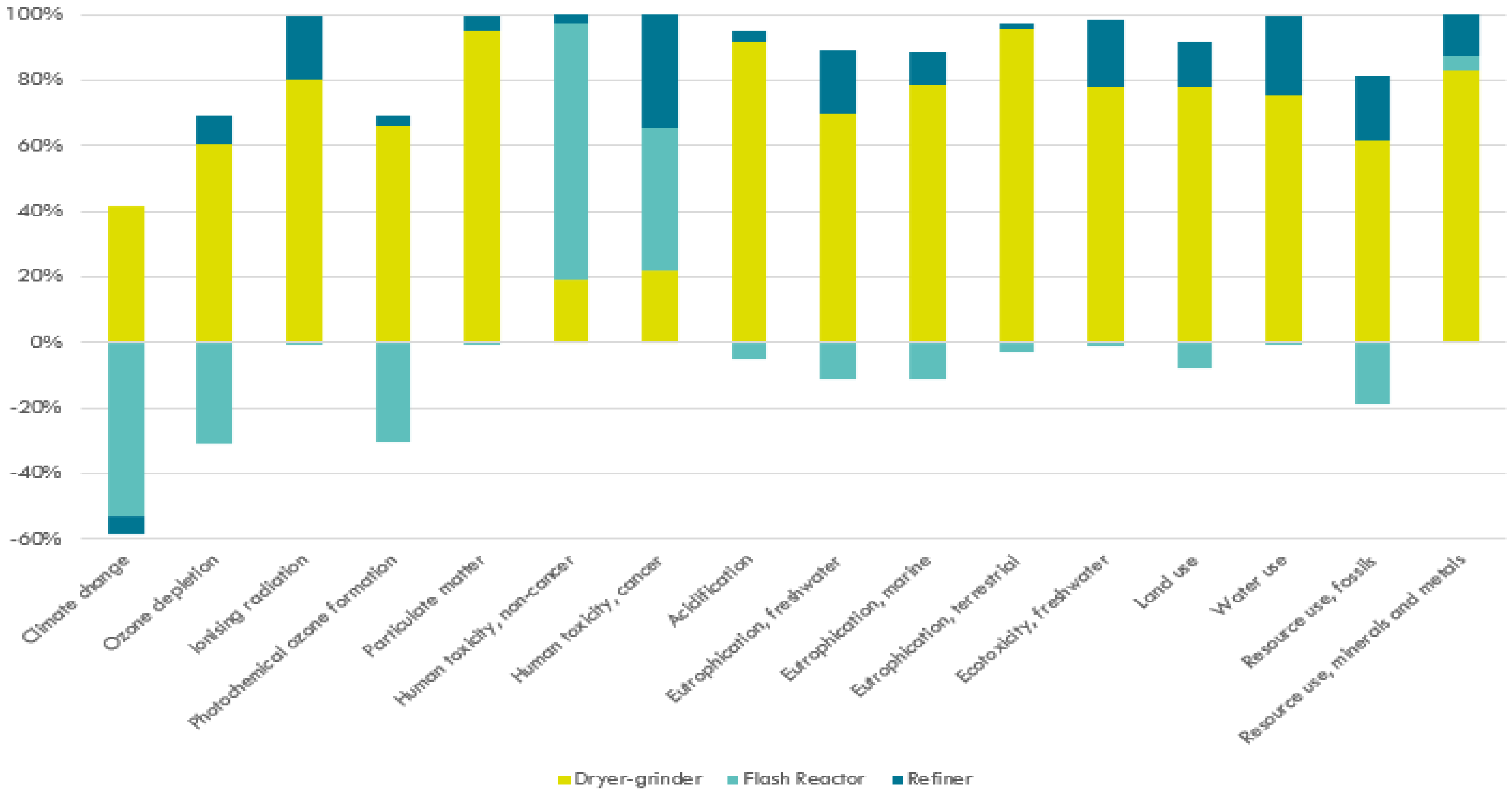
4. RESULTS OF THE LCA



FlashPhos scenario 3 *(%)*

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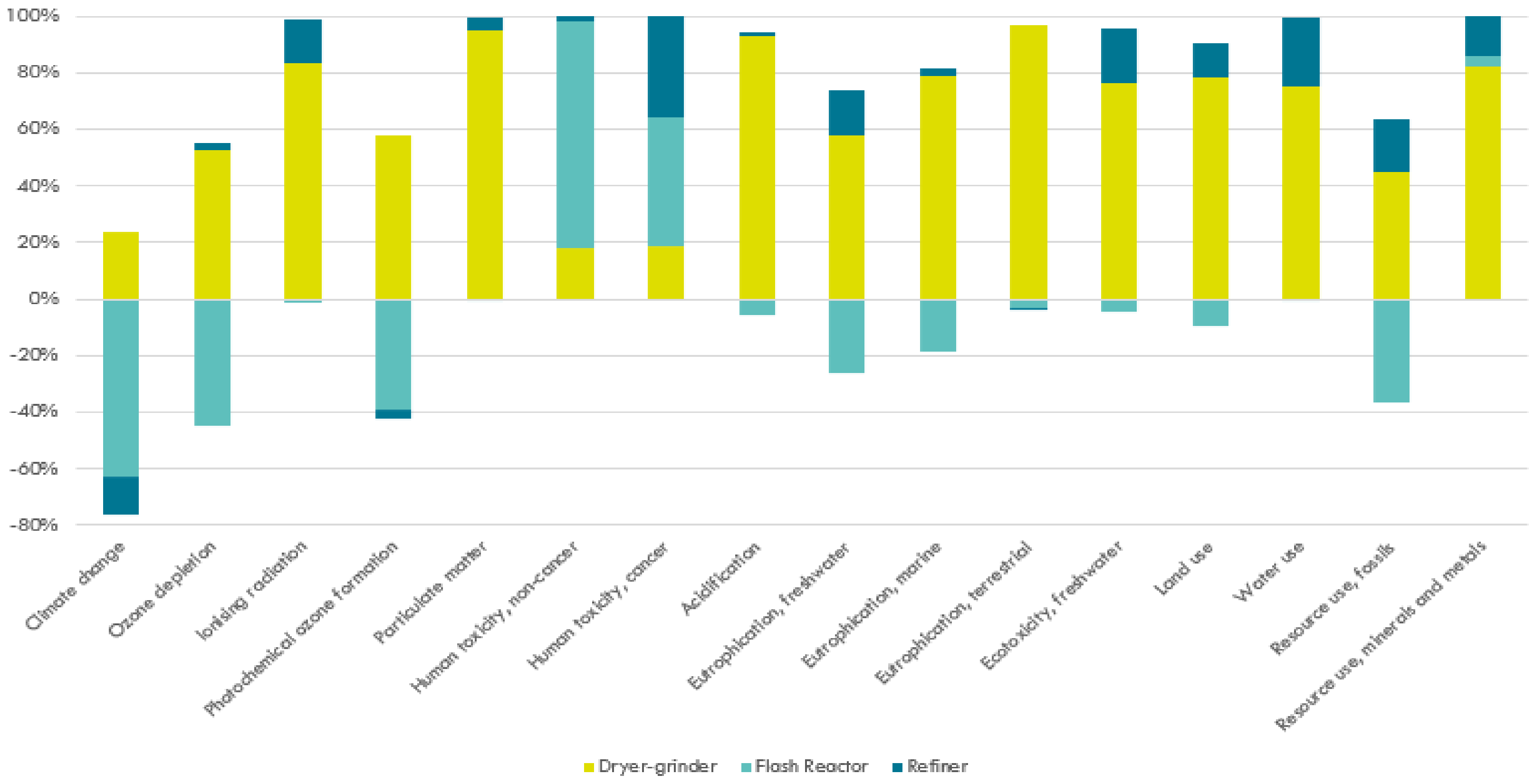
4. RESULTS OF THE LCA



FlashPhos scenario 4 (%)

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5. INTERPRETATION OF RESULTS

FLASHPHOS

Negative impacts

- Avoided fossil fuel use
- Avoided production of raw materials
- Industrial symbiosis

The LCA results improve progressively from scenario 1 to 4

LCA results

Negative impact do not represent physical removal!

Due to the integration. How the FlashPhos process impact on cement plant?

Avoided impacts

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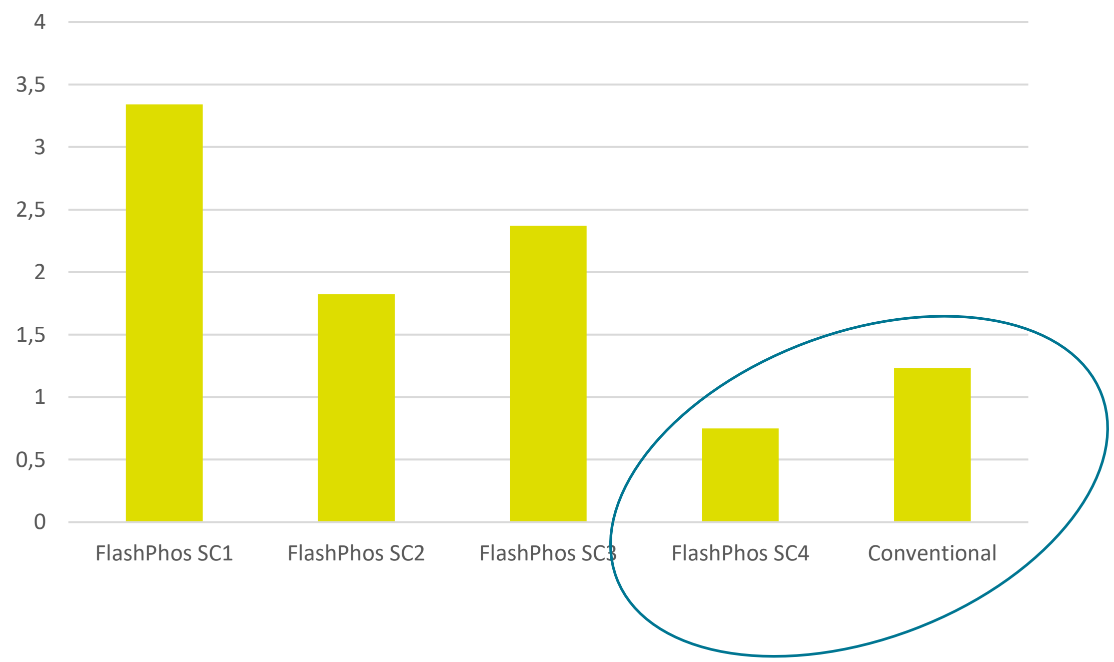
6. COMPARISON TO CONVENTIONAL PROCESS



Single score method

- Process overall environmental performance
- Allows the comparison
- The improvement of some categories do not imply the detriment of others

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MAIN CONCLUSIONS

Objective achieved

LCA demonstrate the benefit from the environmental point of view: climate change contribution, resource use and other impact categories

FlashPhos integration

Impact of the **integration of FlashPhos into a cement plant**

- Substitution of calciner mix fuels by FlashPhos syngas
- Replacement of virgin clinker raw materials by FlashPhos slag

Reference scenario

The **scenario 4** is the reference configuration for future deployment due to its alignment with European policies and objectives

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

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EU Project FlashPhos

@FlashPhos

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

Socio-Economic Impact of FlashPhos

Maria Cristina Pasi

Italmatch Chemicals SpA

21 April 2026

Italmatch Chemicals

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TABLE OF CONTENT

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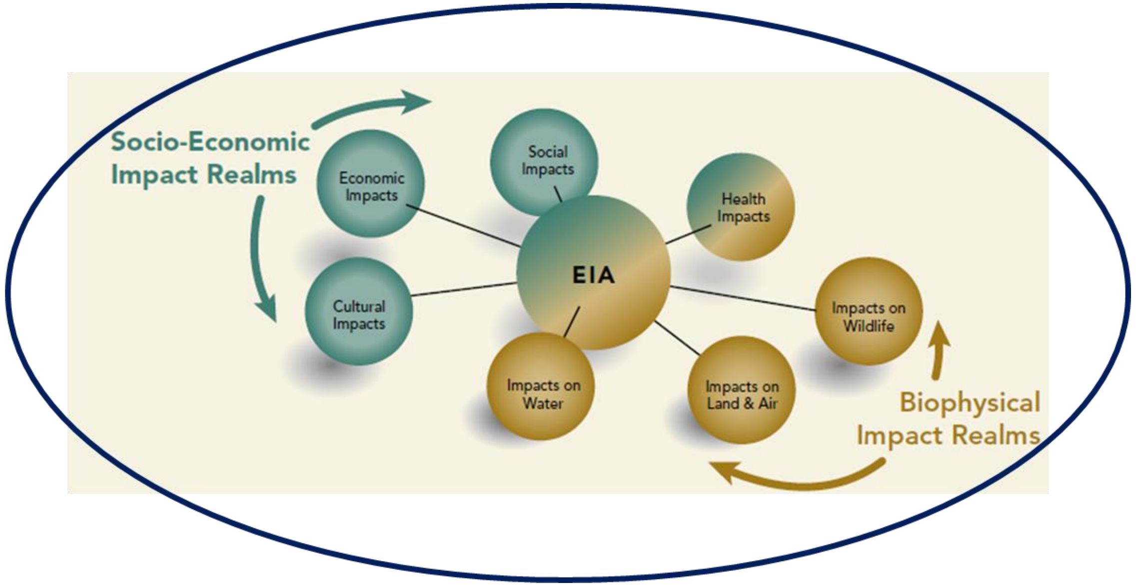
SEIA: DEFINITION & RELEVANCE

SEIA is the systematic analysis used during EIA to identify and evaluate the potential socio-economic and cultural impacts of a proposed development on the lives and circumstances of people, their families and their communities. If such potential impacts are significant and adverse, SEIA can assist the developer, and other parties to the EIA process, finding the ways to reduce, remove or prevent these impacts from happening.

Therefore, a comprehensive SEIA recognizes through its methodological approach the importance of relationships between people, culture, economic activities and the biophysical environment



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SEIA RELEVANCE FOR THE WHOLE FLASHPHOS VALUE CHAIN

FLASHPHOS

MANUFACTURERS

- gain by reducing dependency from primary sourced phosphorus through the recycling WWTPs' sludge into a valuable Critical Raw Material
- gain by energy decarbonisation and material circularity within the cement industry
- longer-term beneficial opportunities for the local economy related to the know-how generated in phosphorus & cement sector

WATER TREATMENT PROVIDERS

- benefit from a more efficient, sustainable and circular solution to reduce wastes stock
- benefit from circular water use

CONSUMERS & COMMUNITIES

- better well-being from circular decentralized solutions at present and for future generations
- job opportunities creation in production, research, and business development, promoting a sustainable industry growths
- economic growth generated by the solution developers within the service industry

ENVIRONMENT

- reduce EoL waste and CO_2 emissions
- reduce primary sources extractions
- reduce induced by land fill eutrophication

SUSTAINABILITY

- fostering innovation in recycling and upcycling technologies
- GRI (Global Reporting Initiative) standards fulfillment

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Italmatch Chemicals

STRUCTURE AND MAIN PILLARS

FLASHPHOS

- EXECUTIVE SUMMARY
- INTRODUCTION
  - Purpose and Target Groups
  - Contribution of partners
- METHODOLOGICAL APPROACH
- GOALS AND SCOPE DEFINITION OF THIS STUDY
  - System boundaries
  - Stakeholders' identification
  - Materiality assessment
- HOTSPOSTS IDENTIFICATION
  - Key social topics for relevant stakeholders
  - Social hotspot database (**SHDB**) risk mapping tool
- IMPACT ASSESSMENT
  - Impact assessment based on PSIA 2020
  - Economic assessment
    - Methodological approach
    - Limitations of the study
- RESULTS AND INTERPRETATION
  - Interpretation of the impact assessment based on the PSIA 2020
  - Interpretation of the economic assessment
  - The driving economic activities of FlashPhos & the Supply chain capacity of the envisaged scenarios
  - Economic impact of the Atec/Dickerhoff hosting industry scenario
  - Economic impact of the P manufacturers hosting industry scenario
- CONCLUSIONS

UNEP/SETAC guidelines for social economic LCA (UNEP/SETAC, 2009)

LCA methodology (EC_JRC,2010):
- ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework (ISO, 2006a).
- ISO 14044:2006 - Environmental management - Life cycle assessment - Requirements and guidelines (ISO, 2006b)

Handbook for Product Social Impacts Assessment (PSIA 2020)

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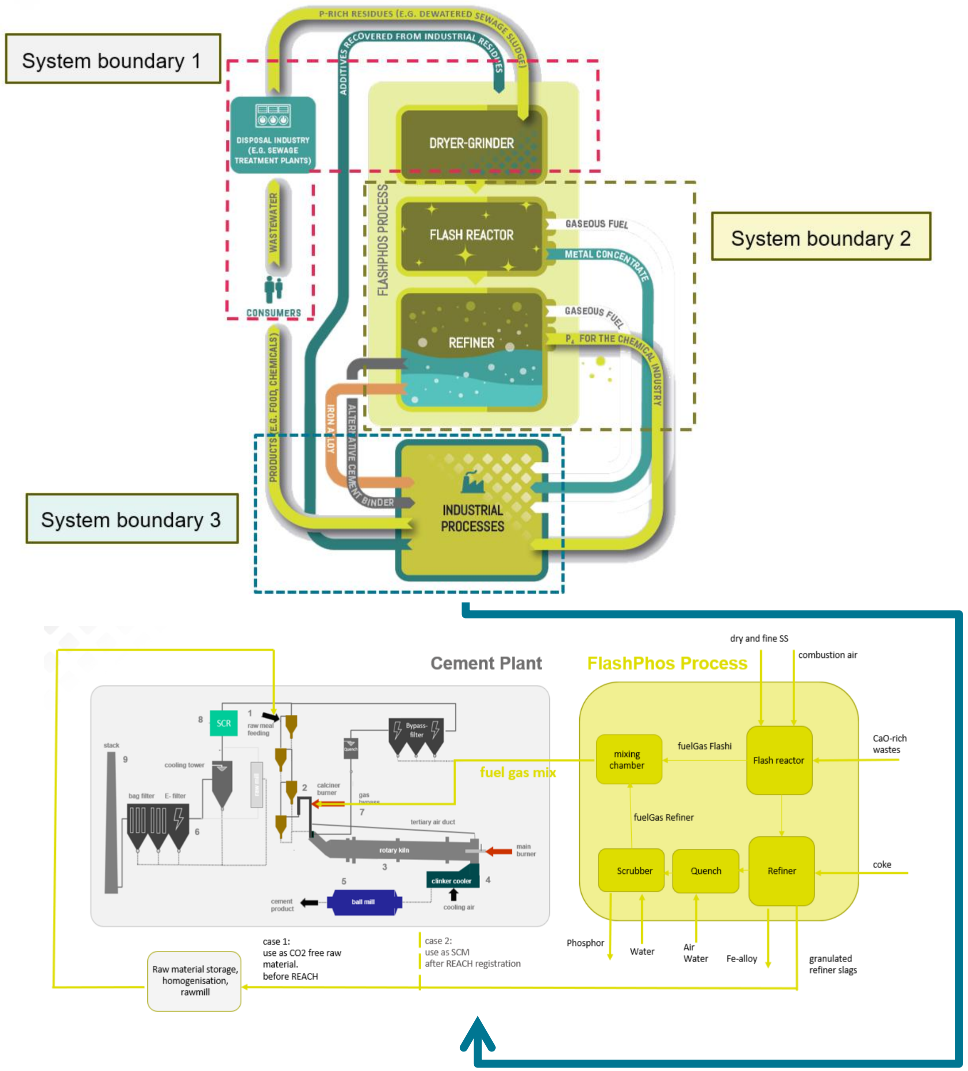
STRUCTURE AND MAIN PILLARS

FLASHPHOS



SYSTEM BOUNDARY I: exploration of results:
Supply chain: wastes management
Manufacturers: technology opportunities and threats
Social impact: wastes reduction vs SoA
Economic impact: spillovers vs SoA

SYSTEM BOUNDARY II: exploration of results:
Supply chain: energy management, engineering, materials management
Manufacturers: technology opportunities and threats
Social impact: environmental topics, H&S, well-being vs SoA (gender dimension and jobs opportunities), circularity
Economic impact: technology vs SoA, circularity, spillover vs P qlty upcycling

SYSTEM BOUNDARY III: exploration of results:
Supply chain: energy management, engineering, materials supply management
Manufacturers: technology opportunities and threats
Social impact: environmental topics, H&S, well-being vs SoA (gender dimension and jobs opportunities), circularity
Economic impact: technology vs SoA, circularity, spillover vs alloys & additives qlty

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BENEFICIAL & ADVERSE IMPACTS IN THE WHOLE FLASHPHOS LIFE-CYCLE

STAKEHOLDERS TYPOLOGY
Policy making and Regulatory officers
Solution developers - Research & Innovation actors and Technologists
Solution adopters – Business & Innovation actors and Technologists
Phosphorus cycle supply chain workers: manufacturers, installation & adaptation specialists.
Citizens- End users

THE RELEVANT SOCIAL TOPICS AND CORRELATED SOCIAL AND ECONOMIC IMPACTS OF FLASHPHOS

SOCIAL TOPICS (PSIA, 2020)	SELECTED IMPACT TOPICS		TYPE OF IMPACT	RELEVANCE MODERATE (M) MAJOR (M)
Health and safety	Wastes reduction	1. WWTP depollution 2. Slag & by products reduction 3. Biodiversity protection 4. Climate change mitigation	Beneficial	1. Major 2. Major 3. moderate 4. moderate
	Decarbonization	1. Incineration reduction 2. Phosphorus extraction reduction 3. Process related CO2 reduction	Beneficial	1. Major 2. Major 3. moderate
	Dust control	Phosphate rock and cement related minerals extraction grinding dust reduction	Beneficial Adverse	moderate
	Circular water	Water reuse	Beneficial	Major
Access to material and immaterial resources and Affordability	Level of commerce activity	1. Novel supply chains for phosphorus 2. Novel supply chain for cement 3. Novel process sensoring & digital twin technologies 4. Carbon tax reduction	Beneficial	1. Moderate 2. Major 3. Major 4. Major
	Process constancy	Plants fill rate & capacity	Adverse Beneficial	Major
	Energy security	Local additional supply, diversity of supply, circular energy	Adverse/ Beneficial	Major

THE RELEVANT SOCIAL TOPICS AND CORRELATED SOCIAL AND ECONOMIC IMPACTS OF FLASHPHOS

SOCIAL TOPICS (PSIA, 2020)	SELECTED IMPACT TOPICS		TYPE OF IMPACT	RELEVANCE MODERATE (M) MAJOR (M)
Child labour	Primary source extraction	Primary Phosphorus, CRMs reduction need	Beneficial	moderate
Community engagement	Well-being of future generations	1. Pollution & related diseases reduction 2. Circularity increase & carbon tax reductions 3. Jobs creation 4. Provision of education	Beneficial	Major
Contribution to economic development	Social impact	Decentralization of economic growth	Beneficial	Major
	Economic impact	Direct and secondary economic income, spill over sectors	Beneficial	Major
Land rights protection	Social impact	Protection of natural resources and extraction areas and soil in general by landfill reduction	Beneficial	Major
Effectiveness	Social & Economic impact	ESG Ecosystem's advantage CRM for all	Beneficial	Major
	Economic impact	Cost of goods sold, more balanced availability of materials, price stability	Adverse Beneficial	moderate

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SOCIAL ASSESSMENT

FLASHPHOS

RELEVANT SOCIAL TOPICS FOR THE SOLUTION ADOPTERS	
HOTSPOT IMPACT TOPICS ASSESSMENT FOR THE SOLUTION ADOPTERS	
Decarbonization	WWTPs deriving wastes management: avoidance of incineration processes; avoidance of wastes transportation; avoidance of landfilling. Cement Industry: valorisation of FlashPhos syngas and heat recovery by replacing fuels in clinker production. Phosphorus industry: avoidance of primary sources transportation; reduction of particulate matters and decontamination energy intensive procedures
Secondary sourcing and circularity	WWTPs waste management: enhanced water reuse; additionally, as the European Union has concluded that landfilling of materials that are possible to recycle must be restricted from 2030 (EC, accessed 2023), materials for final coverage at landfills ought to decrease. Cement and Phosphorus industries: resource use, fossils, minerals and metals.
Wellbeing of future generations	Reduction of land and water use; reduced eutrophication; Climate change impacts drop by ~60%; natural resources protection; enhanced ethicality of the process in terms of reduced child and /or over exploitation of human workers at the primary extraction sourcing locations; circularity increase, provision of innovative educational and professional routes
Energy security	Cement Industry: valorisation of syngas replacing fuels in clinker production. All industries: renewable electricity deriving from decentralized integrated systems
Economic impact	Cement and Phosphorus direct and secondary impacts: see table 4 and Chapter 5; circularity based decentralized industrial profit centers; improved stakeholder capacity to deal with phosphate rock price volatility; inclusion in the revenue's calculation of the additional co-benefits; enhanced initiatives of global binding agreements based on taxing the consumption of natural resources and related externalities and reducing the tax burden of renewable resources and labour

RELEVANT SOCIAL TOPICS FOR WORKERS OF THE NOVEL SUPPLY CHAIN	
HOTSPOT IMPACT TOPICS ASSESSEMNT FOR WORKERS OF THE SUPPLY CHAIN, MANUFACTURING AND INSTALLATION COMPANIES	
Occupational Health & Safety	The extent to which the management of the company maintains or improves the safety and overall health status of the workers, with specific reference to health, safety and environmental hazards for defined systems of the process units, utilities and offsites. The Safety Integrity Levels have been identified and listed as well as the Explosion indices in D8.2.a complete HAZID and HAZOP have been developed based on the assumed scenarios
Occupational Toxics and Hazards	There is a significant occupational risk related to: phosphorus handling, sampling operations, air quality related to the content of specific volatile compounds (D7.1) and noise level. Additionally, considering the cement industry integration, critical conditions include shutdown scenarios (cement kiln trip leading to FlashPhos shutdown, or overpressure causing risk of pyrolysis gas release).
Labor rights and decent work conditions	No relevant social topics are identified as critical in an adverse concept within this specific context, as the decentralization provides a more sustainable working system and new professional opportunities

Italmatch Chemicals

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ECONOMIC ASSESSMENT

SELECTED ECONOMIC INDICATORS

GROSS ECONOMIC OUTPUT

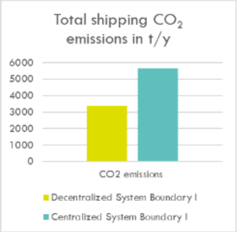
- refers to the overall impact in monetary terms upon an industry or the overall economy linked to the deployment of the FlashPhos project.
- This can be differentiated between direct output (the expenditures required to build and deploy the FlashPhos integrated plant) and indirect output (the further spendings affecting industry's suppliers)

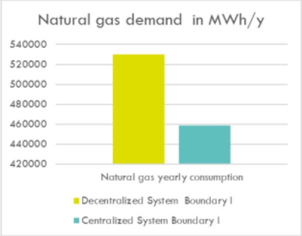
EMPLOYMENT

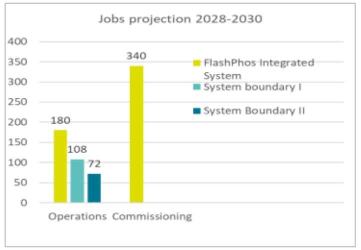
- number of jobs that are created by the deployment of the FlashPhos integrated plant into the cement industry
- forecasted employment level increase generated by the value chain stakeholders involved

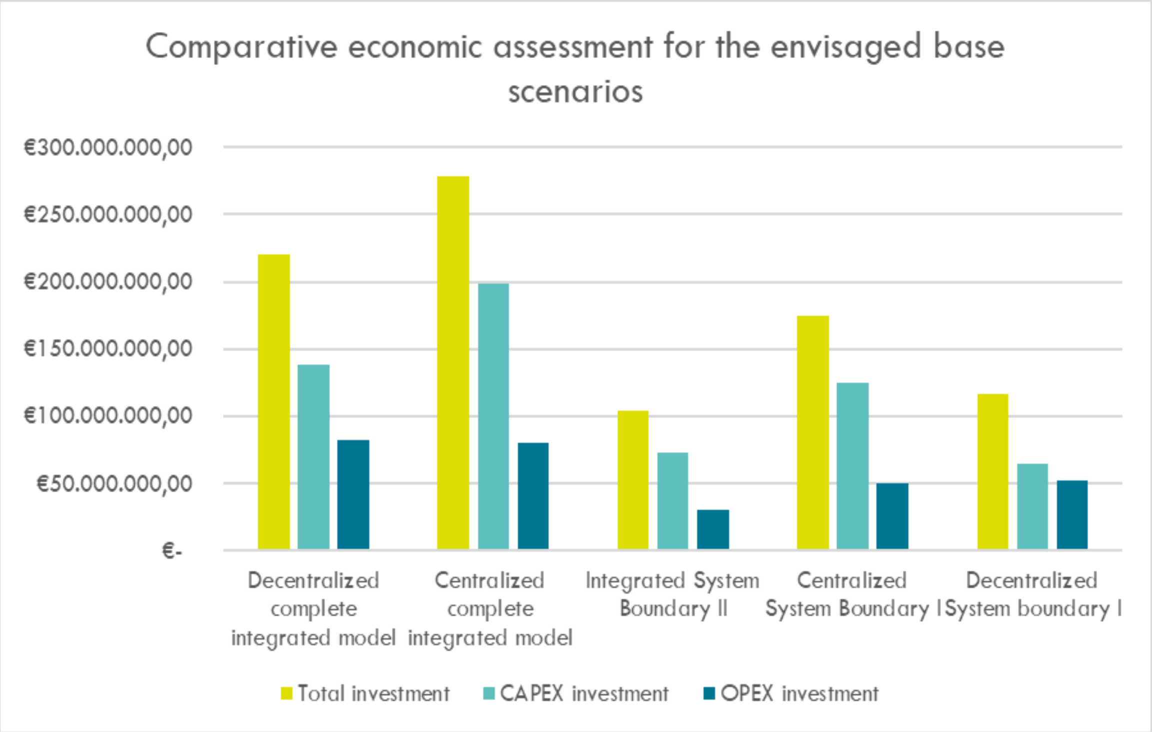
CO-BENEFITS FROM SPILLOVER ADOPTIONS

a rough evaluation of the wealth creation for the economy within the systemic value chains deriving from spillover sectorial applications. Longer terms opportunities for the economy related to the know-how generated in the secondary P sourcing sector and the possibility to export this expertise to wider secondary minerals extraction markets are part of this assessment, whatever they are, quantitative and/or qualitative









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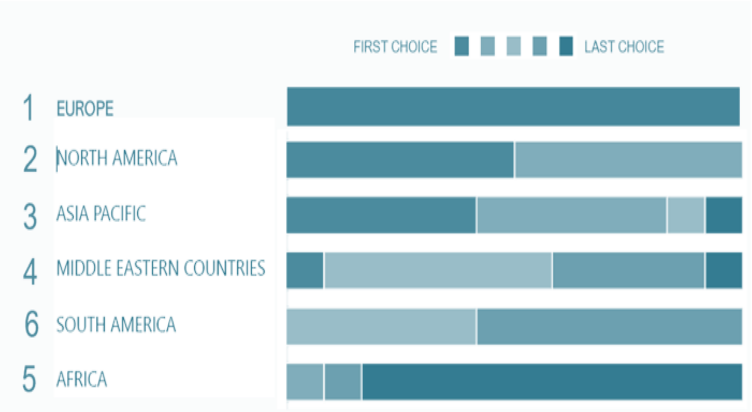
MARKET SCENARIOS

FLASHPHOS

Sectorial perspective

Geographic perspective



<u>Service and utilities industries</u>:
Ecodesign service by the adoption of simulations and digital twin models for various typologies of wastes, for thermochemical processes aimed to advanced materials development, for wastes stocks optimization and incineration reduction, for process energy optimization. Additionally contractual research services can be envisaged in the high specialty sectors

<u>Technologies, components and online sensoring manufacturers</u>:
Solution providers for metallurgic, steel, electrolytes and energy storage precursors industrial sectors

<u>Output materials adopting industries</u>:
Sustainability gain in a more circular supply chain for industrial phosphorus sector (P_4) to serve water management industries, Oil & Gas industry, Energy industry, Pharmaceutical Industry; for cement and construction sector (the commercial use of FlashPhos slag as an SCM depends on REACH registration and the preparation of an Environmental Product Declaration (EPD) according to EN 15804 / ISO 14025, both of which are still pending), for defence sector

BIZ model perspective

IP ASSETS

- **<u>Patents</u>**
- **<u>Know-how industrial property</u>**
- **<u>Trademarks</u>**

ADDITIONAL MARKET SCENARIOS

Generation of:

- **intangible assets**, such as royalties on licensed IP exploitation contracts or IP acquisitions
- **tangible assets**, such as merging & acquisition actions towards upstream or downstream integrations, NewCo formation

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Italmatch Chemicals

FLASHPHOS

The complete thermochemical recycling of sewage sludge

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EU Project FlashPhos @FlashPhos

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FLASHPHOS

The complete thermochemical recycling of sewage sludge

Exploitation and Market Deployment

Luigi Di Rienzo

Italmatch Chemicals, Steinbeis

21/04/2026 Leoben, Austria

Italmatch Chemicals

Steinbeis Europa Zentrum

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Agenda

- From pilot demonstration to future exploitation
- Exploitation vision
- Foreseen exploitation pathways
- What enables exploitation today
- Remaining challenges & next steps

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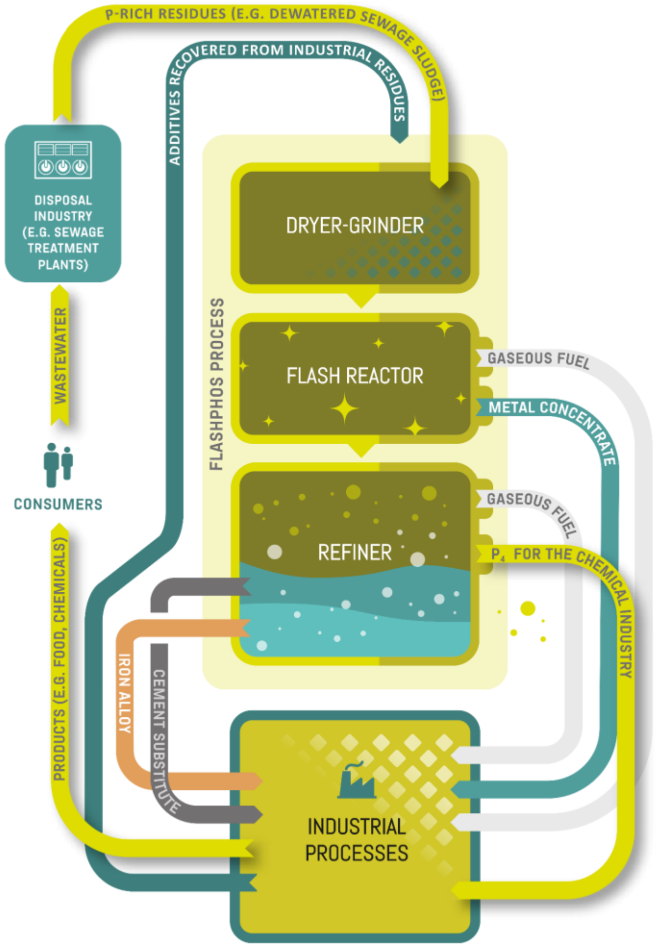
From pilot demonstration to future exploitation

The pilot plant and the results achieved so far represent a great asset for the future

The lessons learned and the scale-up information are already a huge step ahead for the exploitation

An extra mile is needed to confirm the full validation



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The 2021's Vision being confirmed

FlashPhos goes to market in Europe: first process in the world to sustainably produce **White Phosphorus (P4)** for the chemical industry in a full circular economy model, surpassing the current quality level offered in the market.

The same occurs for the by-products.

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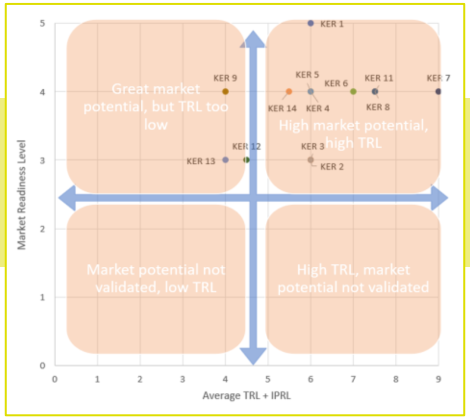
What we have delivered

Precise and valuable list of results

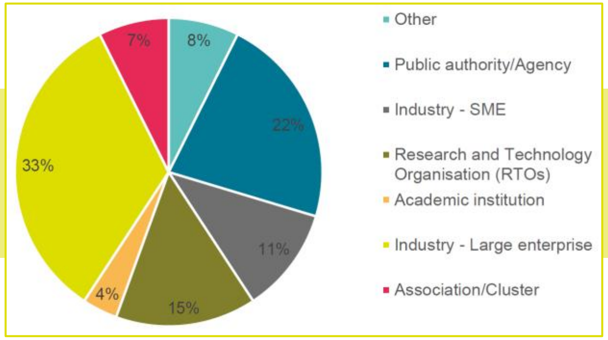
11 KERs between 3 and 5 MRL, and 4 to 8 TRL+IPRL, a strong trademark

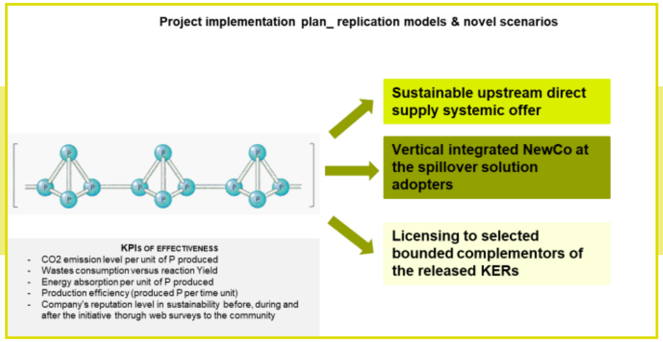
New potential overarching categorization (marked with ◊)

- Complete Pilot Plant
- Plant engineering
- Plant operation
- Process knowledge base
- Resource management
- Output material



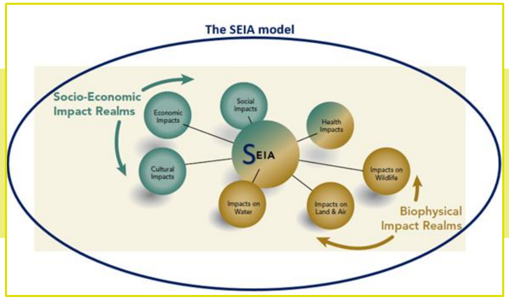
FLASHPHOS
CERTIFICATE OF REGISTRATION

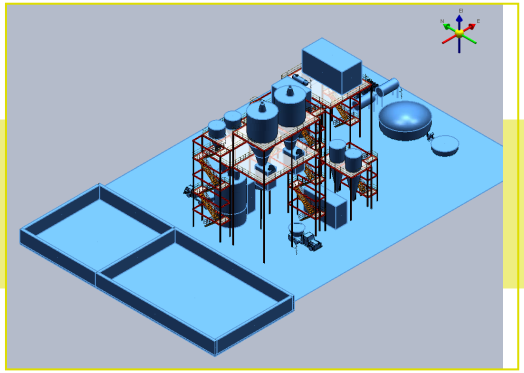




Various possible exploitation strategies & stakeholders list

LCA, Scale-up FEED and SEIA analysis





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Foreseen exploitation strategies

Advanced pilot-scale validation →
- Process optimization
- Raw material quality & adaptability

Multiple exploitation pathways under evaluation →
- Different host industries
- Energy scenario

Engagement of new stakeholders beyond the consortium →
Problem-solving approach:
- Funding
- Energy cost
- Regulatory

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What enables exploitation today

- FlashPhos can introduce an alternative circular pathway for sewage sludge management and the phosphorus market
- The vision and the uniqueness of the initial proposal are still valid after 5 years
- Alternative approaches for industrial development are available
- The Regulatory and Legislative framework is likely to further beneficiate FlashPhos application

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Remaining challenges & next steps

FLASHPHOS

Process integration into existing industries

Regulatory aspect to be monitored

Scale-up issues and business case improvement

Process validation

Business case improvement through New Stakeholders' involvement

Definitive industrial proposal for the market

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Project´s route

- We dreamed
- We struggled
- We adapted
- We improved
- We delivered
- We are committed to move ahead

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