CLEAN clinKER by calcium looping for low-CO_2 cement

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9th High Temperature
Solid Looping Cycles Network Meeting
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Scale-up and Economics for a Full-size Plant

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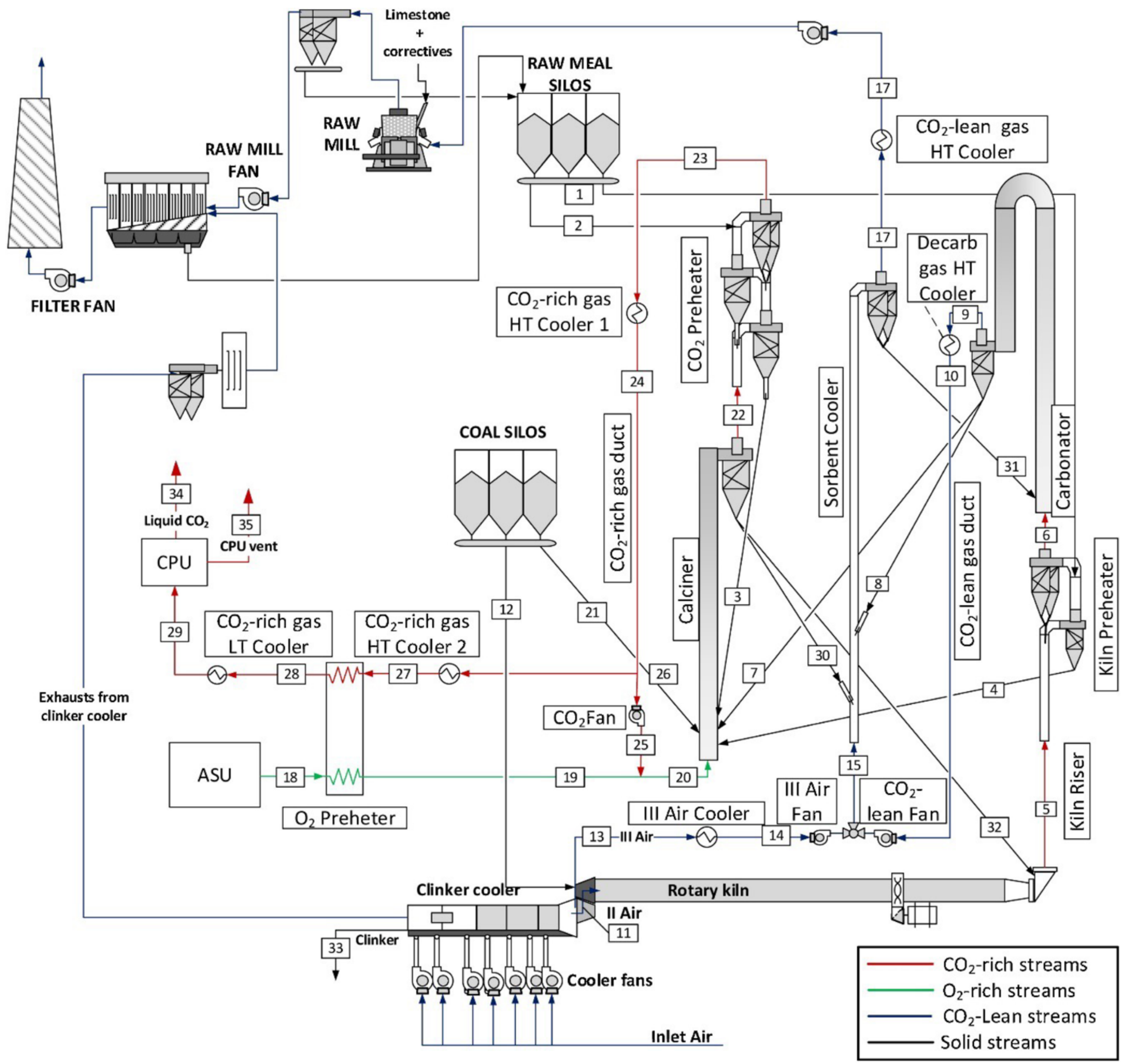
Scale-up for a Full-size Plant

Plant with Integrated CaL Process

- 2 Strings
  - Calciner with Co2 Preheater
  - Kiln Preheater and Carbonator
- Cyclones
- Transfer Chutes
- Sorbent Cooler
- Material Feeding/Distribution
- Gas Coolers
- ASU / CPU as Cost Drivers

Source: POLIMI

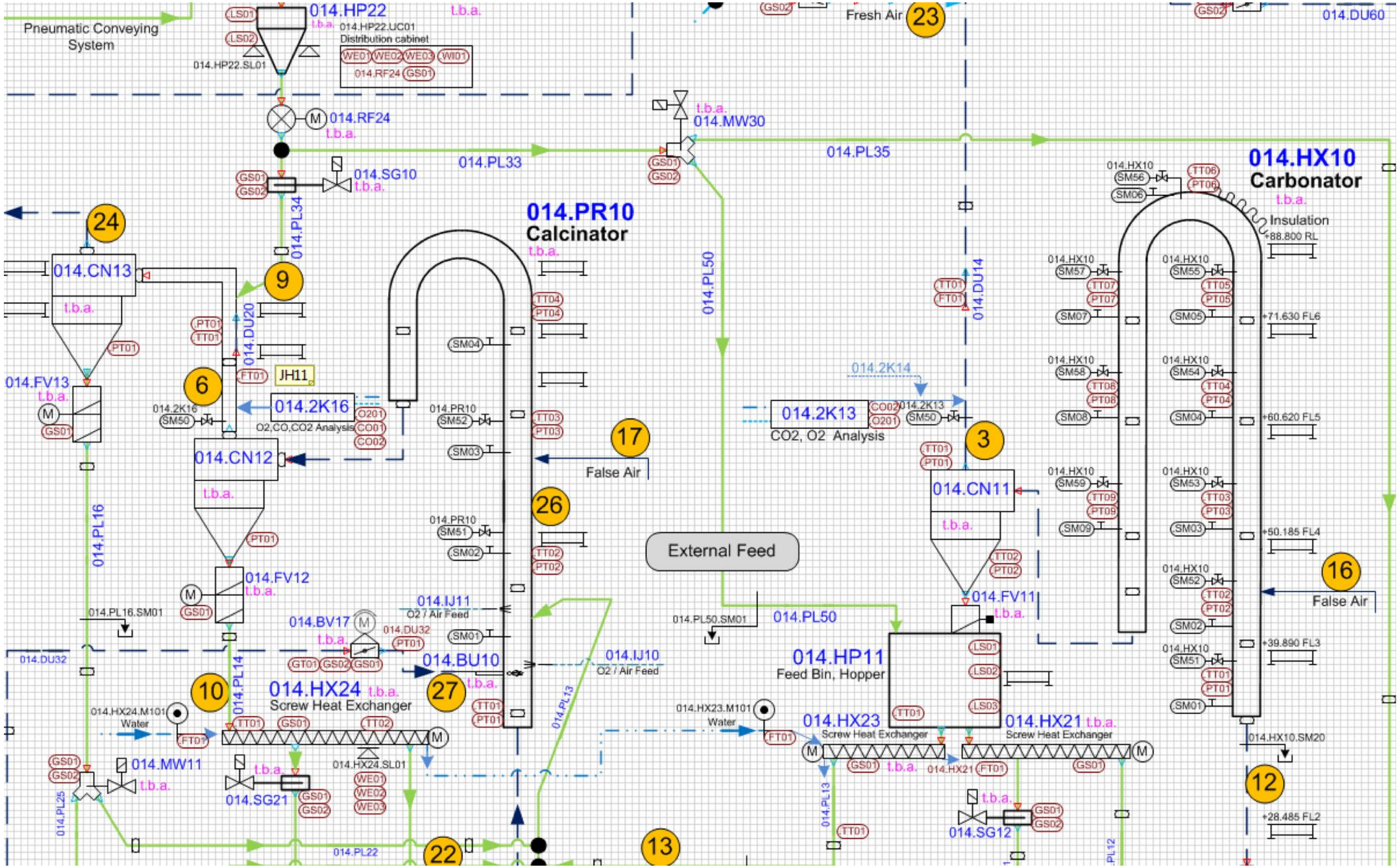


Scale-up for a Full-size Plant

Vernasca:

Flow Sheet

- **Extract Calciner/Carbonator**



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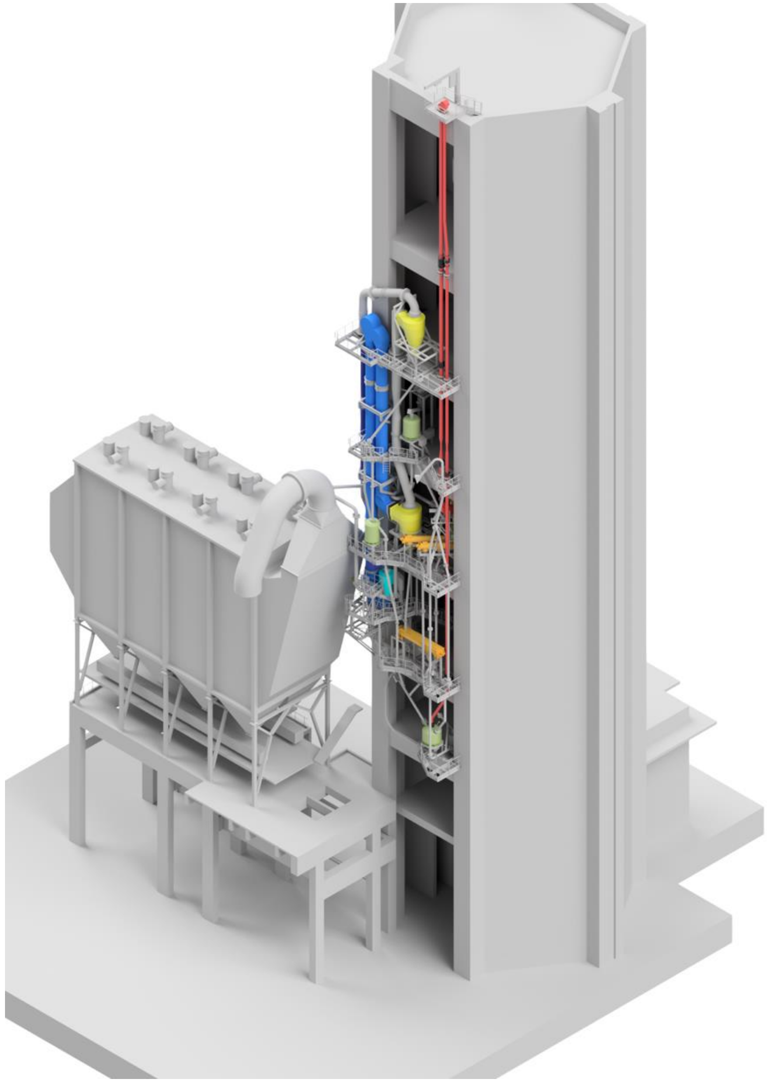
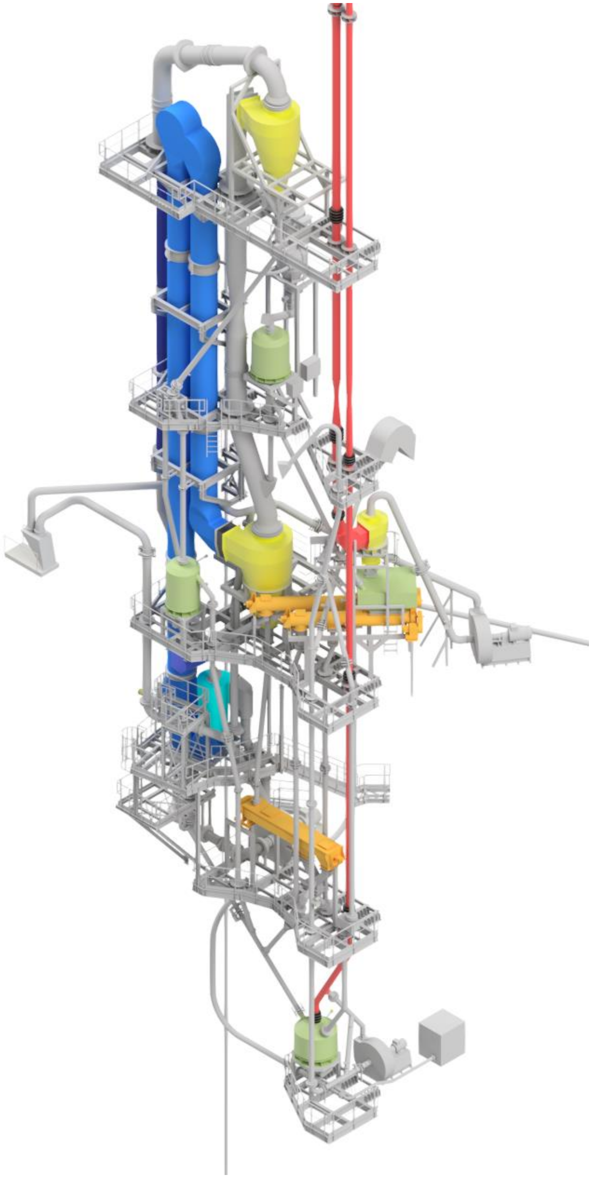
Scale-up for a Full-size Plant

Vernasca:

Plant Overview

- CLEANKER Plant Layout
- Raw Meal Feed: 10 t/h
- Standard Cement Plant: >150 t/h





Scale-up for a Full-size Plant

Vernasca: Calciner

- Calciner (45 m), directly heated
  - Shell: Mild Steel / Refractory
  - Heat Expansion joints
  - Scale-up as per gas speed
- Oxyfuel Burner
  - Geometrical Scale-up (more or less depending on the Fuel type)

Photo: LEAP

Scale-up for a Full-size Plant

Vernasca: Carbonator

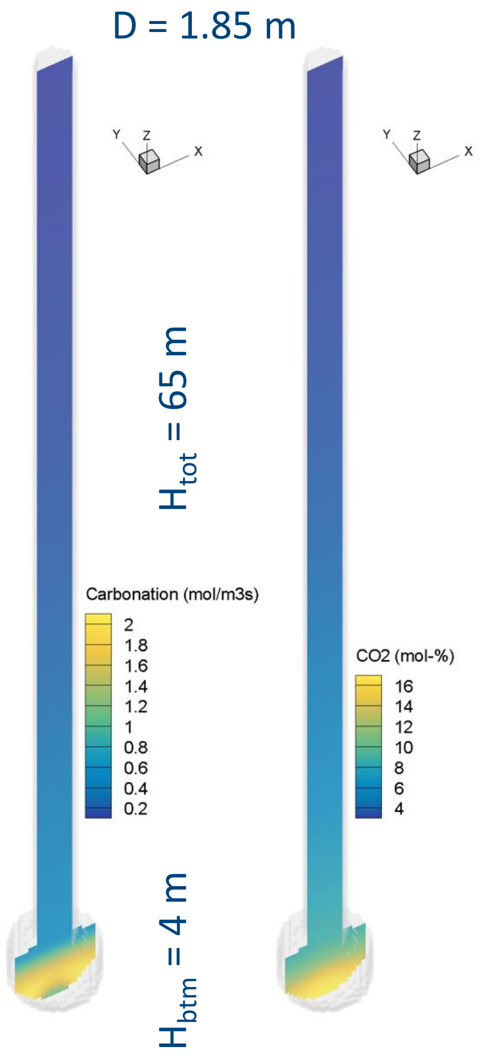
- Carbonator (Vernasca)
  - Length: 105 m
  - Diameter: 0,25 m (Up), 0,35 m (down)
  - Material: Stainless Steel
  - Insulation: Partially

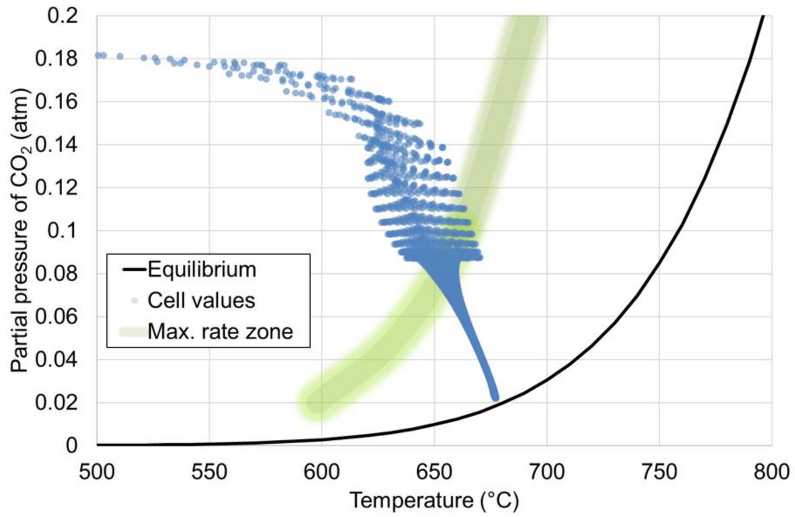
- Carbonator (Scale-Up)
  - Shorter: approx. 65 m
  - Material: Mild Steel / Refractory / Insulation

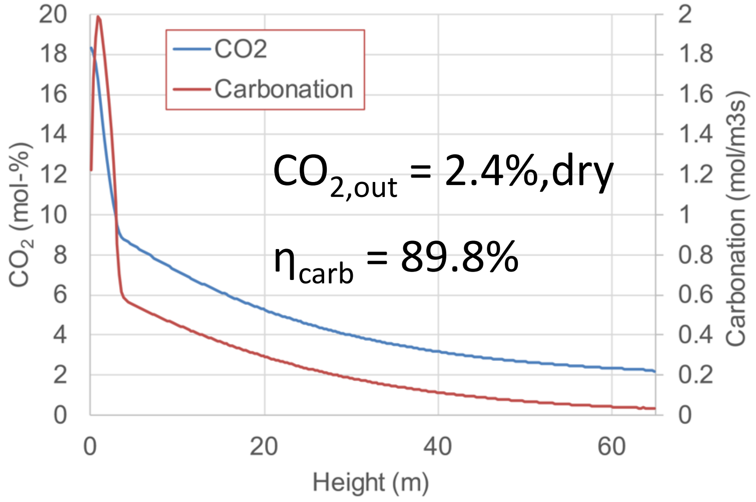
Scale-up for a Full-size Plant

Scale-up: Carbonator

- **Shorter Pipe**
  - **Effective Mixing Chamber at Material Feed**
  - **Acceptable capture rate already after 60 m**







Source: LUT

Vernasca: Cyclones

- Cyclones
  - State of the Art
- Ductwork
  - State of the Art

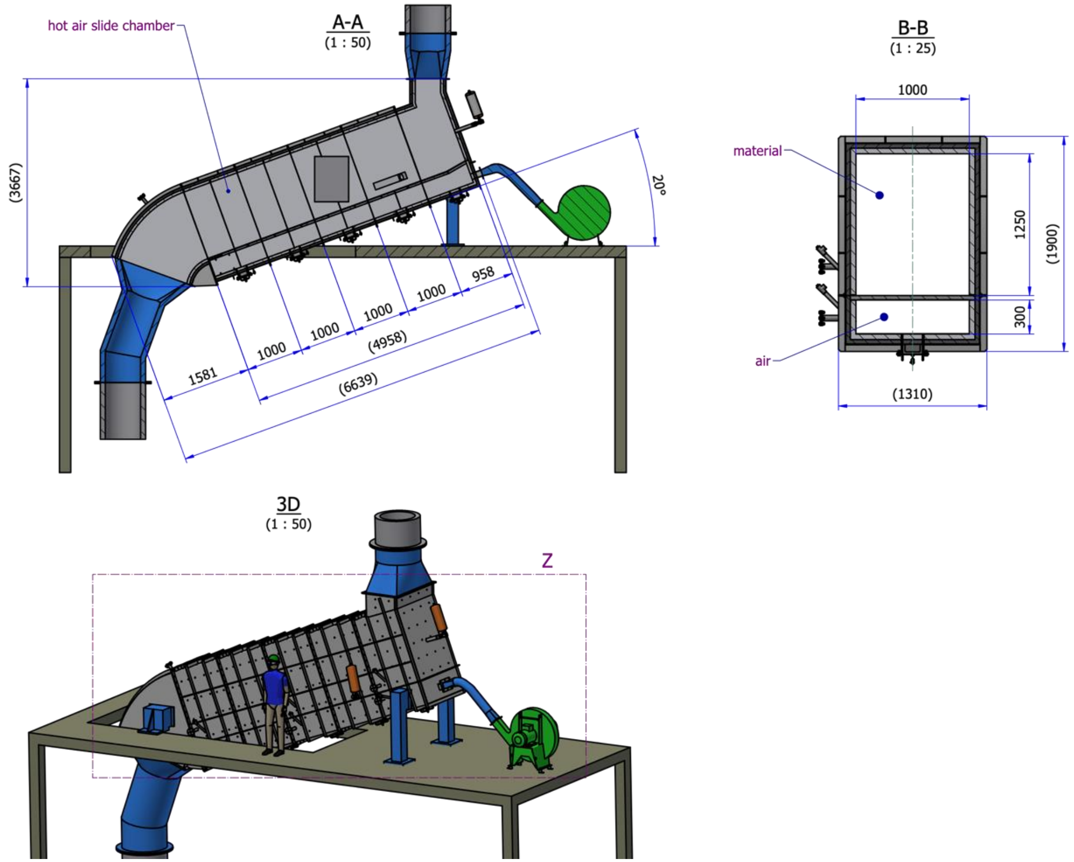
Scale-up for a Full-size Plant

Vernasca: Transfer Chutes Water-cooled Screws

- Carbonator Outlet bin
- Screw Conveyors (HX21, HX23)
  - Carbonator -> Calciner
  - Watercooled devices
  - 650 / 600 °C
  - Diameter: 0,4 m
  - Not suitable for Scale-up

Scale-up: Transfer Chutes

- **Hot Air Slide**
  - Refractory covered ducting
  - 10/20 degree inclination
  - Ceramic Aeration floor
  - Minimum Aeration for no cooling, just transportation
  - Fine Jet Slots for transport efficiency



Scale-up: Transfer Chutes

- Hot Air Slide
  - Installation at Test Facility
  - 10/20 degree inclination

Scale-up: Transfer Chutes

- Hot Air Slide - Test Runs
  - 900 °C
    Calcined Raw Meal
  - Basic tests at ambient with Raw Meal

Scale-up for a Full-size Plant

Vernasca: Sorbent Cooler Water-cooled Screw

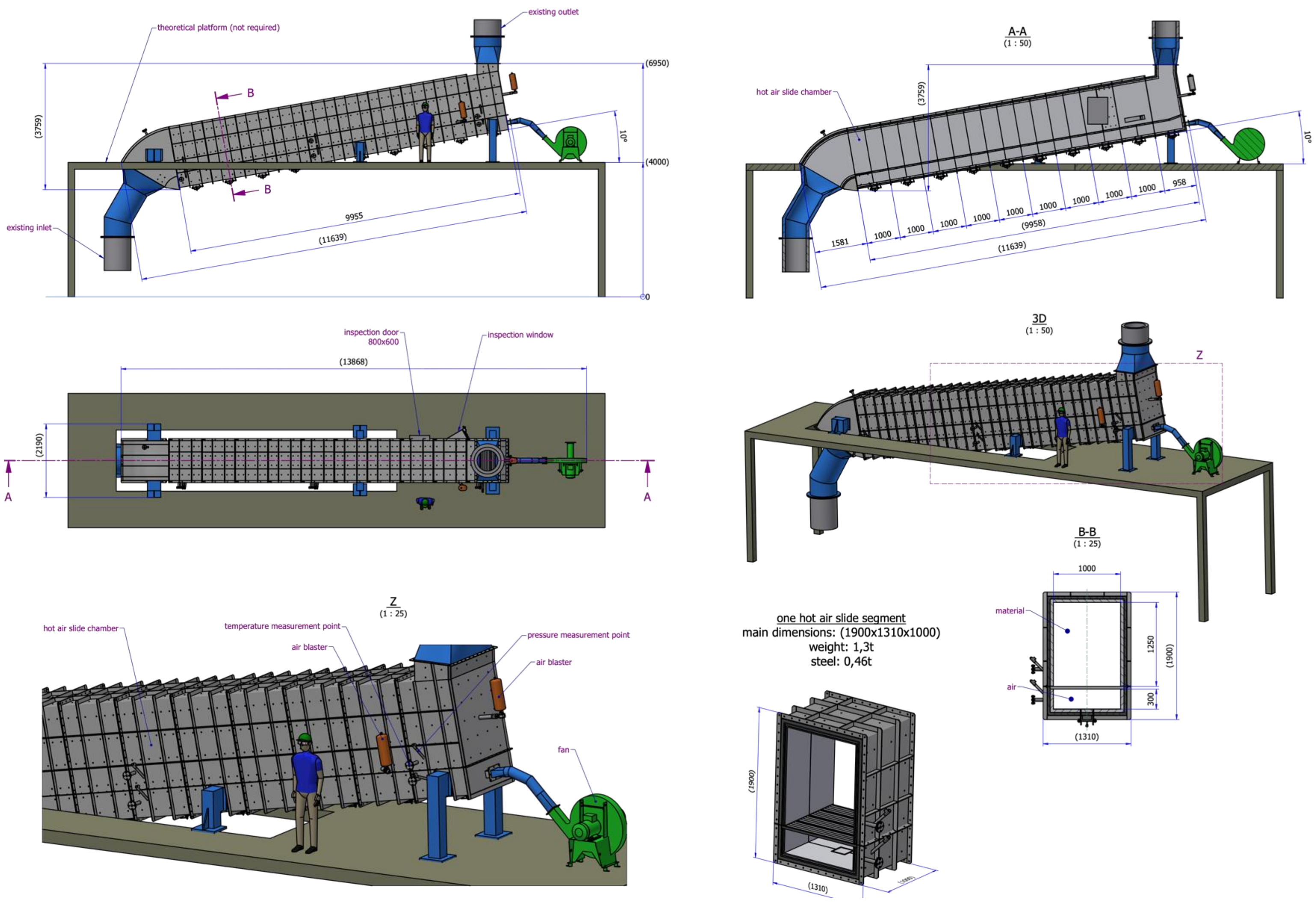
- Screw Conveyor / Screw Cooler (HX24)
  - Calciner -> Carbonator
  - 900 / 700 °C
  - Watercooled, Shaft and Shell

- Not suitable for Scale-up

Scale-up for a Full-size Plant

Scale-up: Sorbent Cooler

- Sorbent Cooler
  - Calciner -> Carbonator
  - 900 / 700 °C
  - Air Cooled
  - Concept Variation of HAS
  - Wider Slots for more air
  - Cooling Air Source



Vernasca: Material Feeding

Splash-Box

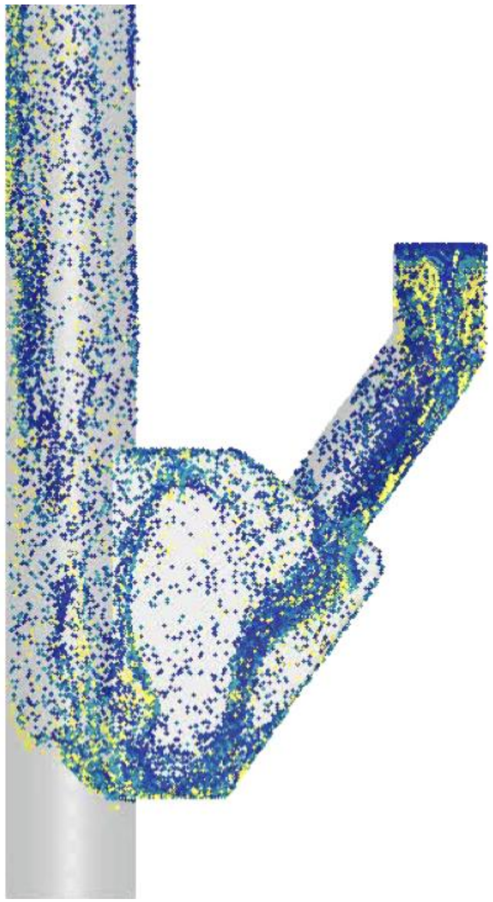
- Splash Box
  - Calciner
  - Raw Meal Feed

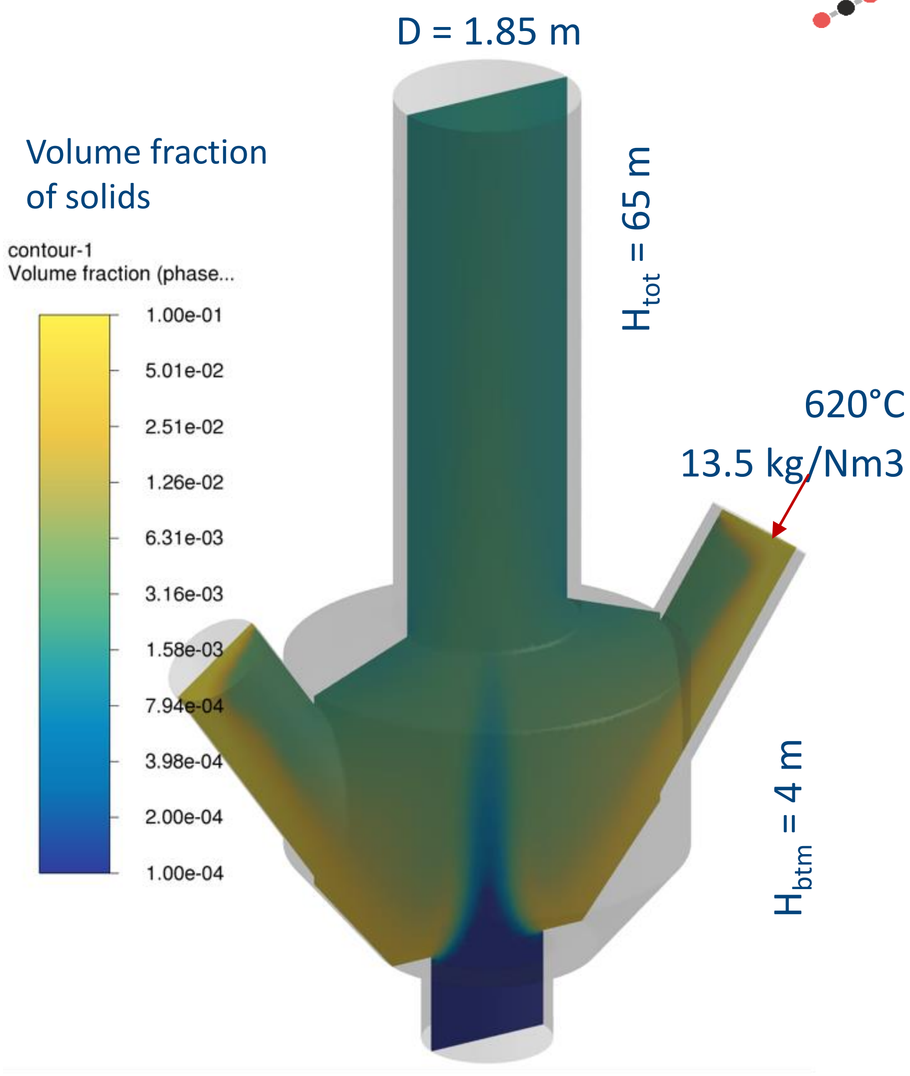
Scale-up for a Full-size Plant

Scale-up: Material Feeding

Splash-Chamber

- Splash-Box (Vernasca, left)
  - Scaled-down from Plant devices
  - Circulating Flow
- Splash-Chamber
  - Similar Flow Pattern
  - Additional Feed Points





Source: LUT

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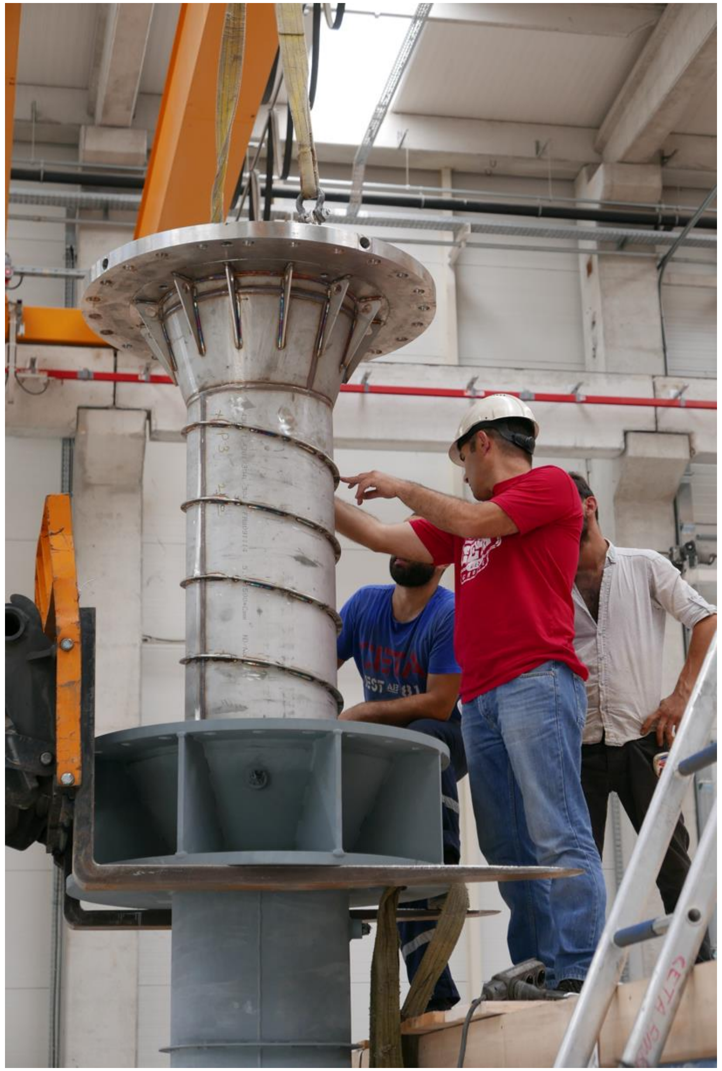
Scale-up for a Full-size Plant

Vernasca: CO2 Cooler

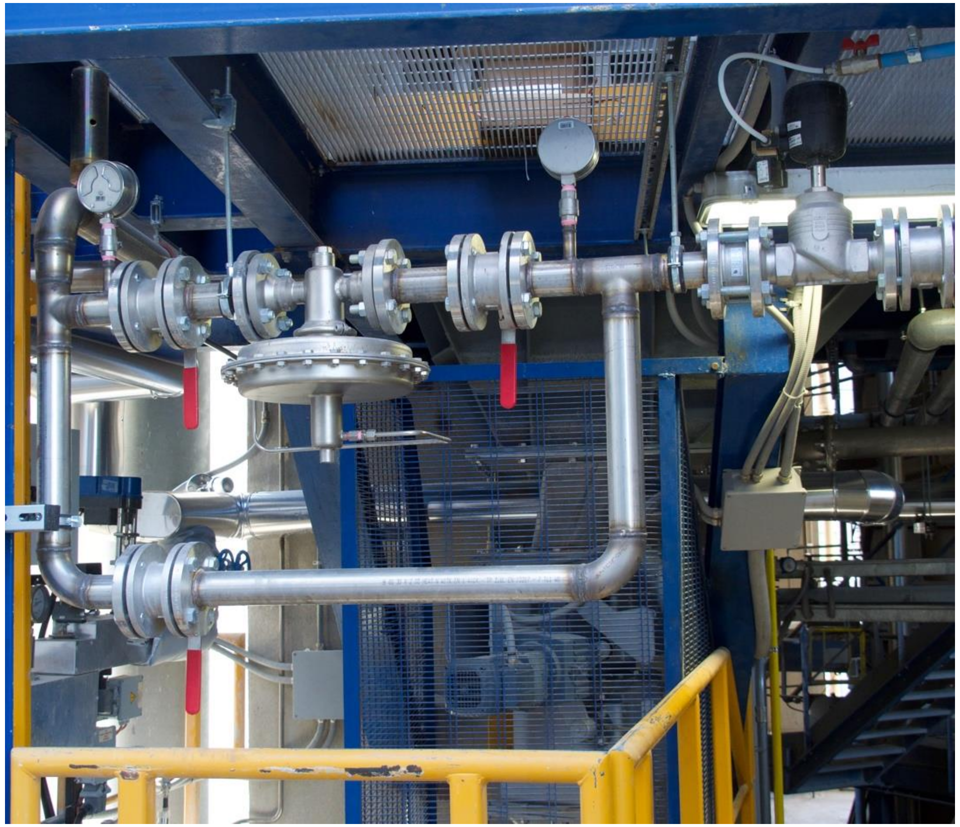
- Gas Cooler
  - 700 / 500 °C
  - Water Cooled
  - Concept not really suitable for Scale-up
  - Alternative Proposals
    - Under investigation



Scale-up for a Full-size Plant

Vernasca: Oxygen-Tank

- Vernasca Installation
  - Oxygen Valve Train
  - Tank / Gasifier
- Full Scale
  - Complete ASU Plant



Scale-up for a Full-size Plant

Conclusions:

- Safe for Scale-Up
  - Calciner
  - Carbonator
  - Cyclones

- Some Challenges ahead
  - Hot Air Slides
  - Sorbent Cooler
  - Splash-Chambers
  - Various Heat Exchangers

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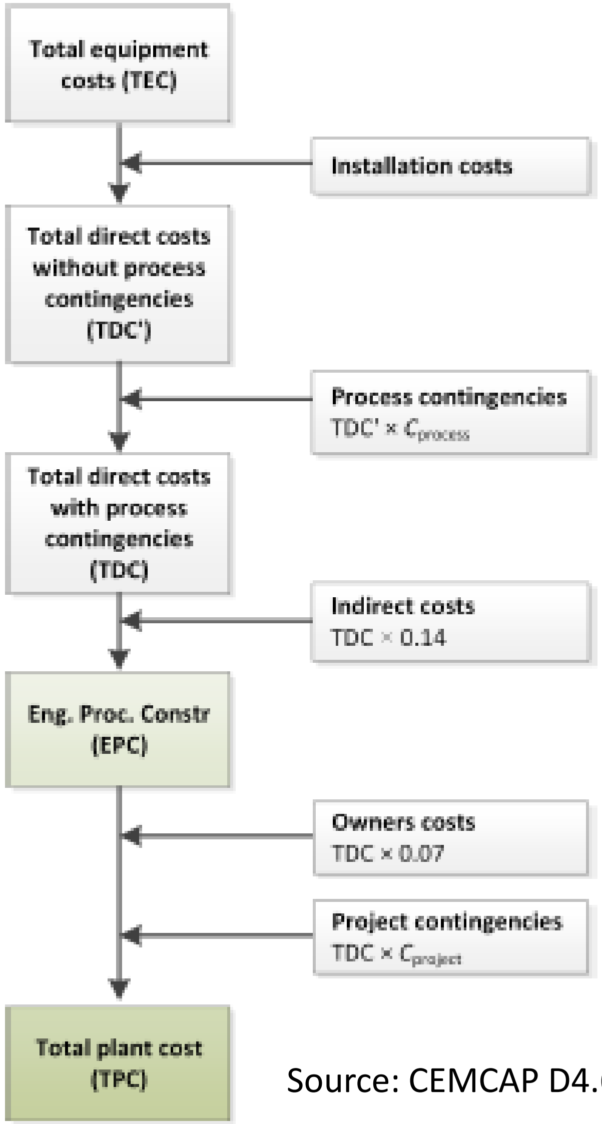
Economic analysis

WP 6 – D6.3: Full economic analysis of cement plants equipped with CaL

- Economic assessment based on CEMCAP methodology
- New cost functions were drawn to improve the accuracy of the Total Plant Cost estimation
- Retrofitting a 3000 t/d BAT Cement plant with CaL EF was assessed (100% coal firing)
- 2018 year basis
- Targeted cost uncertainty: ± 30%
- Estimations based on the results of validated process models



Source: CEMCAP D4.6

WP 6 – D6.3: Full economic analysis of cement plants equipped with CaL

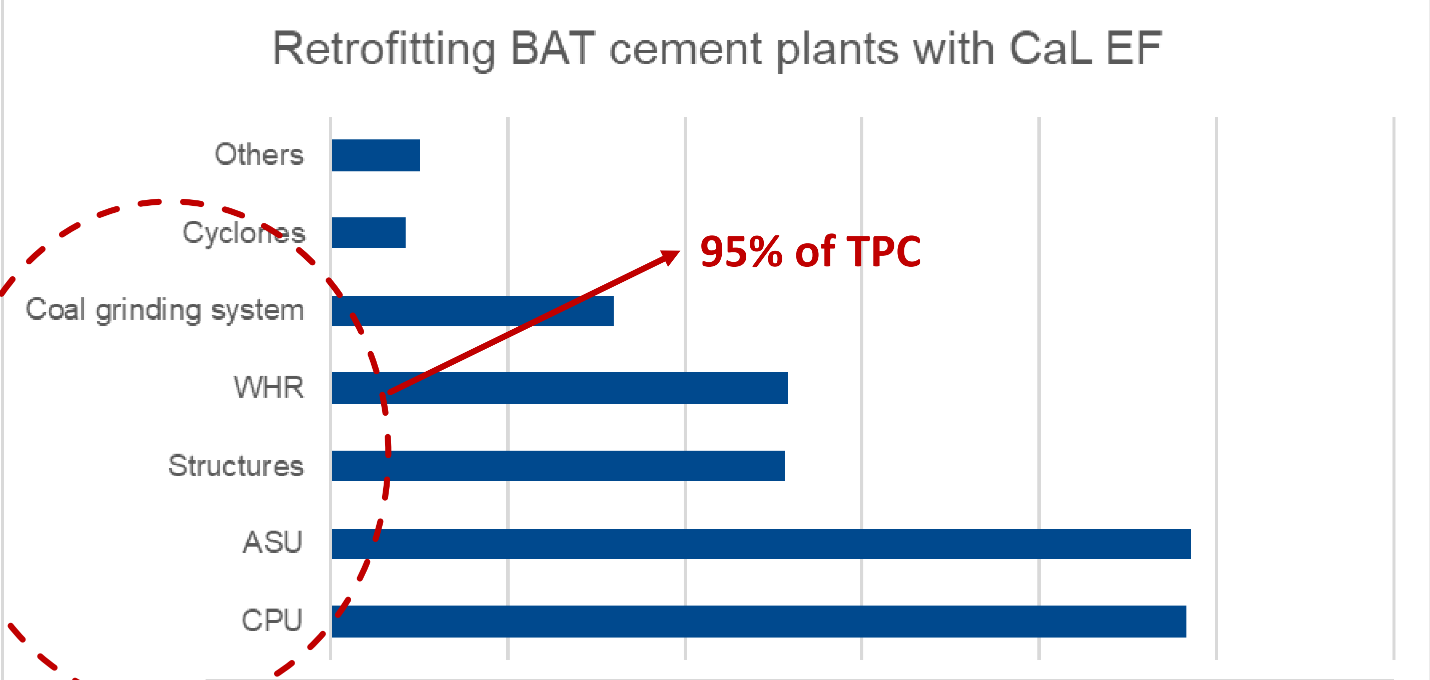
- **Some relevant assumptions for the economic assessment:**

Utilities and Consumables	*Unit price*		*Amount*	*Plant without CO_2 capture (Ref. Plant)*	*Plant with CO_2 capture (EF CaL)*
Raw Meal	€/$t_{RawMeal}$	3.125	$t_{RawMeal}/t_{clk}$	1.6	1.6
Fuel	€/GJ_{LHV}	2.40	GJ_{LHV}/t_{clk}	3.24	5.44
Electricity	€/MWh_e	69.30	MWh_e/t_{clk}	0.13	0.17

Economic variables	Uncertainty range
Fuel	± 50%
Electricity	± 30%
CO_2 emission allowances	0 - 100
CAPEX Carbon Capture plant	± 30%

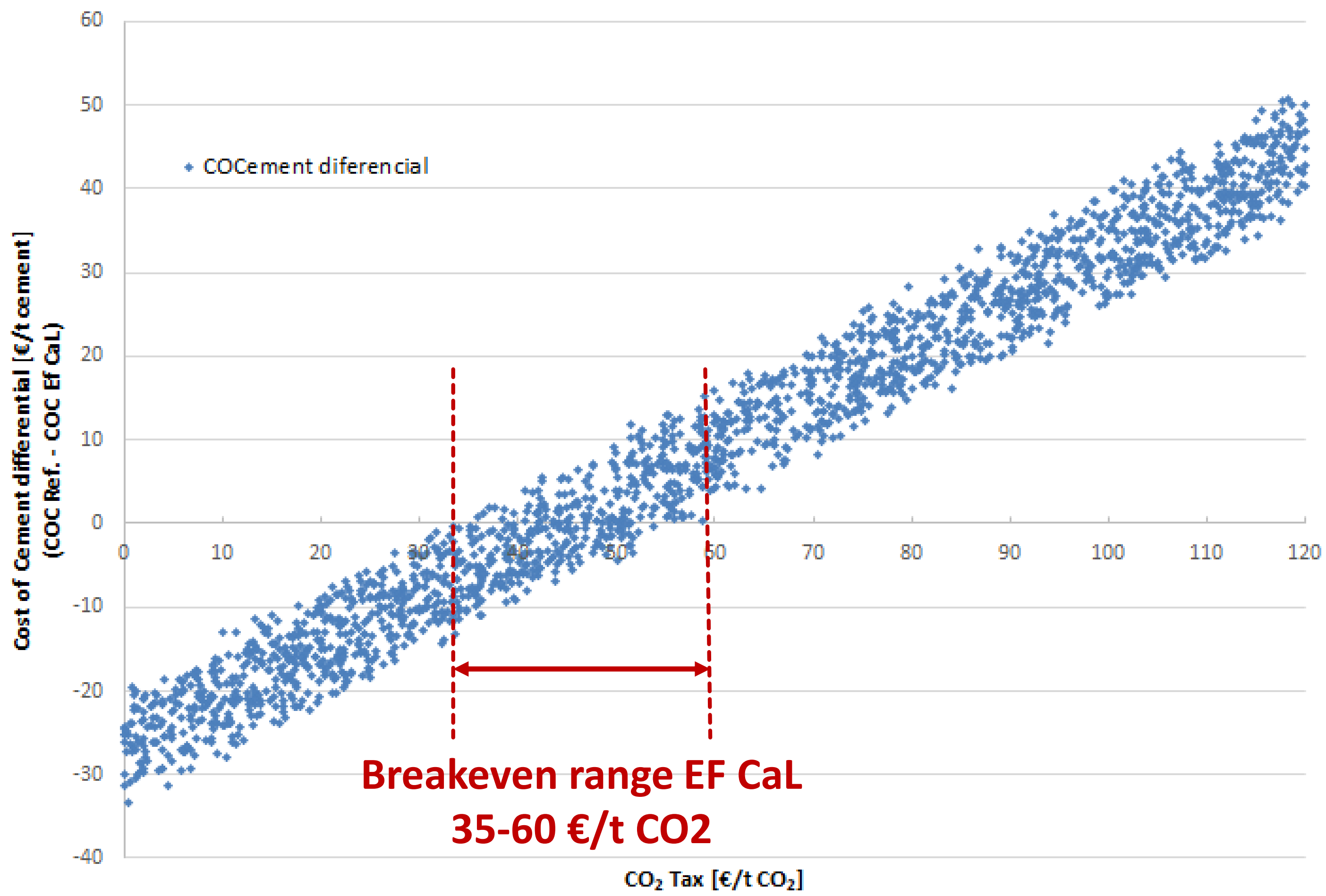
WP 6 – D6.3: Full economic analysis of cement plants equipped with CaL

- **Total CaL EF Plant Cost estimation: ~175 M€; 2018 year basis (retrofitting)**
- **6 components account for over 95% of the total cost (ASU; CPU; WHR; Structures; Coal grinding system; cyclones)**
- **The remaining 5 % include CO_2-rich and CO_2-lean gas ducts; fans; sorbent cooler; carbonator, etc.**
- **Calciner and fuel feeding system need to be adapted → not included**



	CPU	ASU	Structures	WHR	Coal grinding system	Cyclones	Others
TPC [M€]	48.28	48.58	25.63	25.76	16	4.23	5.07

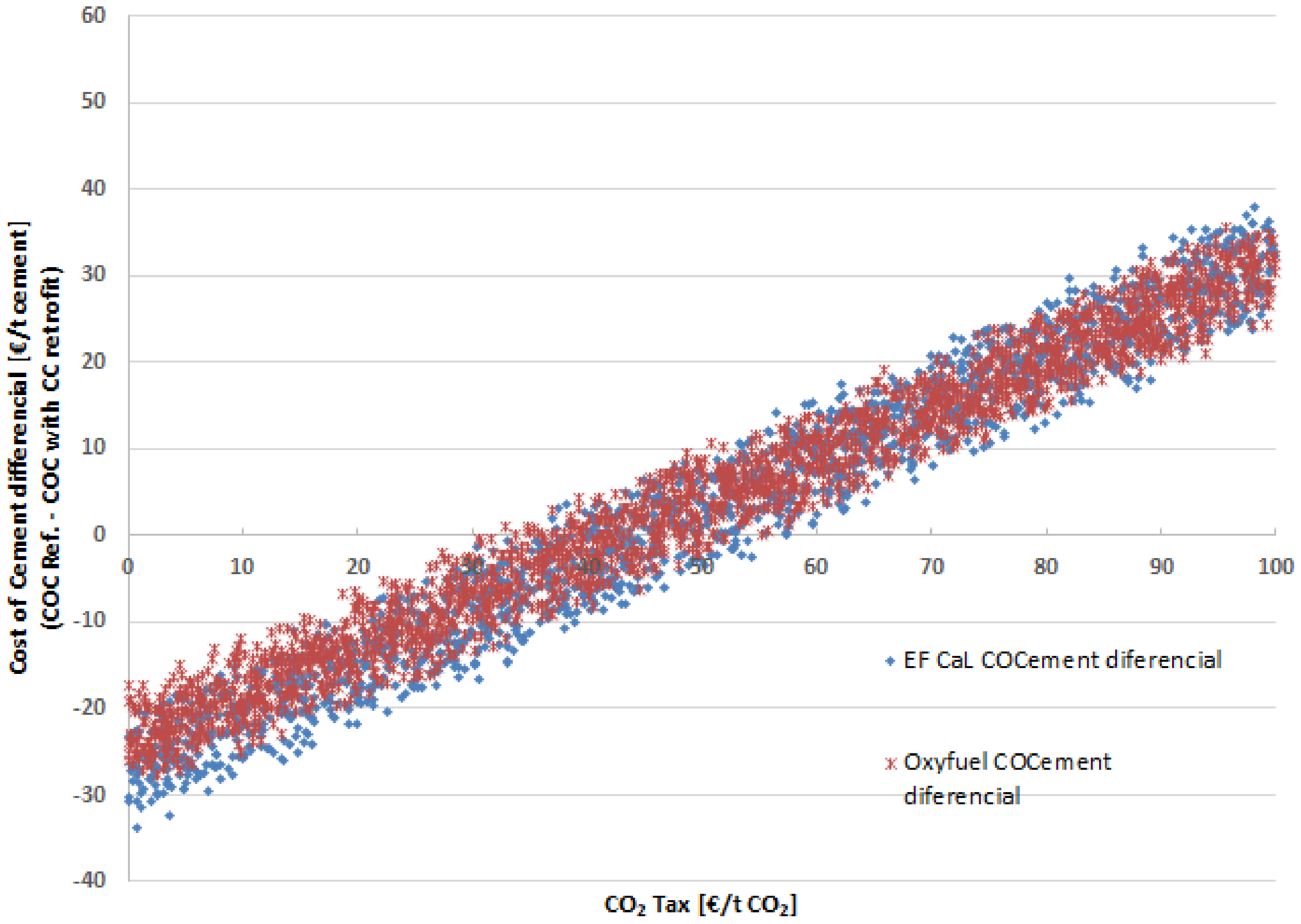
WP 6 – D6.3: Full economic analysis of cement plants equipped with CaL



Interpretation:

- Cost of cement differential < 0 → more economic to pay CO_2 allowances
- Cost of cement differential = 0 → breakeven range
- Cost of cement differential > 0 → more economic to install EF Cal than pay CO_2 tax (without CO_2 transport and storage)

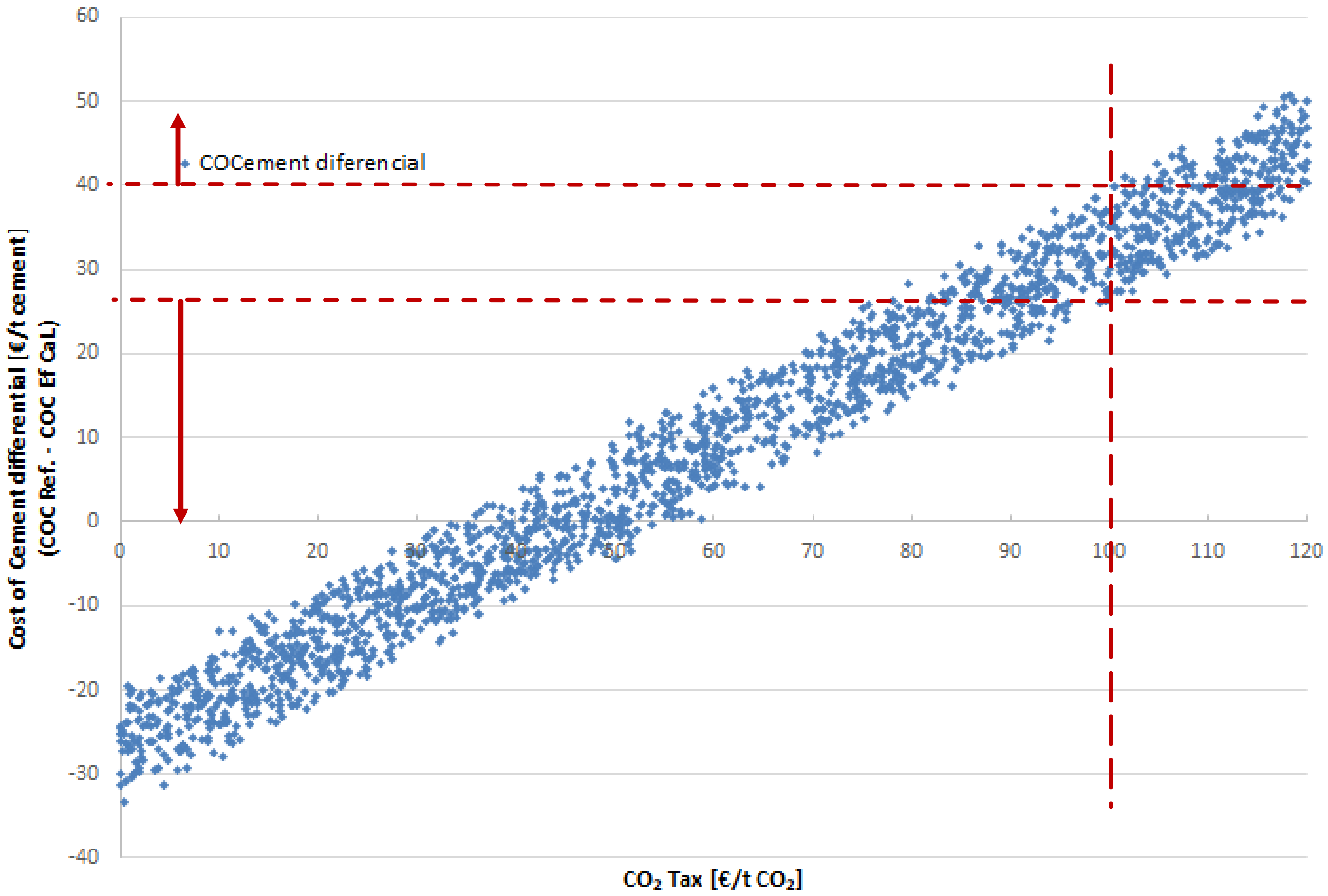
WP 6 – D6.3: Full economic analysis of cement plants equipped with CaL



Benchmarking of EF CaL against Oxyfuel:

- No clear winner
- Case by case assessment is required

WP 6 – D6.3: Full economic analysis of cement plants equipped with CaL



Including CO_2 transport and storage cost and CO_2 price at 100 €/t:

- **CO_2 transport and storage cost > 40 €/t cement → more economic to pay CO_2 allowances**
- **CO_2 transport and storage cost in the range 25 to 40 €/t cement → evaluate case by case**
- **CO_2 transport and storage cost < 25 €/t cement → more economic to invest in CC with EF CaL**

WP 6 – D6.3: Full economic analysis of cement plants equipped with CaL

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Conclusions:

- CO_2 price higher than 65 €/tCO_2 is required to make this technology interesting under the boundary conditions and respective uncertainty ranges chosen (excluding transport and storage)
- At current CO_2 prices of around 100 €/tCO_2 , only an increment on cement cost allocated to CO_2 transport and storage lower than 25 €/t cement would make EF CaL economic viable.
- Strategies to decrease the ASU and CPU size shall be developed
  - optimization of the carbonation efficiency and ratio $\dot{m}_{CaO}$ / $\dot{m}_{CO2_{captured}}$ is fundamental
  - synergies with other technologies shall be evaluated (e.g. water electrolysers)
- Structures account for 15% of TPC. Depending on plant layout, it might be even higher
- An FEED project in a real plant should be performed. It is fundamental in order to have a higher certainty on CAPEX and a better understanding of the complexity associated to retrofitting a cement plant with EF CaL.

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WP 6 – D6.3: Full economic analysis of cement plants equipped with CaL

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Conclusions (cont.):

- The use of “air slides” for transporting hot materials between both reactors might be a good technical option and will not have a relevant impact on TPC
- Experimental campaigns revealed that the carbonator can be 33% shorter than first envisaged. The carbonator with the new length represents only around 1% of TPC → further optimization will not have any relevant impact on the TPC
- Results are strongly dependent on the boundary conditions chosen:
  - 1) Cost of utilities (CaL is sensitive to fuel price; Oxyfuel to electricity price)
  - 2) cement plant operation conditions; ref. case scenario; capture rates; CO_2-Price)

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