Cleanker process analysis and retrofitting

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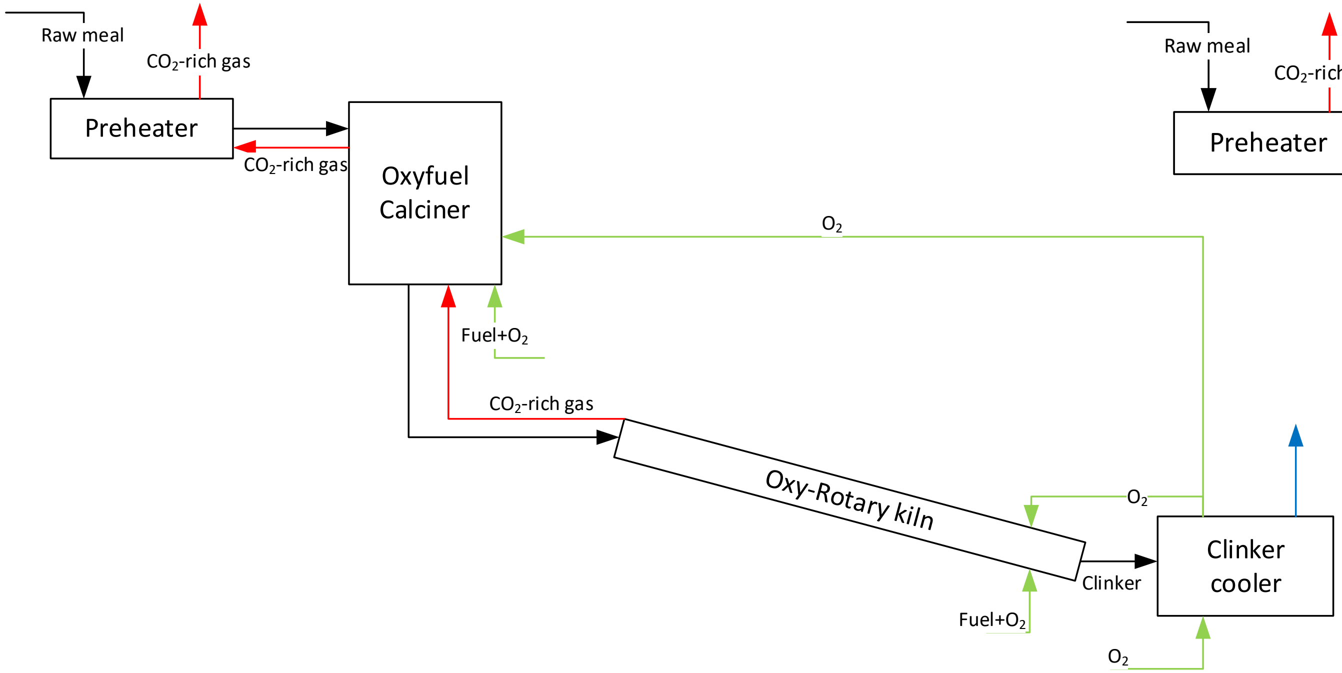
Performances of CaL technologies for low carbon cement production processes

- ***Benchmark technologies: Oxyfuel technologies for CO2 capture in cement plant***

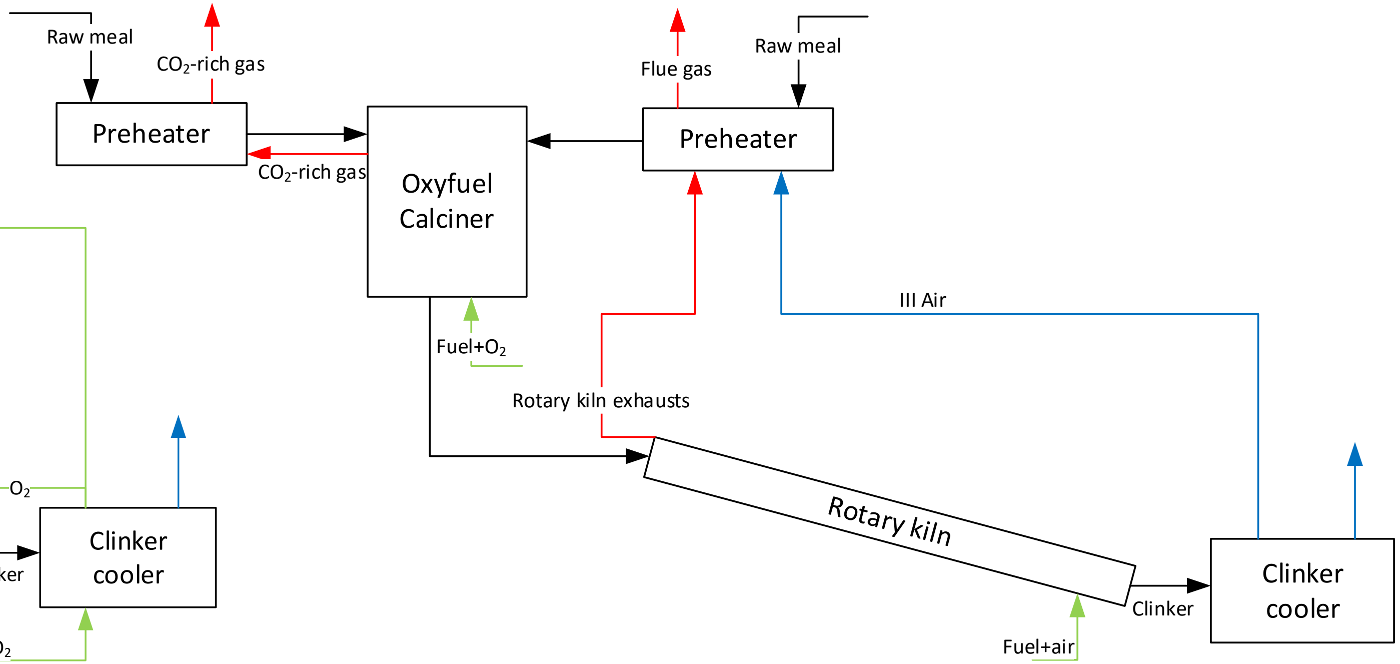
Comprehensive analysis and overview of the advantages and criticalities of Highly integrated CaL technology

Benchmark technologies

Full oxyfuel process



Partial oxyfuel process



Performances of CaL technologies for low carbon cement production processes

- *Benchmark technologies: Tail end CaL system for CO2 capture in cement plant*

Comprehensive analysis and overview of the advantages and criticalities of Highly integrated CaL technology

Benchmark technologies

End-of-pipe process: all cement plant exhaust gas are treated in the carbonator

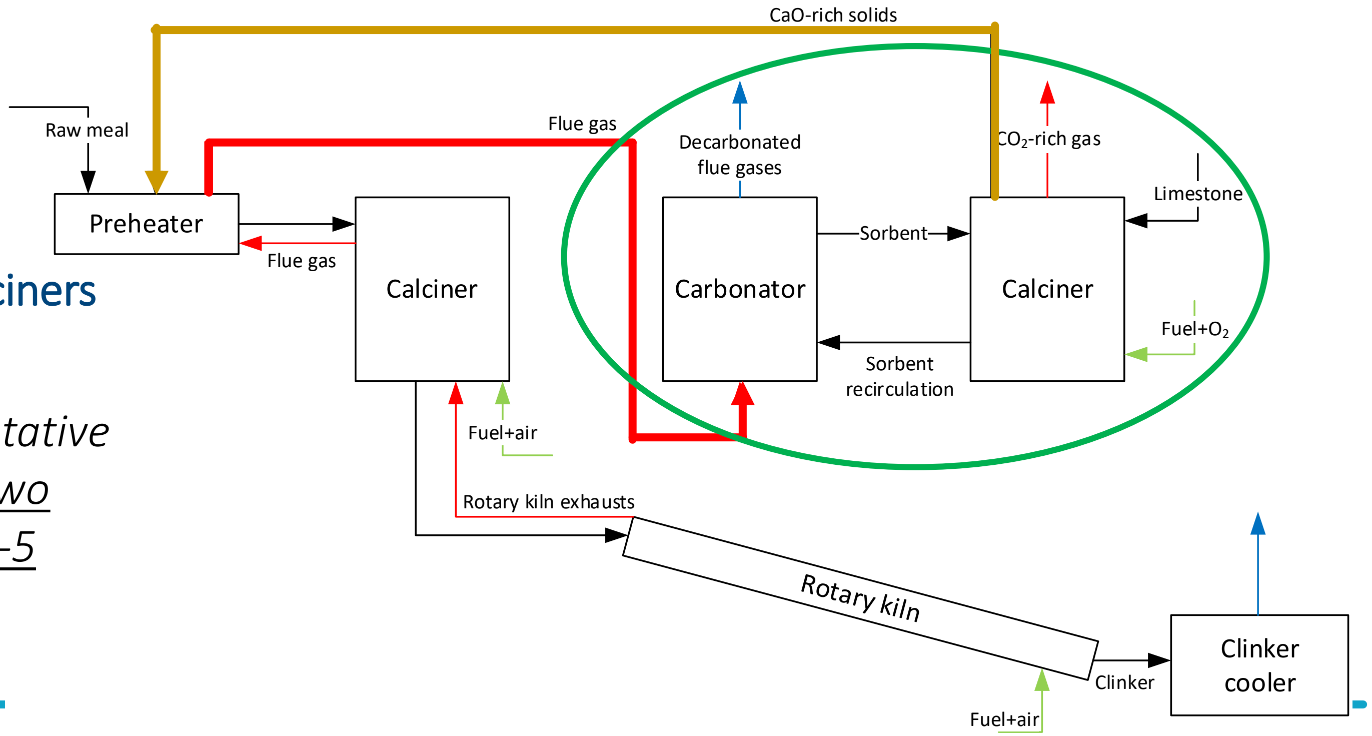
✓ Easily retrofittable

✓ Minimal interactions with the clinker burning process

✓ Exploitation of CaL purge (use for clinker production)

✗ High fuel consumptions, due to the presence of two calciners

The operation of the CaL process in conditions representative for this process has been recently demonstrated in two different facilities at 30 kW$_{th}$ and 200 kW$_{th}$ at TRL 4-5



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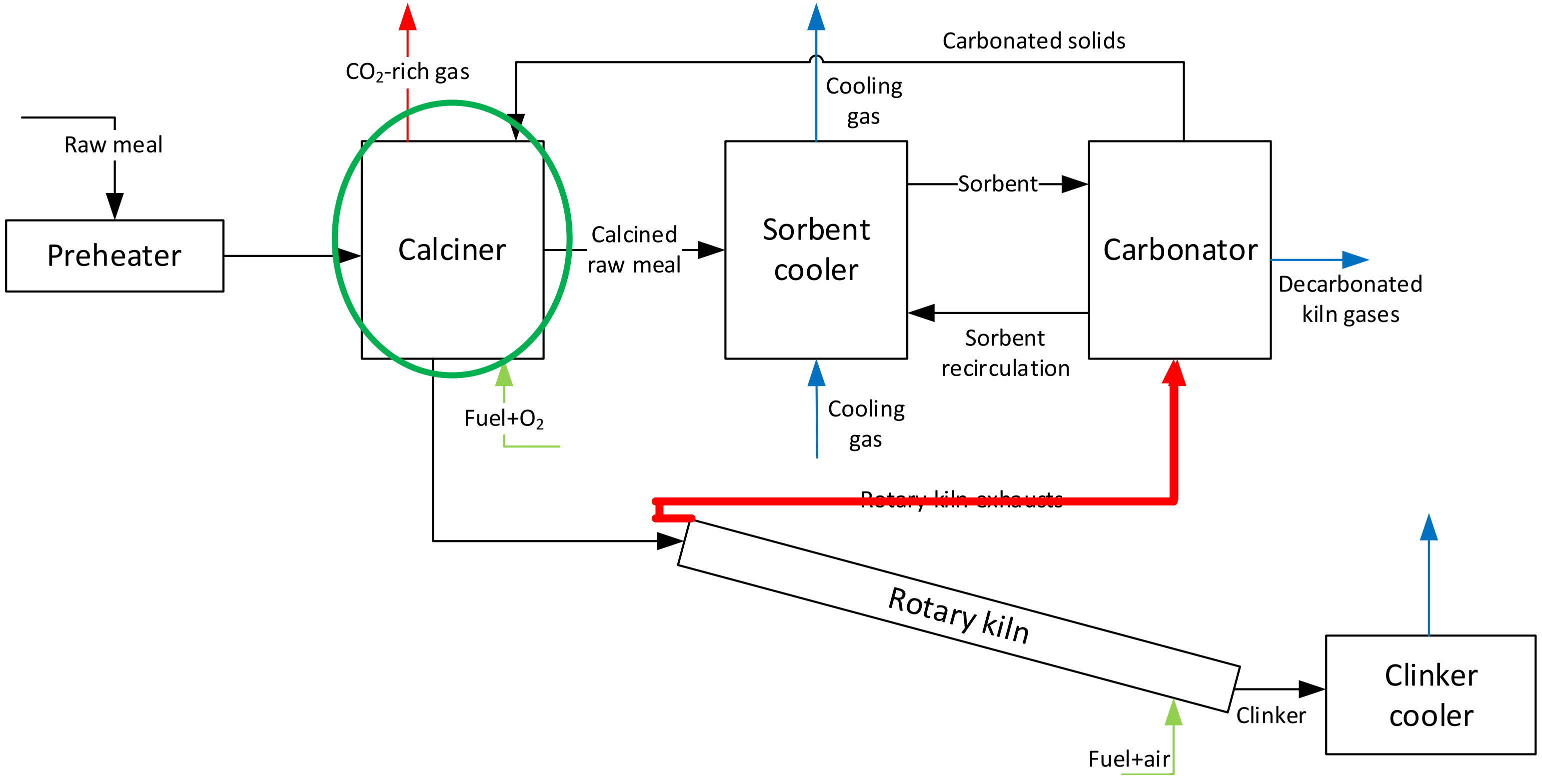
Performances of CaL technologies for low carbon cement production processes

➢ *Integrated CaL technology: process configuration*

Integrated CaL cement kiln: replacement of air-fired precalciner with the oxyfuel CaL calciner

→ *CO_2 from both fuel combustion and raw meal calcination is captured*

- ✓ One single oxy-calciner (instead of CaL calciner + cement plant calciner)
- ✓ Potentially more efficient



Performances of CaL technologies for low carbon cement production processes

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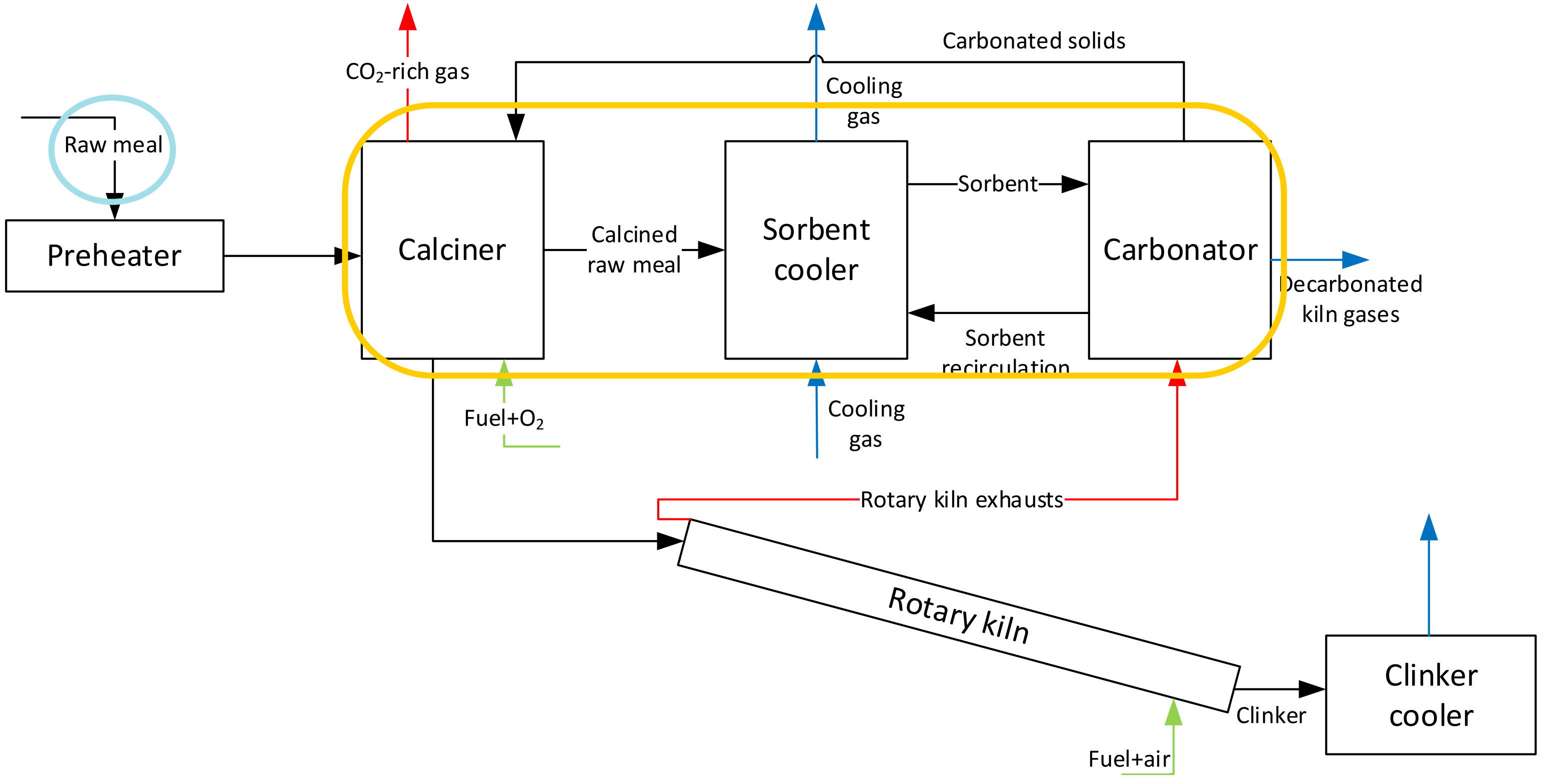
- ✓ Potentially more efficient
- ✗ Technologically uncertain (type of reactors and raw meal used as CO_2-sorbent)



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Performances of CaL technologies for low carbon cement production processes

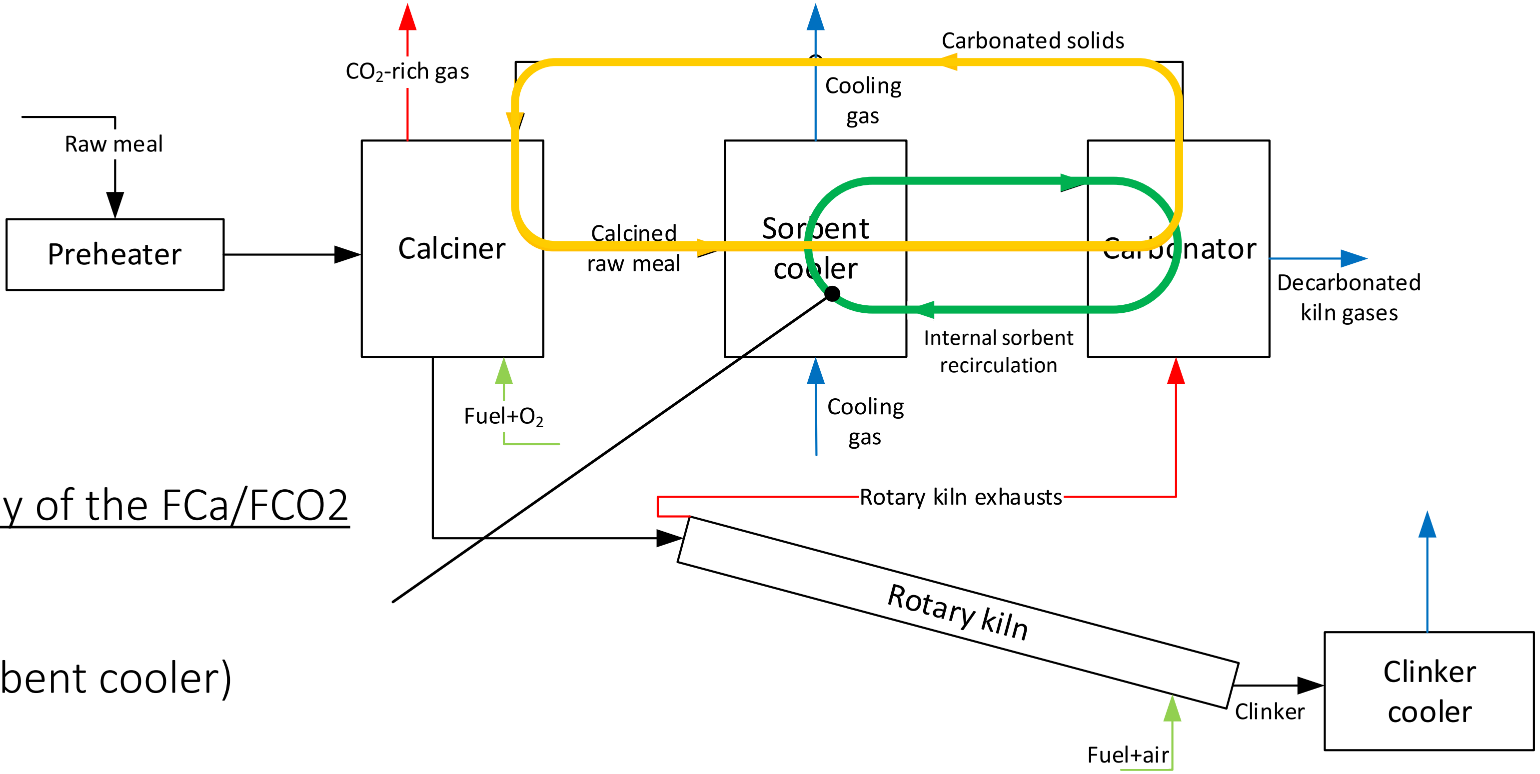
Integrated CaL technology: process configuration

The Integrated EF CaL system has two recirculations of solids:

- a first recirculation between the carbonator and the calciner (which represents the FCa/FCO2 of the system)
- a second recirculation between the carbonator and the sorbent cooler, which is therefore a recirculation within the carbonator

Carbonator inventory independently of the FCa/FCO2

Cooling of the carbonator (with sorbent cooler)



Performances of CaL technologies for low carbon cement production processes

➢ *Definition of Key Performance Indicators*

In order to evaluate the performances of the cement kiln with and without CO_2 capture, the following KPIs are used:

Direct indicators

Direct primary energy consumption (q) [MJ_{LHV}/t_{clk}]: the primary energy consumed through fuel in the plant per unit of clk produced

Direct CO_2 emissions (e_{CO2}) [kg_{CO2}/t_{clk}]: the amount of CO_2 directly emitted at the stack per unit of clk produced

Indirect indicators

Indirect primary energy consumption (q_e) [MJ_{LHV}/t_{clk}]: the primary energy consumption associated to the net electric consumption

$$q_e = \frac{P_e}{\eta_{ref,e}}$$

Indirect CO_2 emissions ($e_{CO2,e}$) [kg_{CO2}/t_{clk}]: the CO_2 emissions associated to the production of the electricity consumed in the process

$$e_{CO_2,e} = P_e \cdot e_{ref,e}$$

Average EU-28 non-CHP energy mix of year 2015	Reference electric efficiency, %	45.9
	Indirect CO_2 emissions factor, kg_{CO_2}/MWh_e	262

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Performances of CaL technologies for low carbon cement production processes

➢ *Definition of Key Performance Indicators*

In order to evaluate the performances of the cement kiln with and without CO_2 capture, the following KPIs are used:

Equivalent indicators

Equivalent primary energy consumption (q_{eq}) [MJ_{LHV}/t_{clk}]: the sum of direct (q) and indirect primary energy (q_e) consumptions

$$q_{eq} = q + q_e$$

Equivalent CO_2 emissions ($e_{CO2,eq}$) [kg_{CO2}/t_{clk}]: total CO_2 emissions, defined as the sum of direct (e_{CO2}) and indirect ($e_{CO2,e}$) emissions

$$e_{CO_2,eq} = e_{CO_2} + e_{CO_2,e}$$

Specific Primary Energy Consumption for CO_2 Avoided (SPECCA) [MJ_{LHV}/kg_{CO2}]: the additional equivalent primary energy consumption to avoid a unit of mass of equivalent CO_2 with respect to the reference plant without a CO_2 capture system (ref)

$$SPECCA = \frac{q_{eq} - q_{eq,ref}}{e_{CO_2,eq\,ref} - e_{CO_2,eq}}$$

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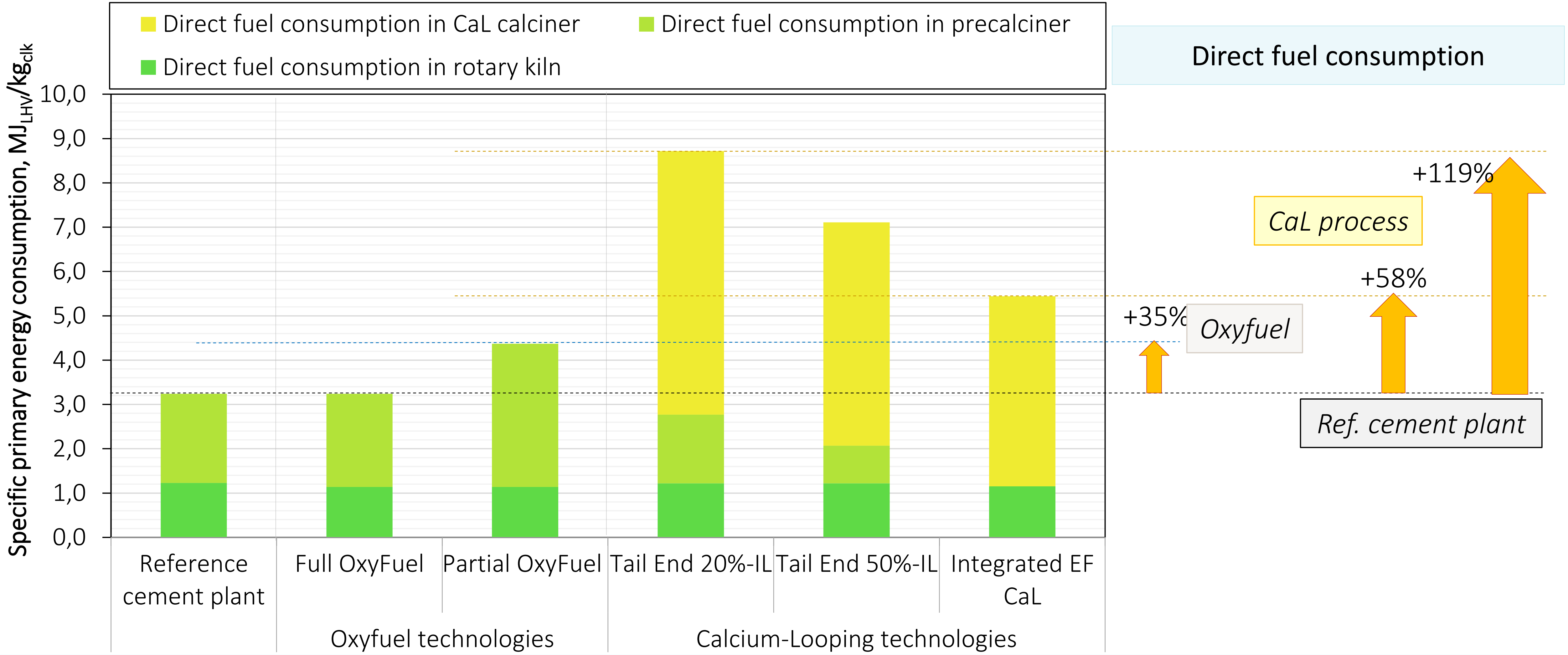
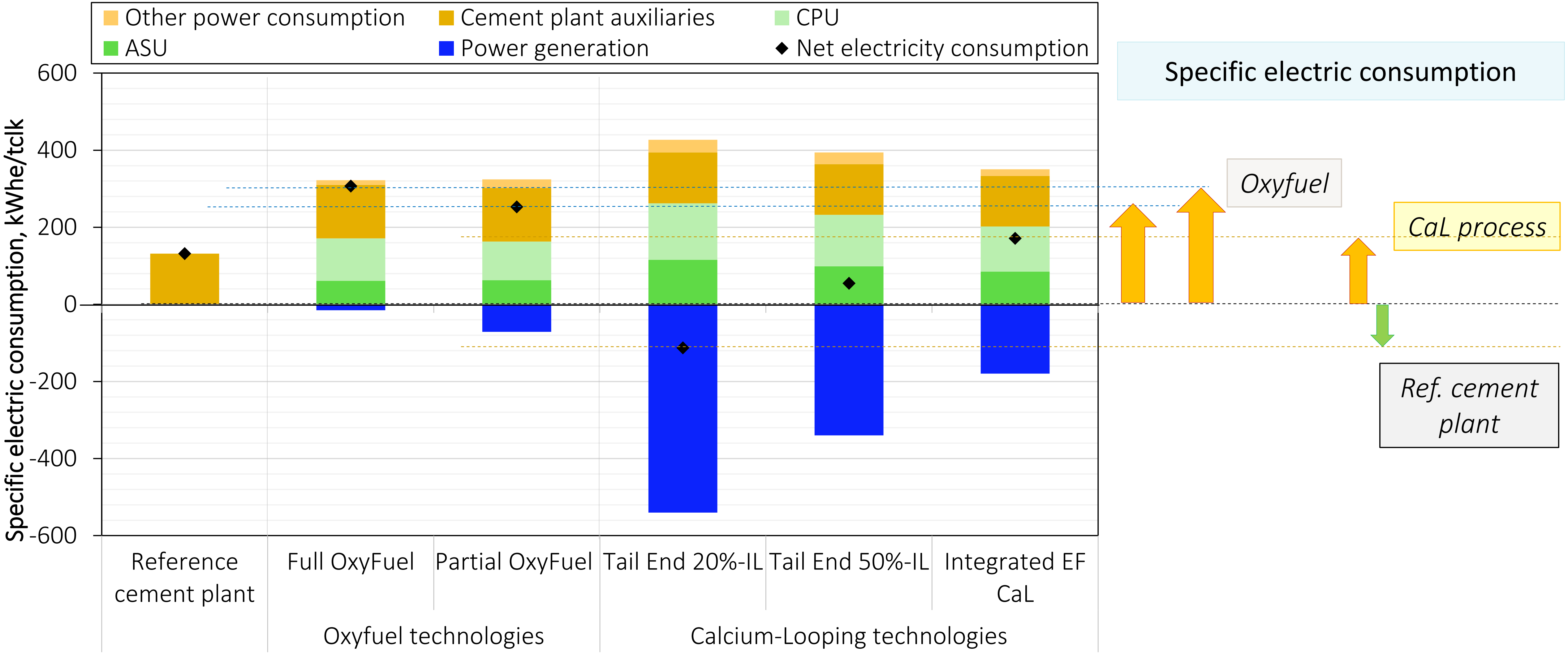
Performances of CaL technologies for low carbon cement production processes

➢ *Comparative analysis*



Performances of CaL technologies for low carbon cement production processes

- *Comparative analysis*



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Performances of CaL technologies for low carbon cement production processes

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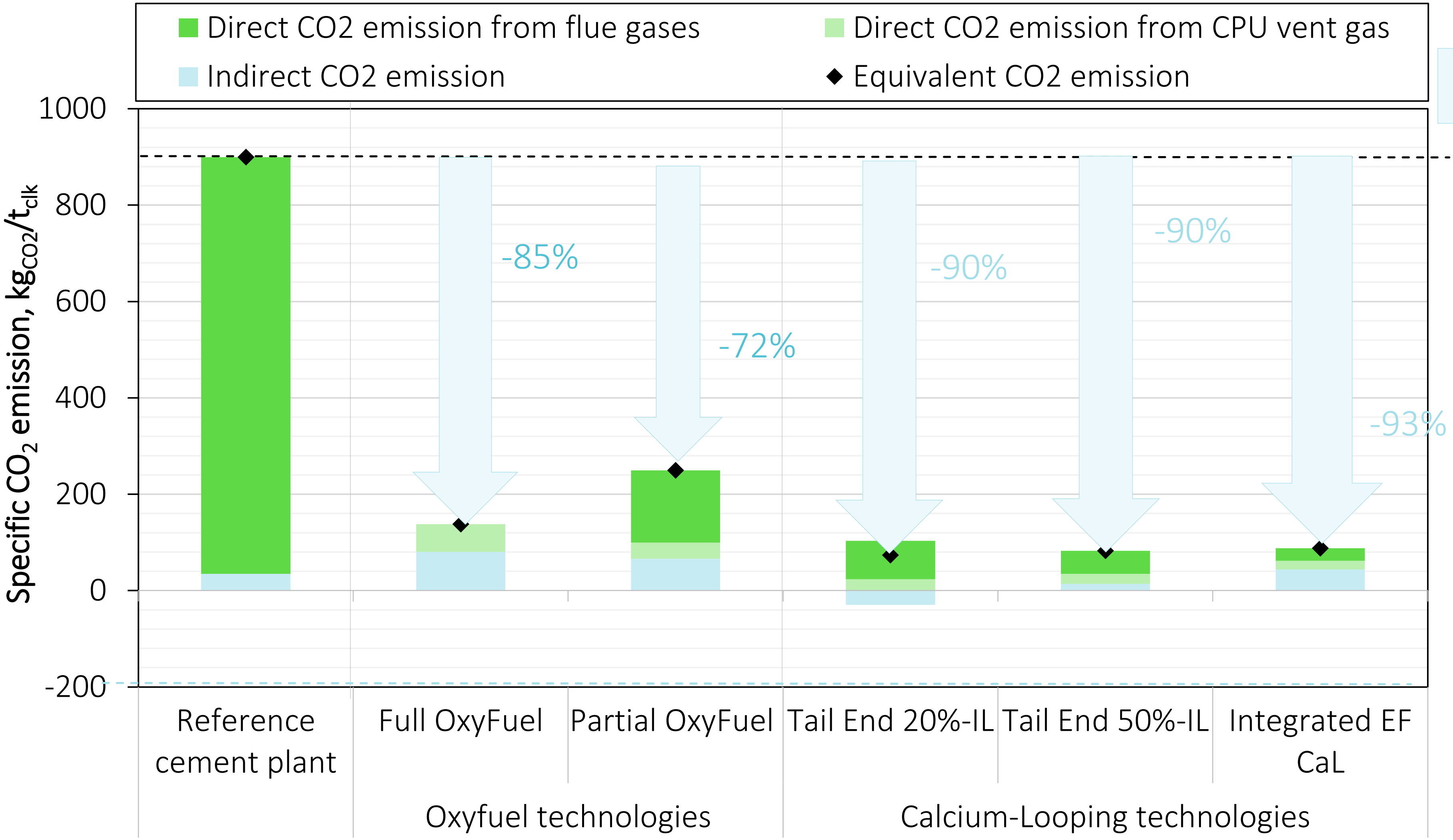

Equivalent CO2 emission

The **Oxyfuel processes** achieve equivalent emission reductions of <u>about 85% (Full) and 72% (Partial)</u>

- **Partial oxyfuel** configuration is the system with the highest equivalent CO_2 emissions (most of them direct)

All **CaL technology processes** achieve equivalent emission reduction of <u>about 90-93%</u>

- **Integrated EF CaL** results as the system with the lowest equivalent CO_2 emissions (most of them indirect)

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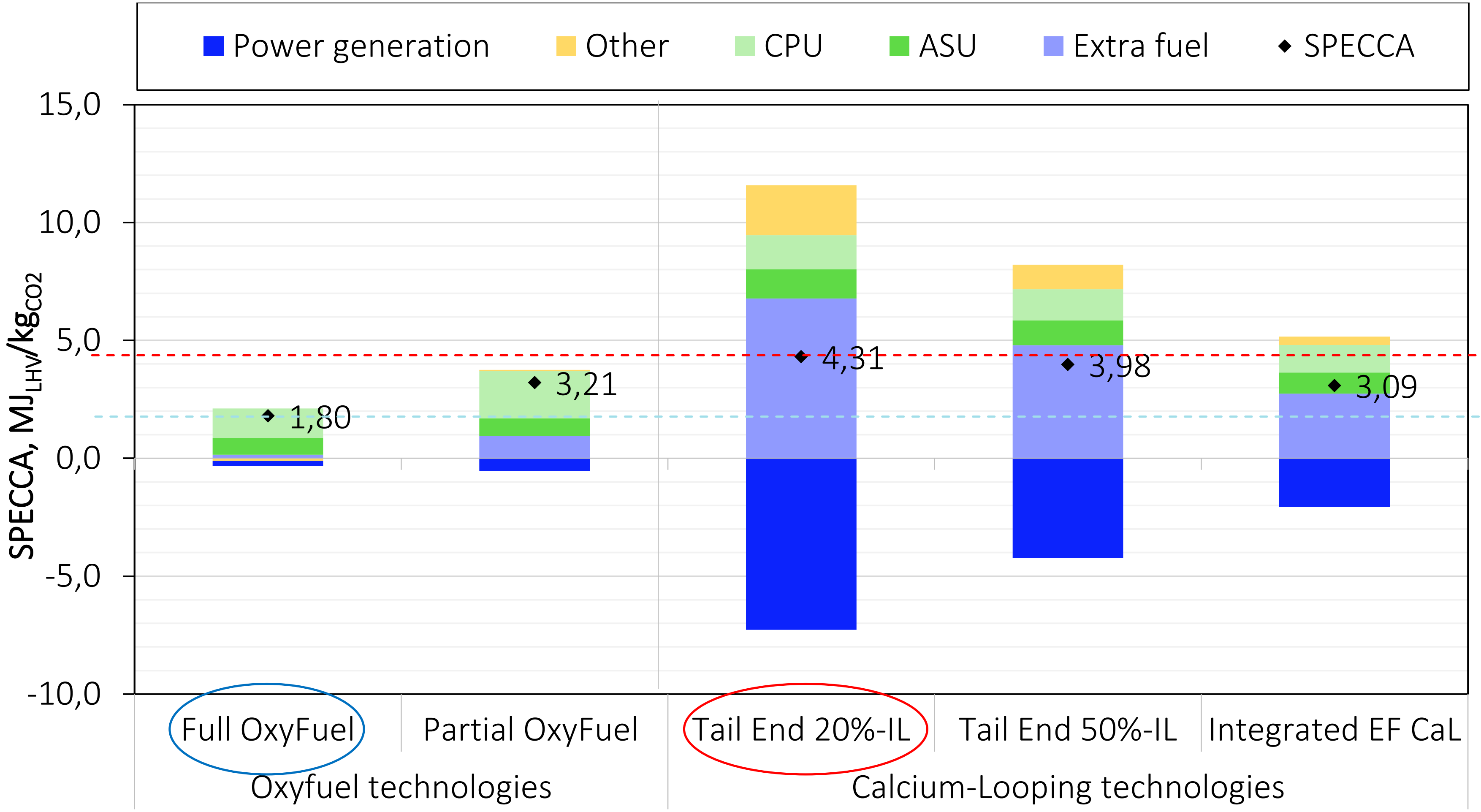
Performances of CaL technologies for low carbon cement production processes

➢ *Comparative analysis*



SPECCA

Tail end CaL

-54%

Full oxyfuel

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Performances of CaL technologies for low carbon cement production processes

- *Integrated CaL technologies: Retrofit vs Greenfield solutions*

	Integrated CaL - Greenfield	**Integrated CaL - Retrofit**
Direct fuel consumption (q) [MW_{LHV} – MJ_{LHV}/kg_{clk}]	157.9 – 4.84	177.2 – 5.44
Direct CO_2 emission (e_{CO2}) [kg/s – kg_{CO2}/t_{clk}]	1.7 – 51.4	1.4 – 44.2
Net electricity consumption (P_e) [MW_e – kWh_e/t_{clk}]	23.4 – 199.7	20.1 – 171.0
EU-28 non-CHP energy mix (2015) (η_e=45.9%, $e_{CO2,e}$ =262 kg_{CO2}/MWh_e)		
Indirect primary energy consumption (q_e) [MW_{LHV} – MJ_{LHV}/kg_{clk}]	51.1 – 1.57	43.7 – 1.34
Equivalent primary energy consumption (q_{eq}) [MW_{LHV} –MJ_{LHV}/kg_{clk}]	208.9 – 6.41	221.0 – 6.78
Indirect CO_2 emission ($e_{CO2,e}$) [kg/s – kg_{CO2}/t_{clk}]	1.7 – 52.3	1.5 – 44.8
Equivalent CO_2 emission ($e_{CO2,eq}$) [kg/s- kg_{CO2}/t_{clk}]	3.4 – 103.7	2.9 – 89.0
Equivalent primary energy consumption increase [%]	50.0	58.6
Equivalent emission reduction [%]	88.5	90.1
SPECCA [MJ_{LHV}/kg_{CO2}]	2.68	3.09

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Performances of CaL technologies for low carbon cement production processes

- *Integrated CaL technologies: Use of alternative fuels*

	Integrated CaL process	
	60%RDF – 40%coal	**100% RDF**
Direct fuel consumption (q) [MW_{LHV} – MJ_{LHV}/kg_{clk}]	202.0 – 6.3	215.9 – 6.7
Direct CO_2 emission (e_{CO2}) [kg/s – kg_{CO2}/t_{clk}]	-1.5 – -47.9	-4.2 – -130.0
Net electricity consumption (P_e) [MW_e – kWh_e/t_{clk}]	14.8 – 127.0	11.9 – 102.1
EU-28 non-CHP energy mix (2015) (η_e=45.9%, $e_{CO2,e}$ =262 kg_{CO2}/MWh_e)		
Indirect primary energy consumption (q_e) [MW_{LHV} – MJ_{LHV}/kg_{clk}]	32.2 – 1.0	25.9 – 0.8
Equivalent primary energy consumption (q_{eq}) [MW_{LHV} –MJ_{LHV}/kg_{clk}]	234.2 – 7.3	241.8 – 7.5
Indirect CO_2 emission ($e_{CO2,e}$) [kg/s – kg_{CO2}/t_{clk}]	1.1 – 33.3	0.9 – 26.8
Equivalent CO_2 emission ($e_{CO2,eq}$) [kg/s- kg_{CO2}/t_{clk}]	-0.5 – -14.6	-3.3 – -103.2
Equivalent primary energy consumption increase [%]	62.0	62.6
Equivalent emission reduction [%]	102.0	116.1
SPECCA [MJ_{LHV}/kg_{CO2}]	3.62	3.86

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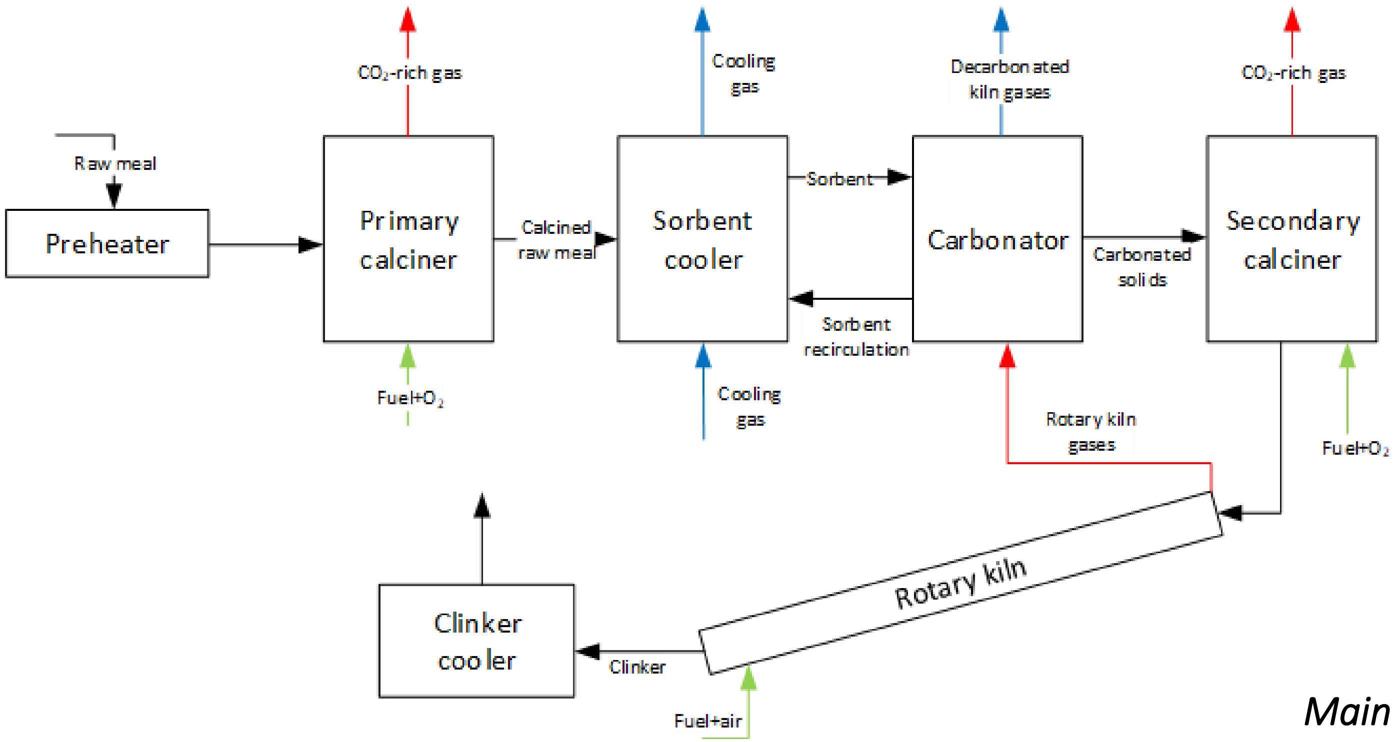
Performances of CaL technologies for low carbon cement production processes

Du-CaL process



PCT patent filed WO/2023/002430
Matteo C. Romano, Edoardo De Lena, Maurizio Spinelli: ASSEMBLY FOR REDUCING CO_2 EMISSION IN PLANTS FOR CLINKER PRODUCTION
https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2023002430&_cid=P20-LEVPST-80572-1

Dual-calciner CaL (Du-CaL) configuration

once-through process
w/o carbonator-calciner recirculation

Main advantages: ✓

1. Improved process controllability (once-through)
2. Improved sorbent activity (1 single calcination experienced) and sufficient availability ($F_{Ca}/F_{CO2} \approx 4$)
3. Increased reliability for clinker production, by disconnecting carbonator and secondary calciner, if needed.

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Performances of CaL technologies for low carbon cement production processes

	Du-CaL		**Integrated EF CaL**
	60m-long	**120m-long**	
Direct fuel consumption (q), MJ_{LHV}/kg_{clk}	5.11	5.04	5.44
Direct CO_2 emission (e_{CO2}), kg_{CO2}/t_{clk}	44.0	45.3	44.2
Direct emission reduction, %	94.9%	94.8%	94.9%
Energy mix (2015) EU-28 non-CHP			
Indirect fuel consumption (q_e), MJ_{LHV}/kg_{clk}	1.48	1.50	1.34
Equivalent fuel consumption (q_{eq}), MJ_{LHV}/kg_{clk}	6.59	6.54	6.78
Indirect CO_2 emission ($e_{CO2,e}$), kg_{CO2}/t_{clk}	49.3	50.1	44.8
Equivalent CO_2 emission ($e_{CO2,eq}$), kg_{CO2}/t_{clk}	93.3	95.4	89.0
Equivalent fuel consumption increase, %	54.1%	53.1%	58.6%
Equivalent emission reduction, %	89.6%	89.4%	90.1%
SPECCA, MJ_{LHV}/kg_{CO2}	2.87	2.82	3.09

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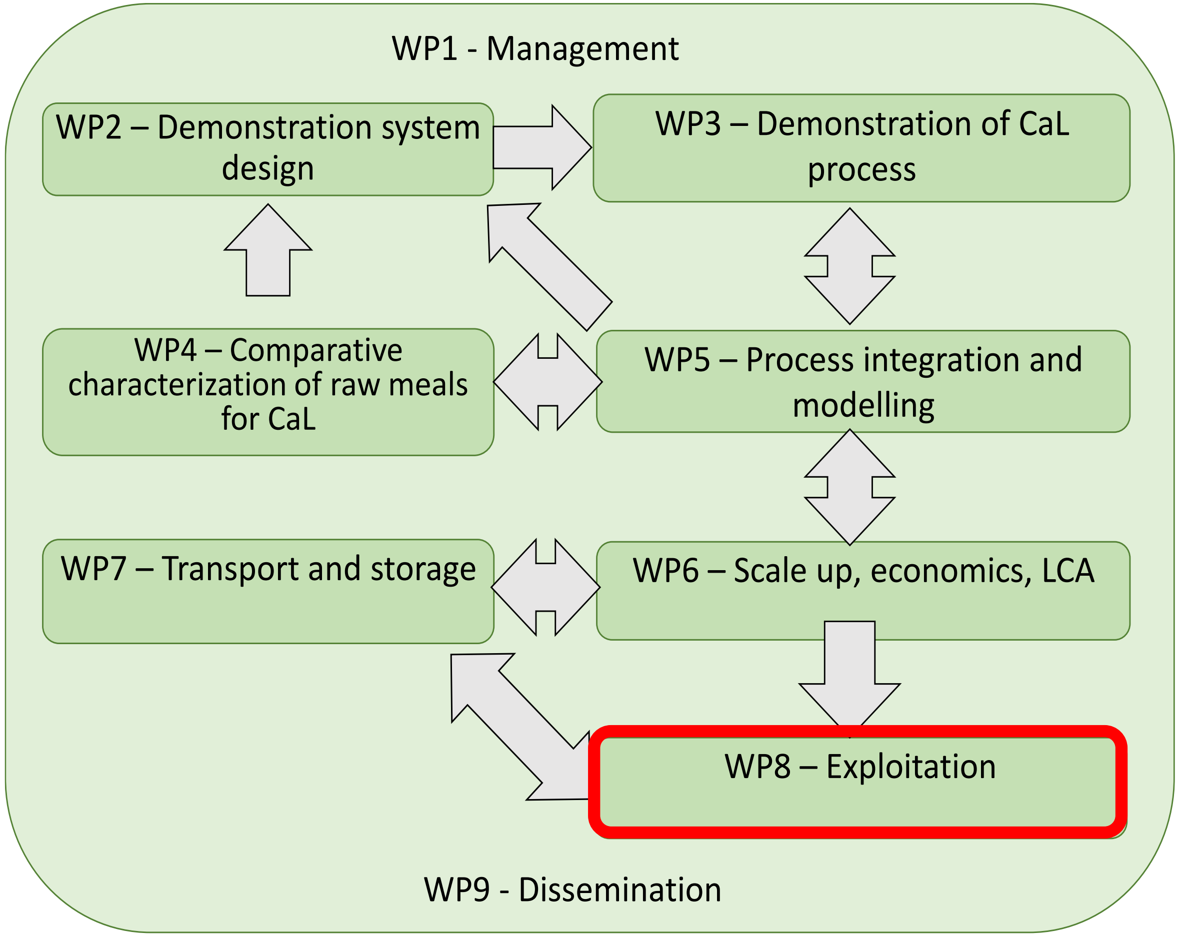
Introduction

The framework of the following study lies within the **exploitation work package of the CLEANKER project: conceptual scale-up of the integrated Calcium Looping system (CaL)**

The present work describes the potential retrofit of an **existing cement plant** with **carbon capture technologies** applied in two sequential steps:

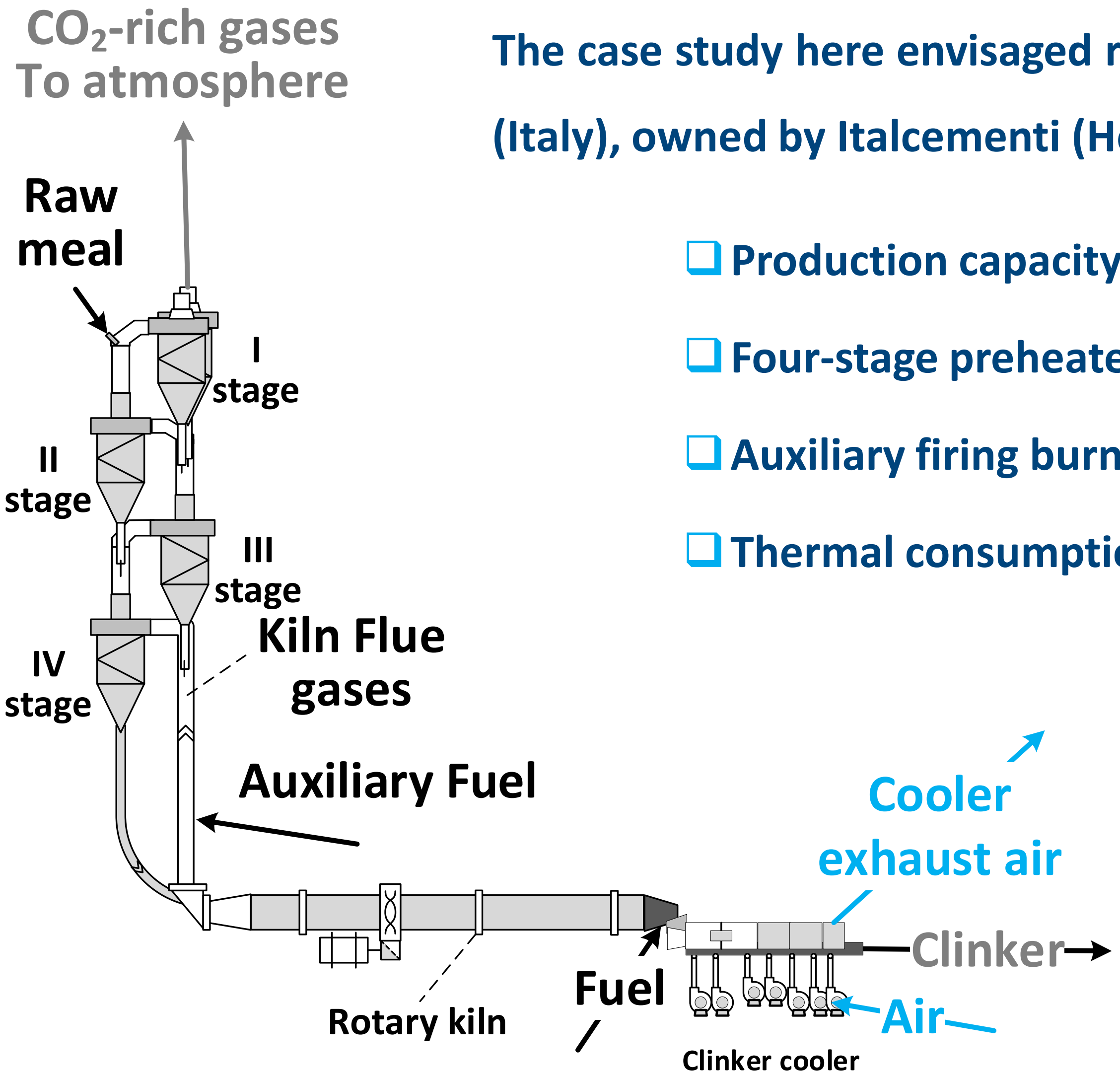
- Implementation of the **partial oxyfuel** concept
- Final retrofit of the **integrated calcium looping (CaL)** process



Introduction – Colleferro cement plant

The case study here envisaged refers to the existing cement plant located in Colleferro (Italy), owned by Italcementi (HeidelbergCement group)

- **Production capacity of about 0.5 Mt_{cem}/y**
- **Four-stage preheater (I stage double) tower without precalciner section**
- **Auxiliary firing burner at kiln back end**
- **Thermal consumption of 3544 MJ/t_{clk}**



Conceptual scheme of the Colleferro cement plant in the current configuration

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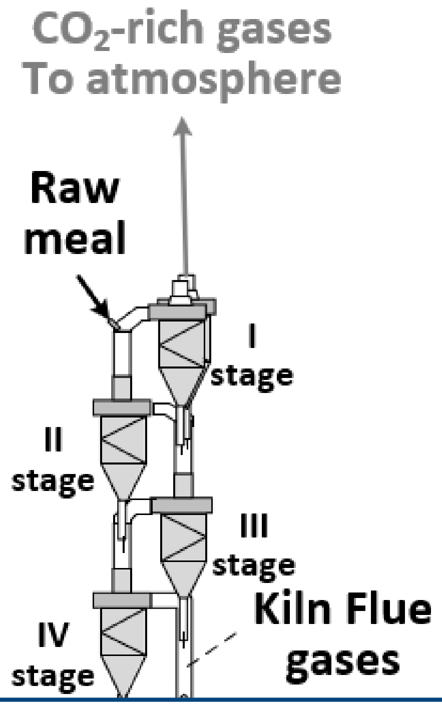
Introduction – Colleferro cement plant



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- ☐ **Auxiliary firing burner at kiln back end**
- ☐ **Thermal consumption of 3544 MJ/t_{clk}**

- ➢ **This reference case has been implemented and simulated in Aspen Plus V10.0®**
- ➢ **Mass & energy balances of the process model have been calibrated with real data from the plant**
- ➢ **The validated reference case served as starting point for the assessment of the partial oxyfuel and integrated CaL configurations in the process simulation software**

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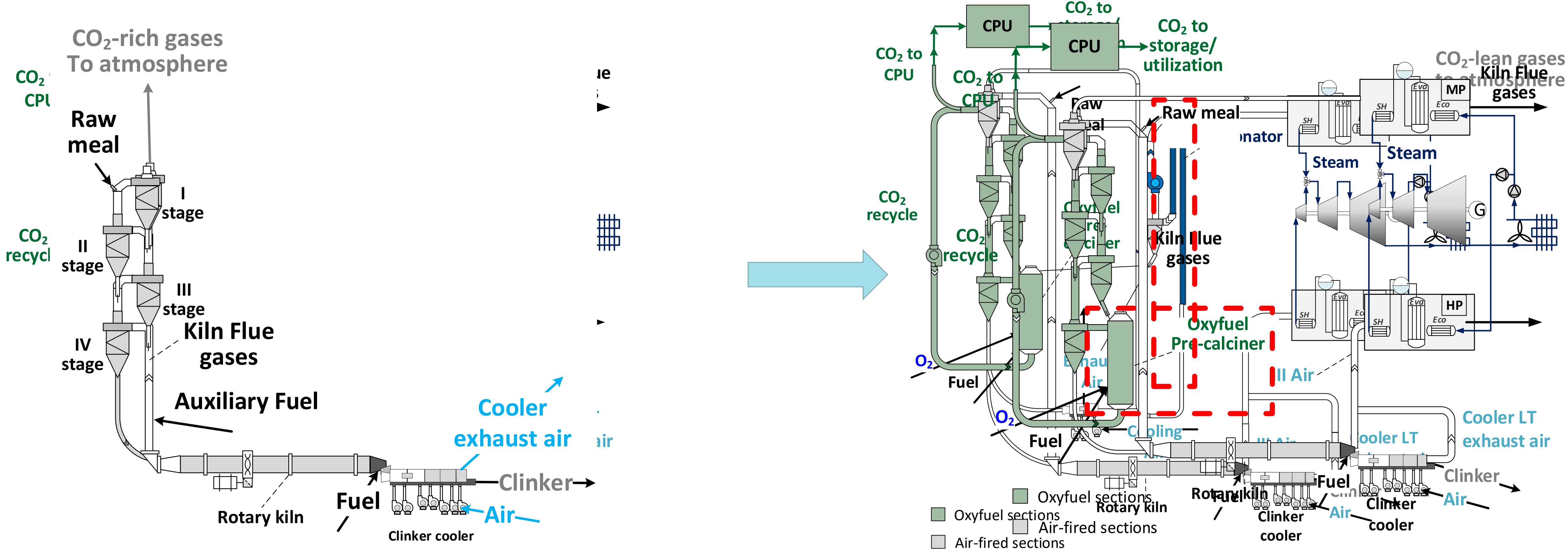
Introduction – The retrofit pathway

- The first retrofit step requires installation of an oxy-fired entrained flow (EF) calciner, a CO_2 recirculation duct, an Air Separation Unit (ASU), a CO_2 purification unit (CPU) and a heat recovery power plant
- Subsequently, the integrated CaL configuration is assessed via the installation of an EF carbonator



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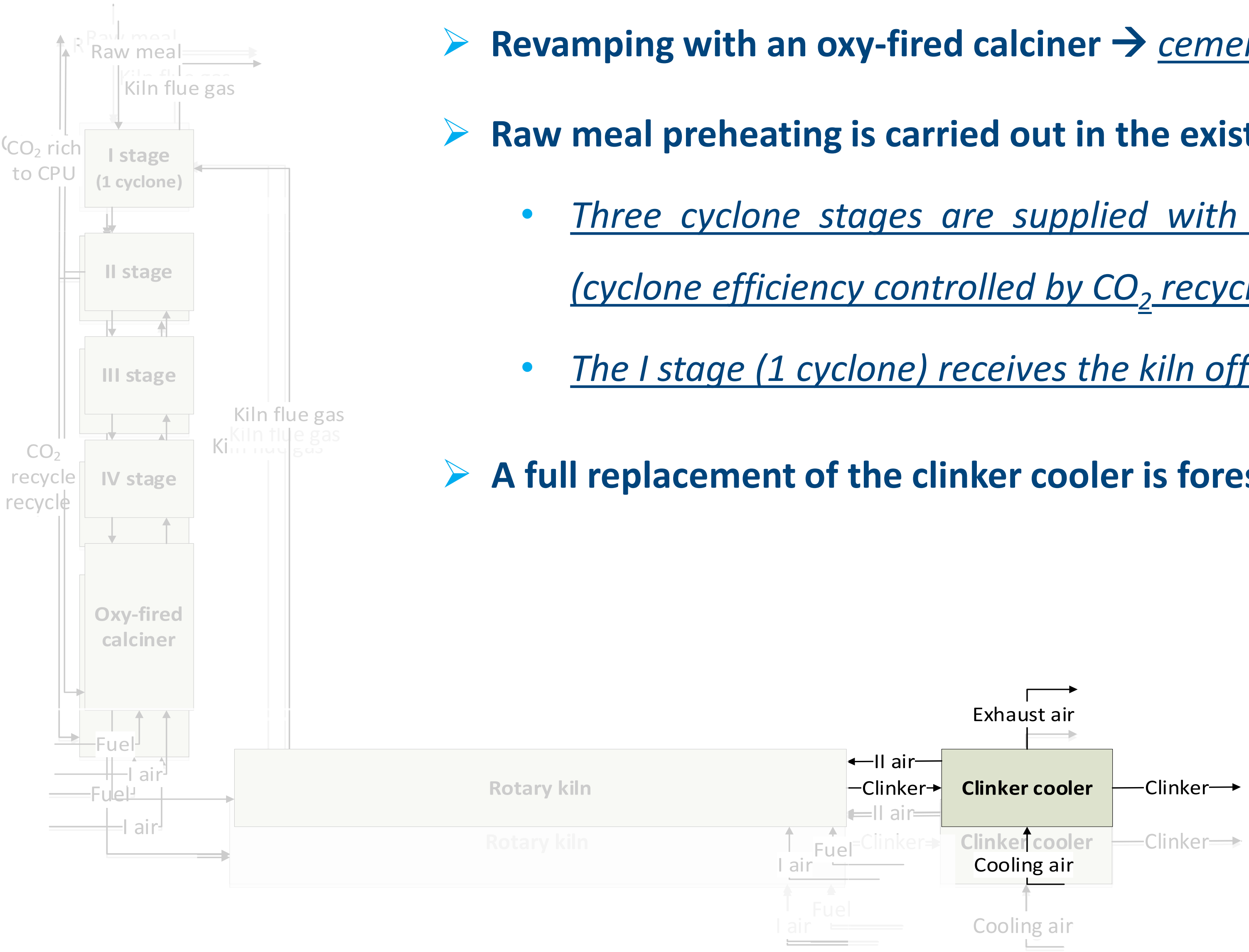
Aspen Plus methodology – Partial oxyfuel model



- **Revamping with an oxy-fired calciner → *cement plant productivity increased by 30%***
- **Raw meal preheating is carried out in the existing four-stage tower (hybrid set up):**
  - *Three cyclone stages are supplied with the CO_2 rich gas from the oxy-calciner (cyclone efficiency controlled by CO_2 recycle)*
  - *The I stage (1 cyclone) receives the kiln off gas (avoiding CO_2 dilution)*
- **A full replacement of the clinker cooler is foreseen to face the increased productivity**

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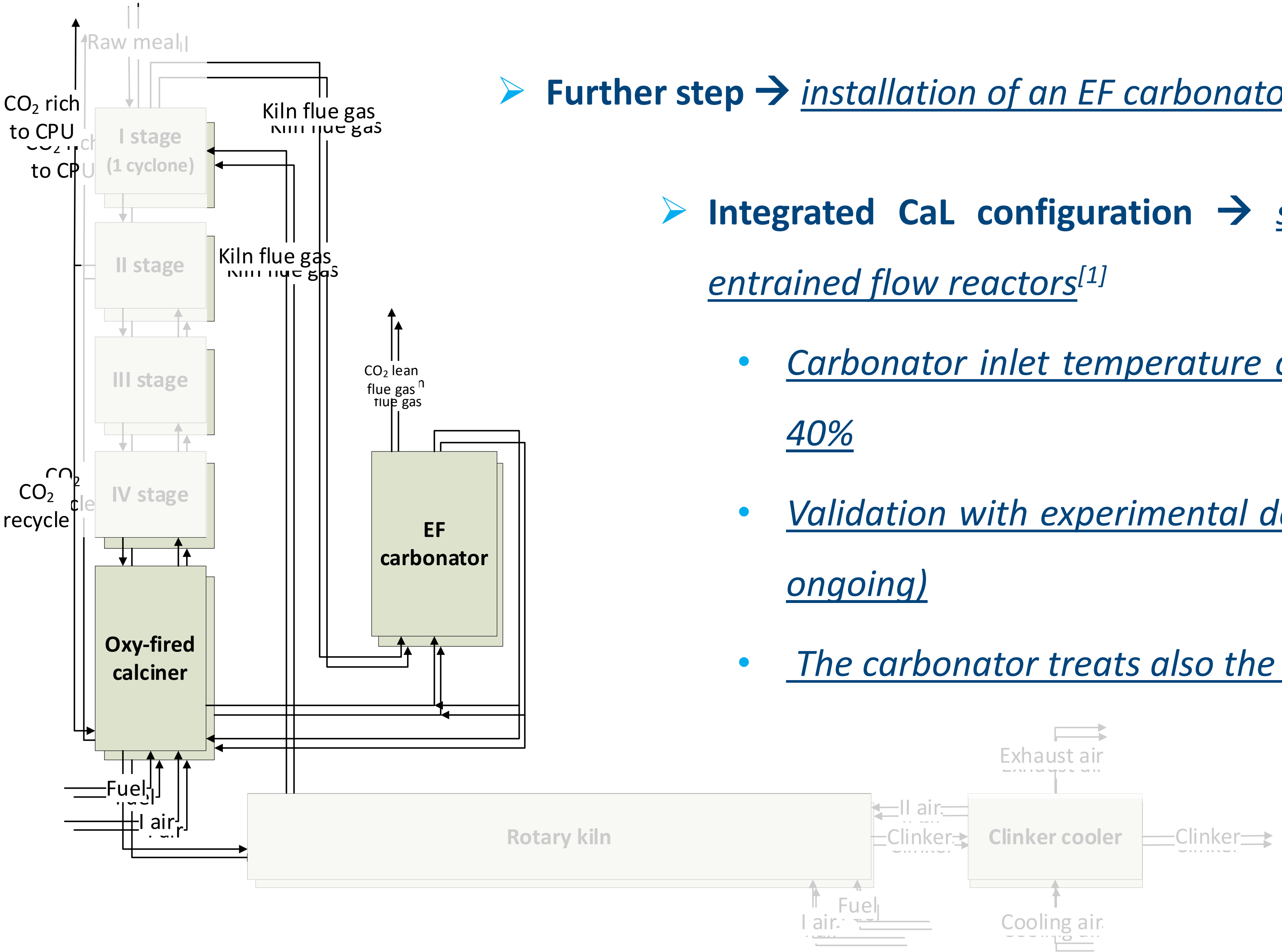
Aspen Plus methodology – Integrated CaL model



- **Further step** → *installation of an EF carbonator (decarbonize kiln effluents)*
  - **Integrated CaL configuration** → *simulated with 1D models of the entrained flow reactors*[1]
    - *Carbonator inlet temperature of 600 °C (controlled),* X_{MAX} *equal to 40%*
    - *Validation with experimental data from CLEANKER campaigns (still ongoing)*
    - *The carbonator treats also the vent gas from the CPU*

[1] Spinelli et al., 2018, Chem Eng Sci 191

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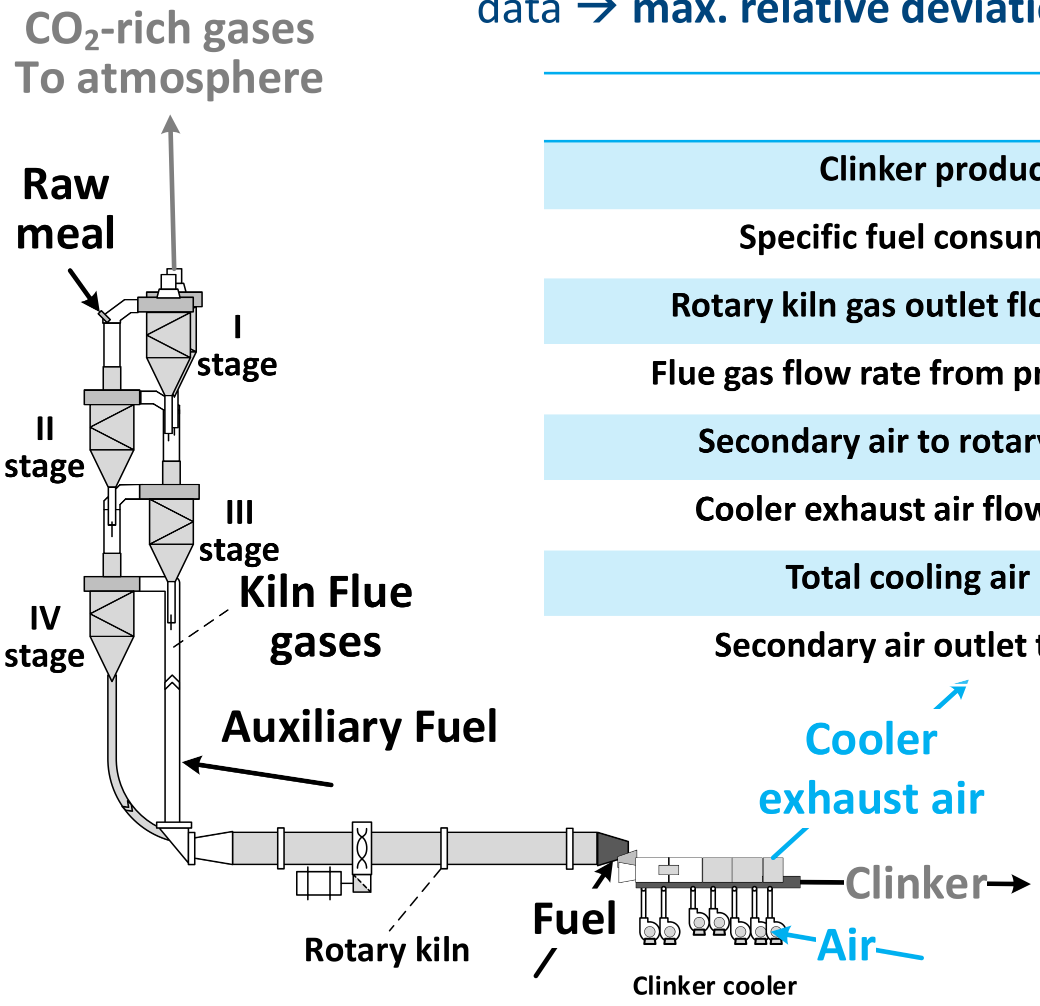
Model results – Cement plant validation

- Good agreement between the Aspen model of the reference case and the plant data → **max. relative deviation < 6%** between main KPIs

	Colleferro plant	Model results	Relative deviation
Clinker production [tpd]	1252	1260	0.64%
Specific fuel consumption [MJ/t_{clk}]	3544	3680	3.7%
Rotary kiln gas outlet flow rate [Nm^3/kgclk]	0.98	1.29	31.38%
Flue gas flow rate from preheater [Nm^3/kgclk]	1.61	1.62	0.92%
Secondary air to rotary kiln [Nm^3/kgclk]	0.80	0.78	-3.1%
Cooler exhaust air flow rate [Nm^3/kgclk]	1.21	1.21	0.58%
Total cooling air [Nm^3/kgclk]	2.14	2.12	-0.8%
Secondary air outlet temperature [°C]	798	750	6.6%



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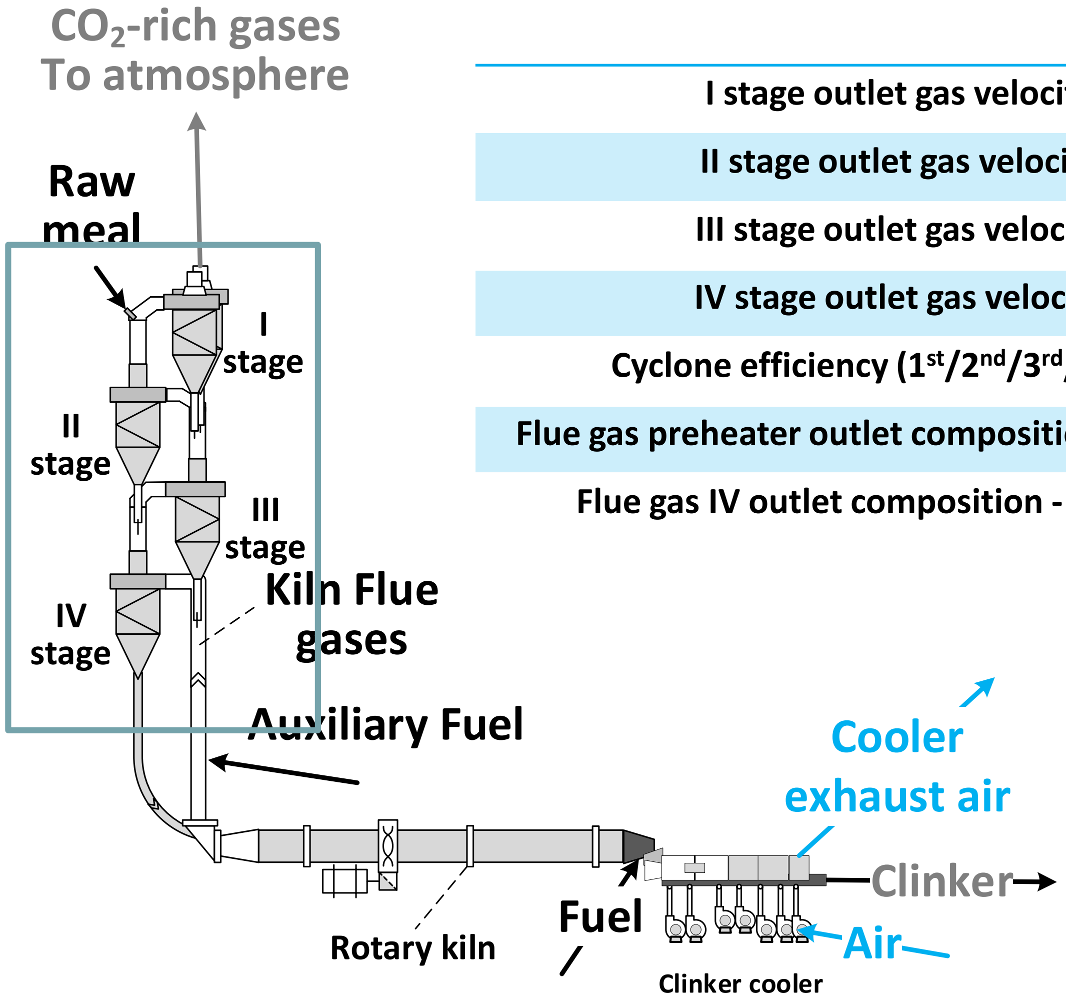
Model results – Cement plant validation



	Colleferro plant	Model results	Relative deviation
I stage outlet gas velocity [m/s]	14.1	14.8	4.6%
II stage outlet gas velocity [m/s]	21.9	23.1	5.7%
III stage outlet gas velocity [m/s]	15.5	15.6	0.86%
IV stage outlet gas velocity [m/s]	15.7	16.0	2.01%
Cyclone efficiency (1st/2nd/3rd/4th stage) [%]	-	92.0/80.1/77.1/75.6	-
Flue gas preheater outlet composition - CO_2 [% mol,dry]	29.7	29.7	-0.14%
Flue gas IV outlet composition - CO_2 [% mol,dry]	33.4	33.4	-0.08%

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Model results – Partial oxyfuel

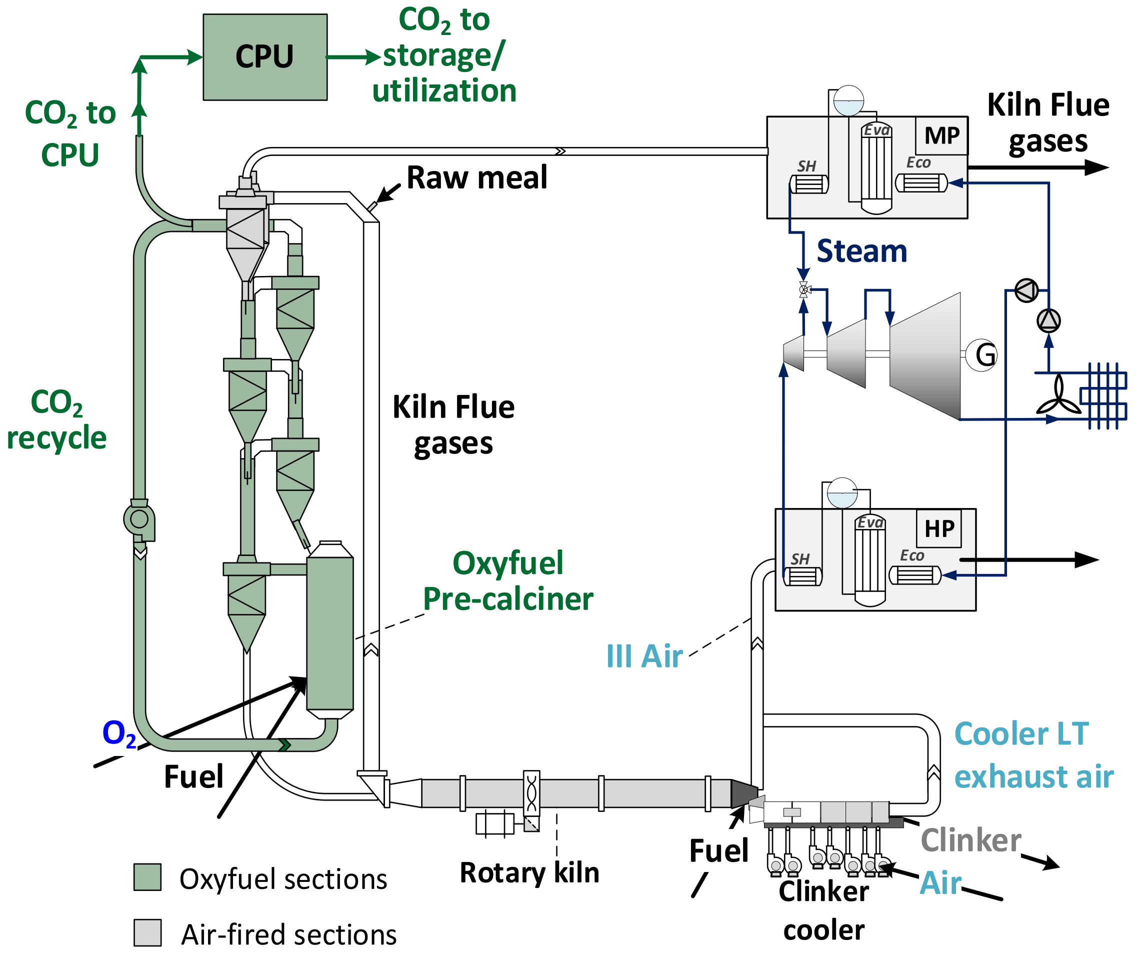
- The increased productivity of the plant due to the installation of the calciner results in a clinker production of **2541 tpd** (almost 100% increase)

- The specific fuel consumption from the model corresponds to **4308 MJ/t_{clk} (17.05% more)**

- Partition fuel **calciner – rotary kiln 69% – 31%**

- Rotary kiln effluents have been reduced, resulting in an outlet gas velocity of **6.5 m/s (31% reduction)**

- **CO_2 emission are reduced by 73.6%** (from 905 $kgCO_2/t_{clk}$ to 239 $kgCO_2/t_{clk}$)



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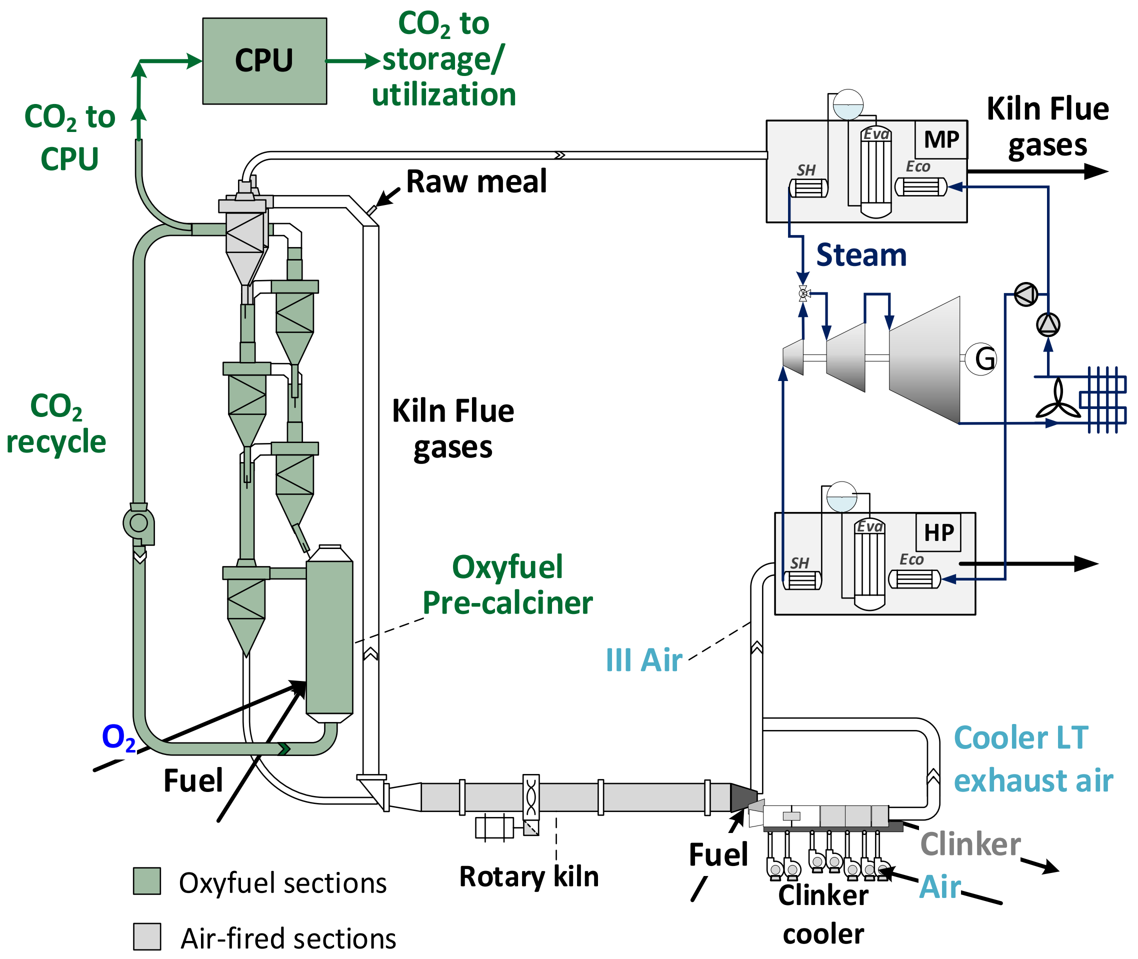
Model results – Partial oxyfuel

	Reference case	Partial oxyfuel
Cyclone efficiency (1st/2nd/3rd/4th stage) [%]	91.9/80.0/77.0/75.4	96/84/79/80
I stage outlet gas velocity [m/s]	14.6	17.1
II stage outlet gas velocity [m/s]	22.8	23.2
III stage outlet gas velocity [m/s]	15.4	15.8
IV stage outlet gas velocity [m/s]	15.9	18.1

- Specific electrical consumption for CO_2 capture (ASU and CPU) = 148.1 kWh/t_{clk}
- Waste heat available (T > 250°C) = 21.9 MW_{th}
- Gross electricity production ($\eta_{el,gross}$ = 29.1%) = 6.3 MW_e
- Net electricity demand for CO_2 capture = 88 kWh/t_{clk}
- Electricity demand is increased by 169% (51.9 kWh/t_{clk} base case)



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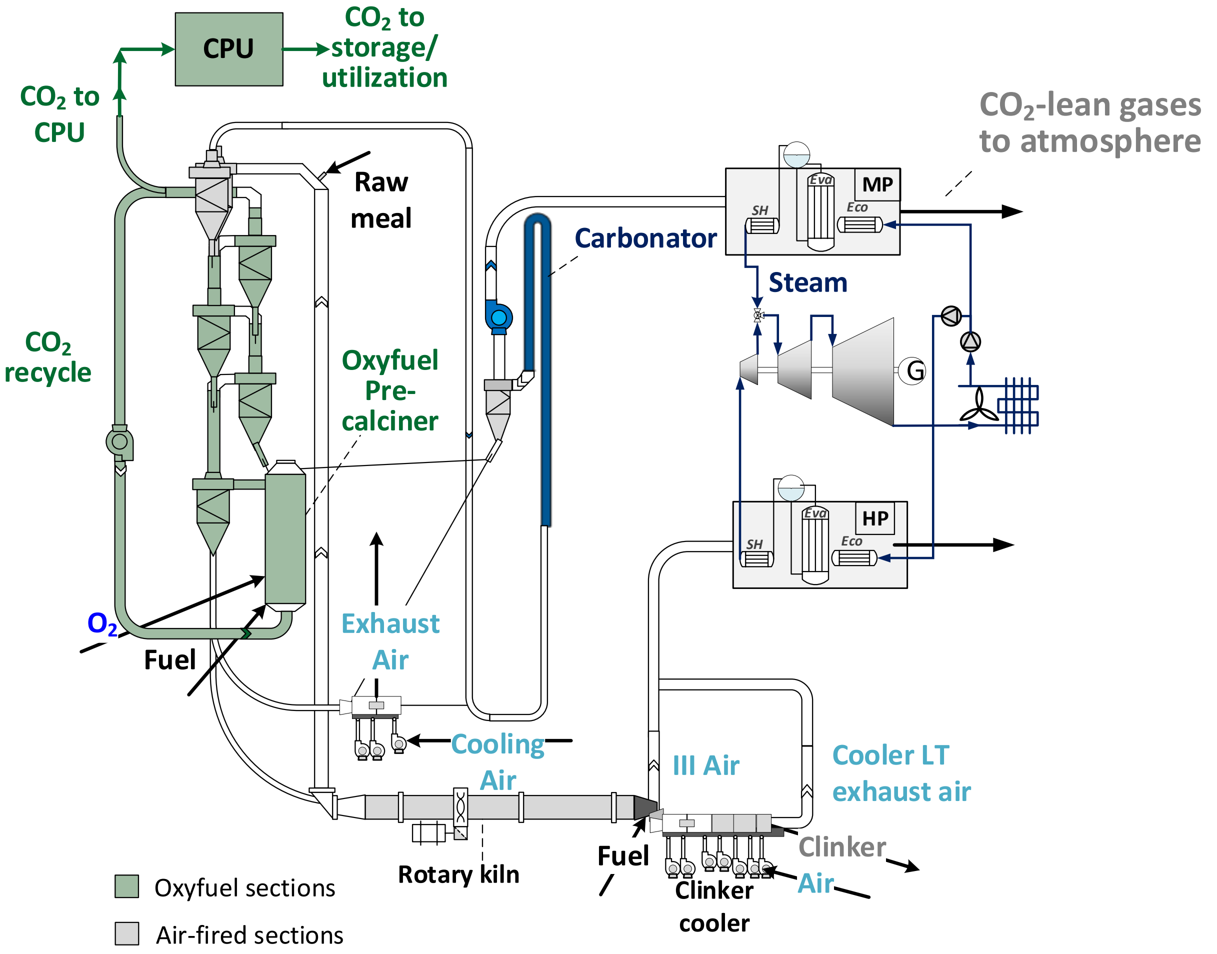
Model results – Integrated CaL

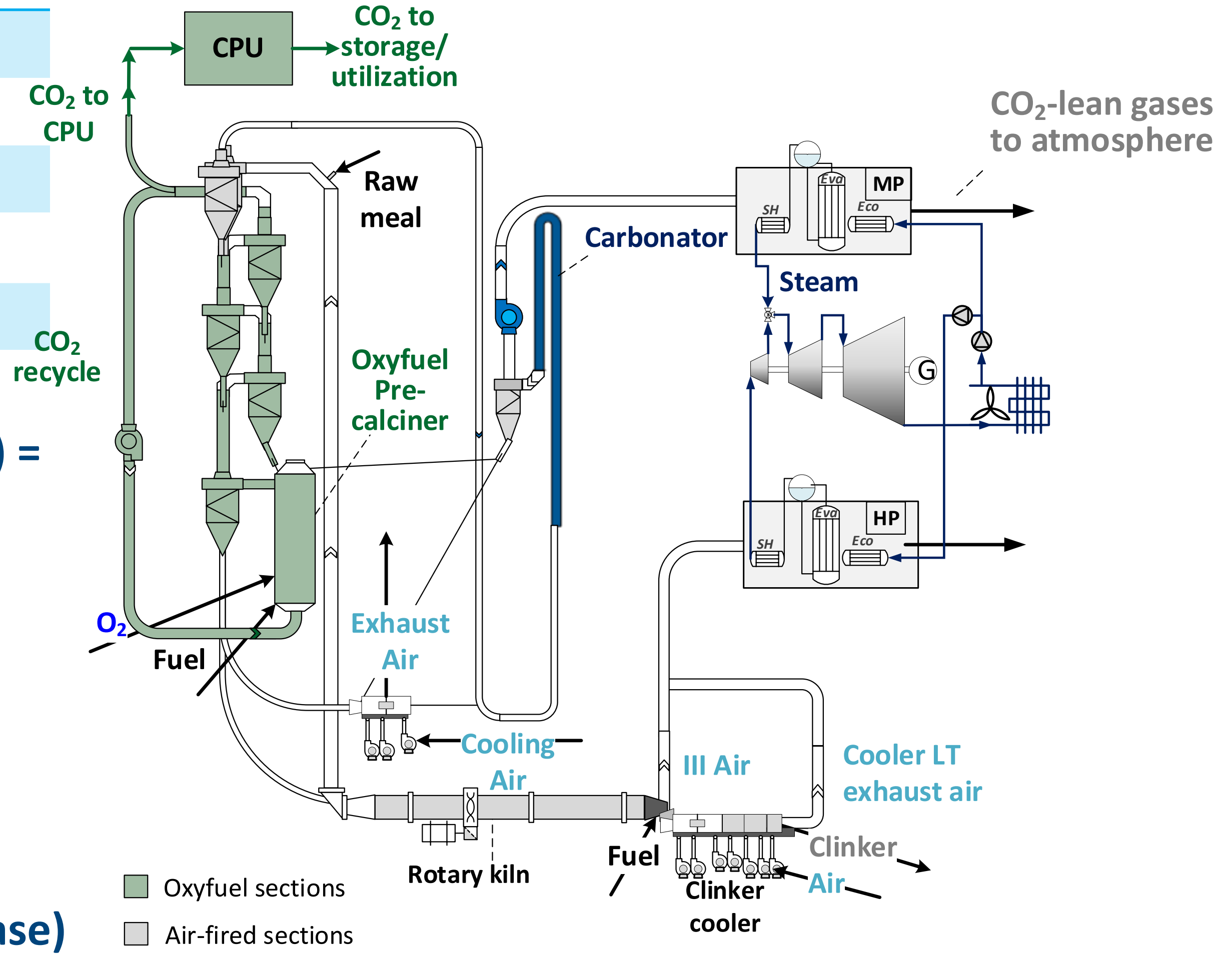
- The clinker production resulting from the model is **2539 tpd** (almost 40% increase)
- The specific fuel consumption **increases by 50.5% (5538 MJ/t$_{clk}$)**
- Partition fuel **calciner – rotary kiln 75% – 25%**
- The flue gas velocity at rotary kiln outlet is **6.5 m/s (31% reduction)**
- **CO_2 emission are reduced by 89.4%** (CO_2 capture efficiency in the carbonator of 70% from 1D model)



Model results – Integrated CaL

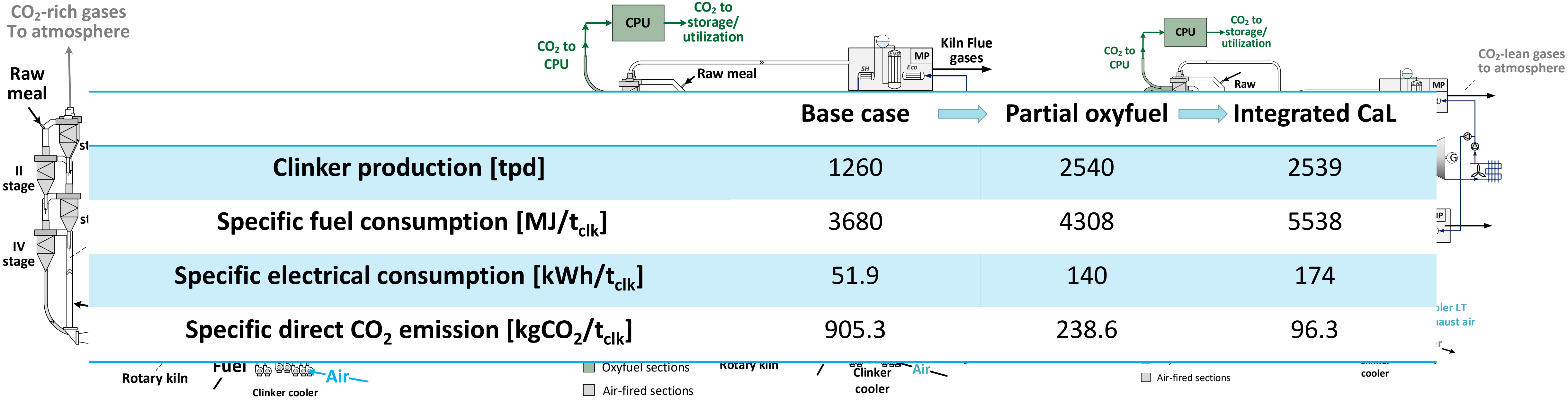
	Reference case	Integrated CaL
Cyclone efficiency (1st/2nd/3rd/4th stage) [%]	91.9/80.0/77.0/75.4	97/86/82/85
I stage outlet gas velocity [m/s]	14.6	16.5
II stage outlet gas velocity [m/s]	22.8	23.3
III stage outlet gas velocity [m/s]	15.4	15.8
IV stage outlet gas velocity [m/s]	15.9	18.4

- **Specific electrical consumption for CO_2 capture (ASU and CPU) = 213 kWh/t_{clk}**
- **Waste heat available (T > 250°C) = 33.4 MW_{th}**
- **Gross electricity production ($\eta_{el,gross}$ = *29.1%*) = 9.7 MW_e**
- **Net electricity demand for CO_2 capture = 122 kWh/t_{clk}**
- **Electricity demand is increased by 234% (51.9 kWh/t_{clk} base case)**



Final remarks

- ☐ The Aspen Plus simulation calibrated with real plant data provides a solid basis for the development of the two cement plant configurations with CO_2 capture
- ☐ The off-design simulation of the preheater tower indicates the technical feasibility of the retrofit applications described for the Colleferro cement plant
- ☐ The two CO_2 capture technologies guarantee a CO_2 emission reduction of about 74% (partial oxyfuel) and 89% (integrated CaL), with an increase in thermal (17% – 50%) and electricity consumption (169% – 234%) compared to the base case



	Base case →	Partial oxyfuel →	Integrated CaL
Clinker production [tpd]	1260	2540	2539
Specific fuel consumption [MJ/t_{clk}]	3680	4308	5538
Specific electrical consumption [kWh/t_{clk}]	51.9	140	174
Specific direct CO_2 emission [$kgCO_2/t_{clk}$]	905.3	238.6	96.3

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Key messages

With the current electricity and fuel mixes, the CLEANKER technology allows a reduction of **70%** in net CO_2 eq. emissions for cement production

The carbon transport and storage in a potential storage site could increase the overall net positive climate emissions of producing 1 t of cement by **1% to 10%, depending on the storage site.**

The carbon capture technology leads to an **increase in the energy footprint of 50% and water footprint of 10%** for cement production compared to the reference current technology, either during the fuel production phase (energy footprint) or in electricity use (water consumption related to hydropower). It is therefore crucial to use alternative fuels in the cement plant with CLEANKER Cal technology. The CO_2 storage generates a minor increase (2%) for these two indicators.

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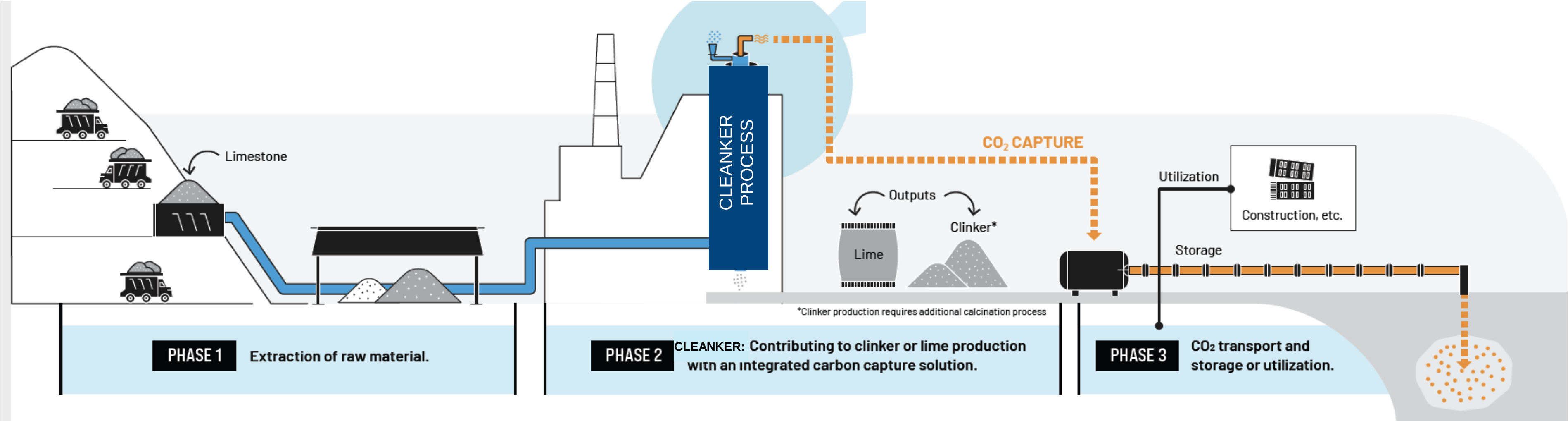
CLEANKER LCA: From raw material to carbon storage



Data inputs

Energy carrers production
Raw material production
Raw material transportation

Data sources

BREF document
Ecoinvent 3.8
WBSCD-CSI tool

Data inputs

Electricity consumption
Diesel consumption
Direct emissions to air
For cement: gypsum, ethylene glycol, electricity, heat

Data sources

CLEAN clinKER by calcium looping for low-CO₂ cement
CLEANKER

Data inputs

Pipeline construction
Energy

Data sources

Wilbotz (2007) for LCI on pipeline, storage in saline aquifer and depleted gas field
CLEANKER for distances by pipeline, average depth of reservoirs

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CCUS scenarios: Focus on the Ravenna depleted gas field

Scenario	Description	Sources
CCS Malossa – saline aquifer	Transport of CO_2 in supercritical phase by pipeline from Vernasca to Malossa (Italy) over 125 km, and storage in geological saline aquifer (average depth: 1.2 km).	Transport distance and storage site: Mariani 2021 Transport and storage infrastructure: Wildboltz 2007
CCS Ravenna – depeleted gas field	Transport of CO_2 in supercritical phase by pipeline from Vernasca to Ravenna (Italy) over 200 km, and storage in an offshore depleted gas reservoir (average depth: between 1 and 3.3 km).	Transport distance and storage site: CLEANKER Transport and storage infrastructure: Wildboltz 2007
CCS Northern Lights	Transport of CO_2 in liquid phase from Vernasca (Italy) to Øygarden (Norway) by pipeline over 500 km and by boat over 4900 km, and storage in an offshore sandstone reservoir (average depth: 2.6 km).	Transport distance and storage site: Northern Lights 2021 Transport and storage infrastructure: Wildboltz 2007
CCU	Transport of CO_2 in supercritical phase by pipeline over 500 km and reuse.	Transport and storage infrastructure: Wildboltz 2007

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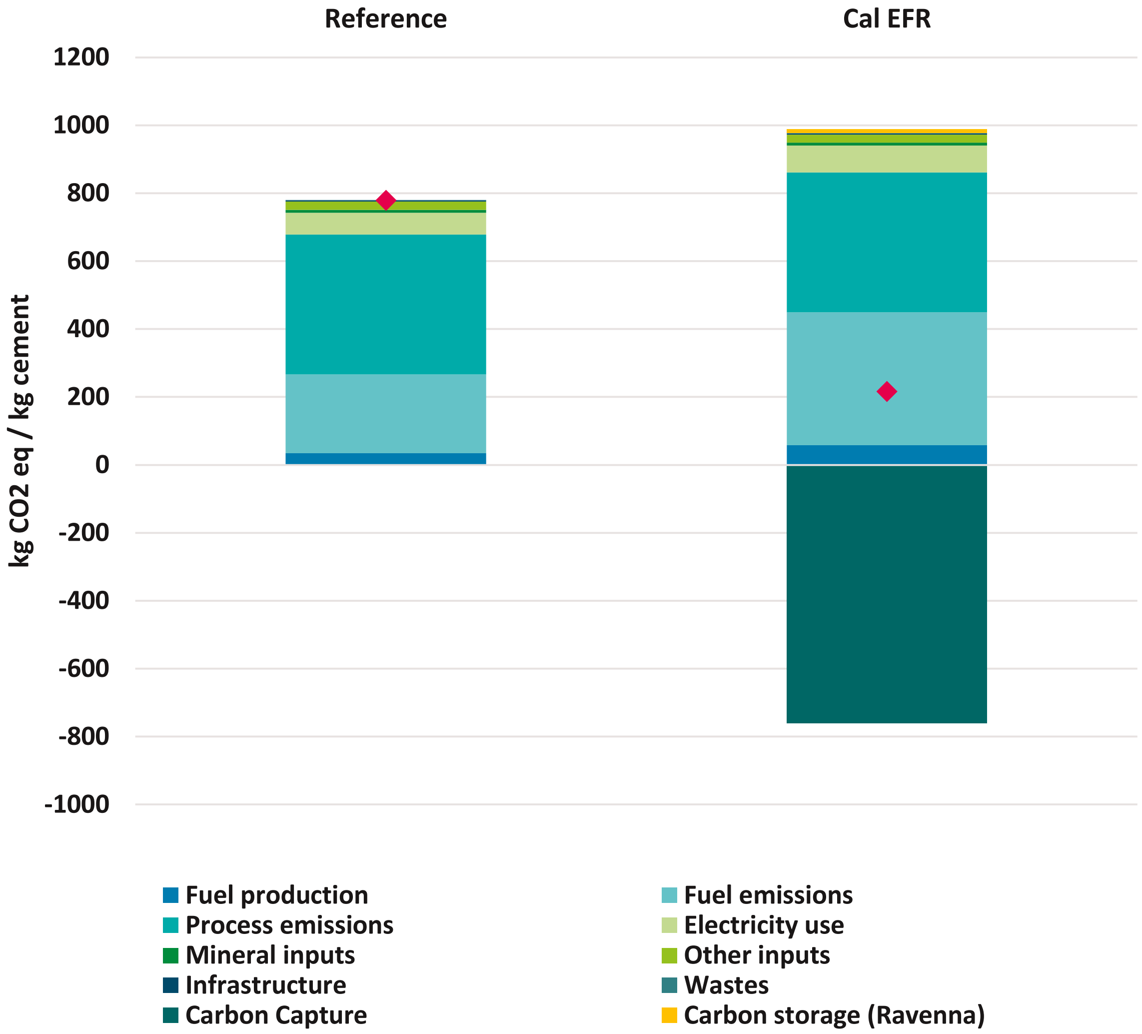
CLEANKER reduces the climate footprint by 70%



This figure shows the **climate footprint of the baseline technology compared to CLEANKER CaL.**

The main drivers of the climate impacts of 1 t of cement are: **process emissions** (**53% for the reference scenario**) and **fuel emissions** (**30% for the reference scenario**).

The CLEANKER CaL technology allows a **70% carbon footprint reduction** associated to 1 t of cement.

The increase in fuel emissions carbon footprint is related to a fuel consumption increase from **3.2 MJ /t clinker in the baseline technology** to **5.4 MJ/t clinker for CLEANKER CaL**.

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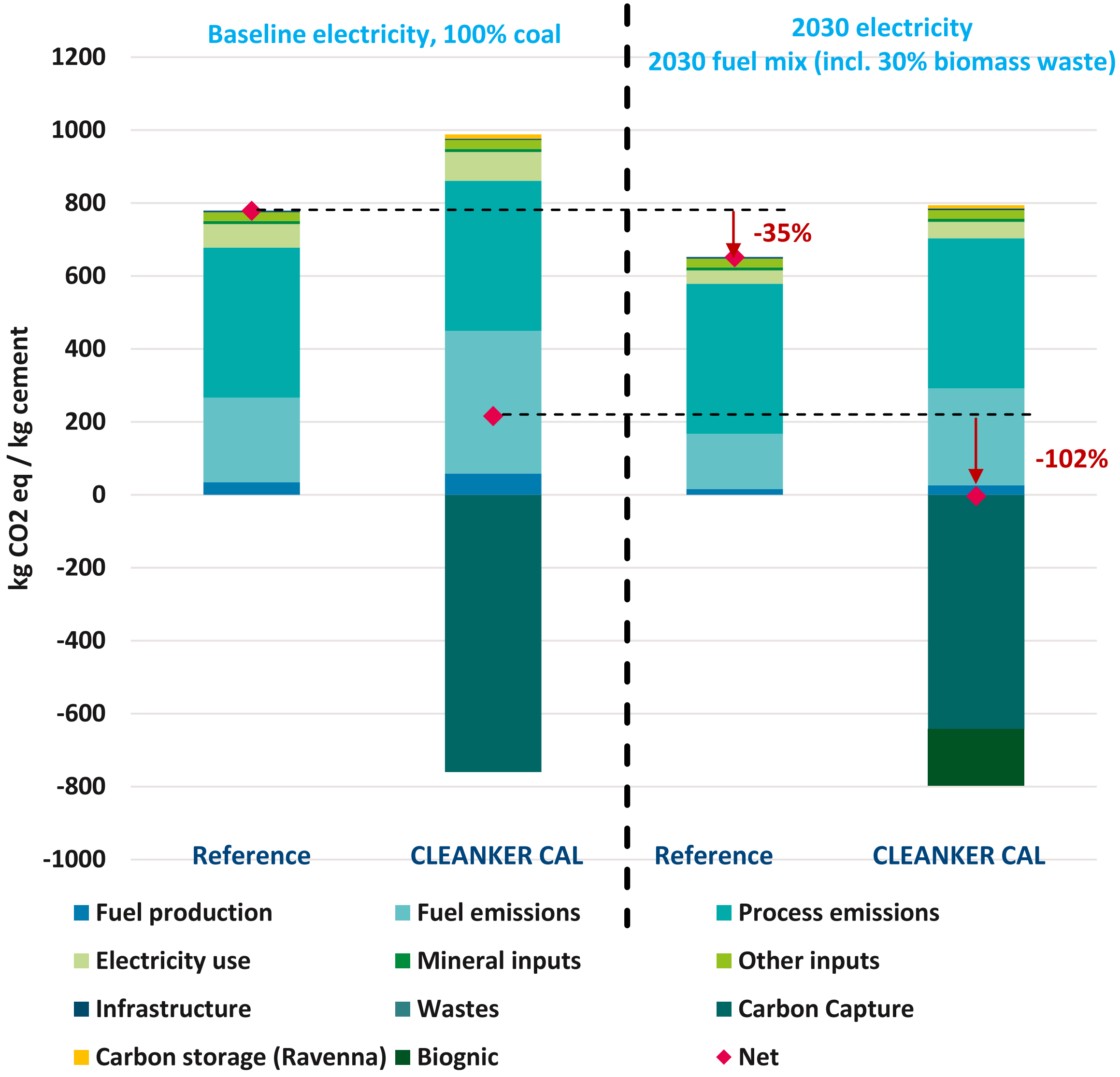
Using alternative fuels further reduces the climate impact



For the baseline technology and CLEANKER CaL, the **reference scenario with a 2020 electricity mix and 100% coal fuel mix** is compared to a **2030 projection with an electricity mix based on 35% renewable electricity and a fuel which includes 30% of fuel from biomass waste**.

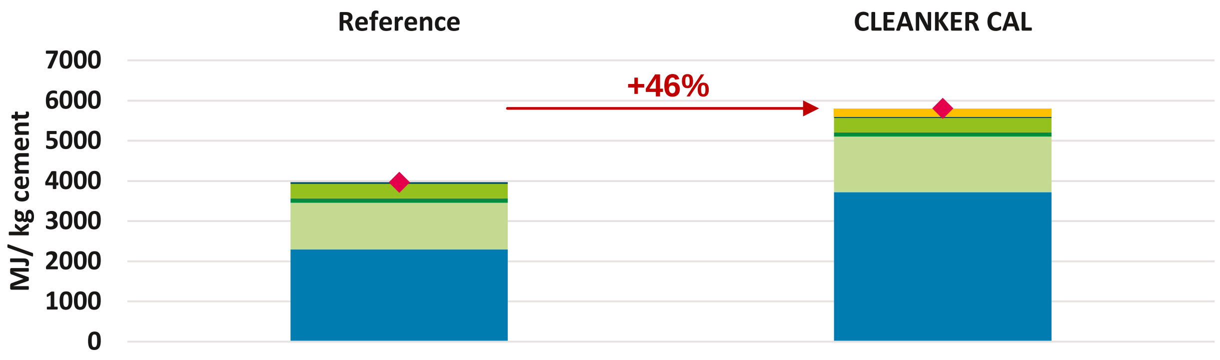
For the **baseline technology**, the switch to the 2030 projection leads to a **16% carbon footprint reduction** to produce 1 t of cement.

For **the CLEANKER CaL technology**, the carbon footprint reduction is greater**: 102%.** This is due to a greater reduction of fuel emissions, as more fuel is required in order to capture the CO_2 and the inclusion of biogenic emissions.

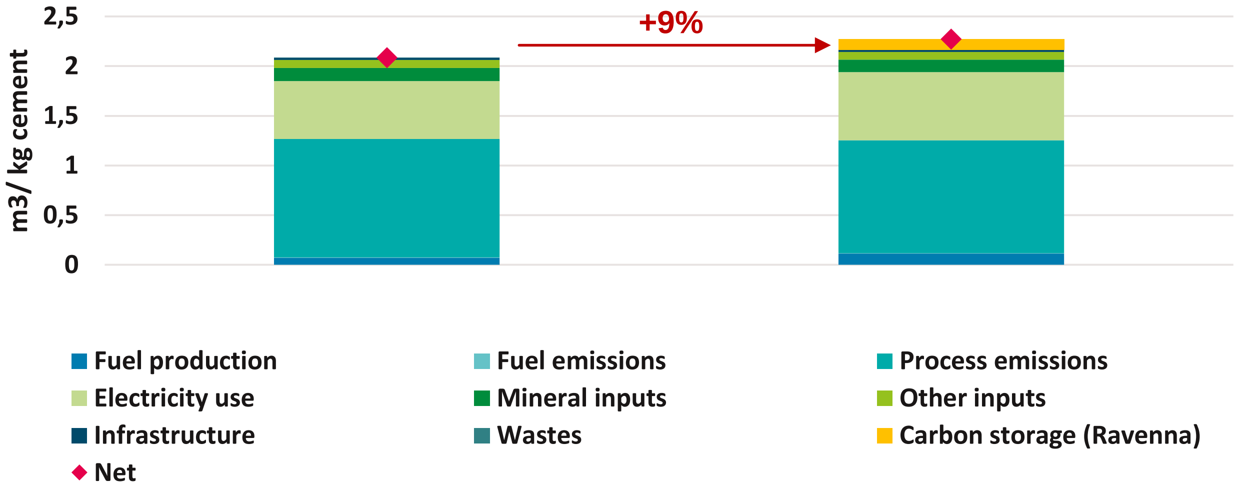
Therefore, the CLEANKER CaL carbon capture technology should be used with alternative fuels to mitigate the increased use of fuel.

Energy and water footprint increases with CLEANKER

Energy footprint



Water footprint



The carbon capture technology leads to an **increase in the energy footprint and water footprint**, either during the **fuel production phase** (energy footprint) or related to the **electricity use** (water consumption related to hydropower).

The **overall increase in energy footprint is 50%** compared to the reference scenario. This is related to a fuel consumption increase from **3.2 MJ /t clinker in the baseline technology** to **5.4 MJ/t clinker for CLEANKER CaL**.

The **overall increase in water footprint** is **10%** compared to the reference scenario.

The **CCS scenario in the offshore depleted gas reservoir in Ravenna** leads to an increase in the **energy footprint** and in the **water footprint** of **only 2%.**

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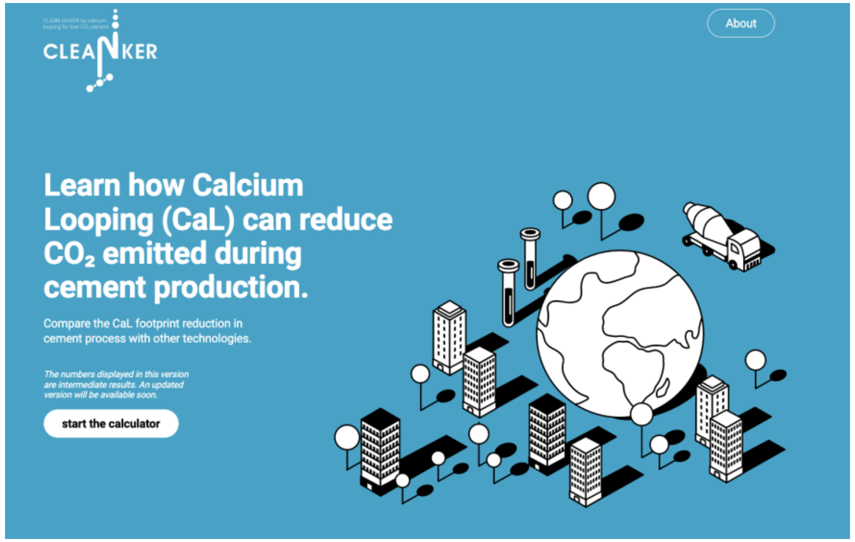
Web-based tool introduction

- QUANTIS developed a **user-friendly web-based footprinter**, based on these LCA result.s Footprinters are easy, user-friendly and robust web-tools allowing users to compare products and technologies (CLEANKER vs. baseline) based on different scenarios.
- The tool is now available to anyone who knows the URL (see below).
- The tool is not yet finished, results, design and equivalency will be updated.
- The tool will be put online in **February 2023**

URL :

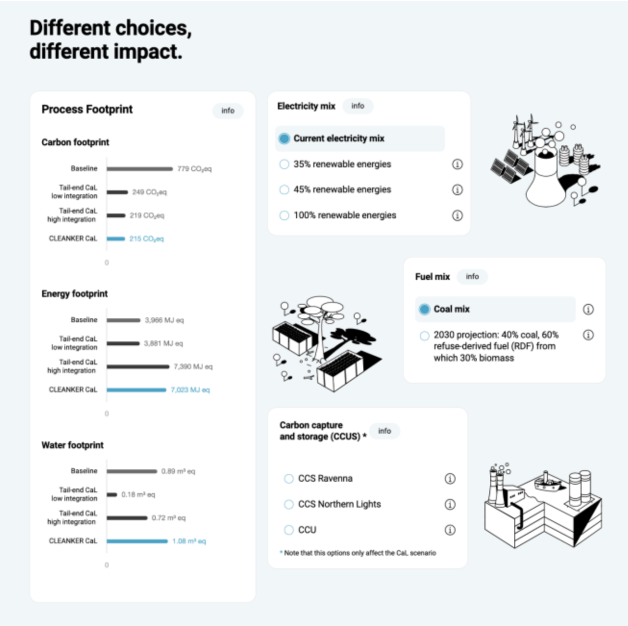
https://footprinter.cleanker.eu/



Learn how Calcium Looping (CaL) can reduce CO_2 emitted during cement production.

Compare the CaL footprint reduction in cement process with other technologies.

The numbers displayed in this version are intermediate results. An updated version will be available soon.



Different choices, different impact.

Process Footprint

Carbon footprint

Baseline 779 CO_2eq
Tail-end CaL low integration 249 CO_2eq
Tail-end CaL high integration 219 CO_2eq
CLEANKER CaL 215 CO_2eq

Energy footprint

Baseline 3,966 MJ eq
Tail-end CaL low integration 3,881 MJ eq
Tail-end CaL high integration 7,390 MJ eq
CLEANKER CaL 7,023 MJ eq

Water footprint

Baseline 0.89 m³ eq
Tail-end CaL low integration 0.18 m³ eq
Tail-end CaL high integration 0.72 m³ eq
CLEANKER CaL 1.08 m³ eq

Electricity mix

● Current electricity mix
○ 35% renewable energies
○ 45% renewable energies
○ 100% renewable energies

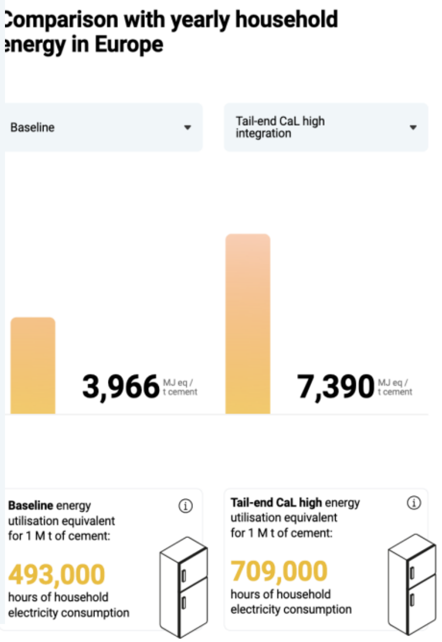
Fuel mix

● Coal mix
○ 2030 projection: 40% coal, 60% refuse-derived fuel (RDF) from which 30% biomass

Carbon capture and storage (CCUS) *

○ CCS Ravenna
○ CCS Northern Lights
○ CCU

* Note that this options only affect the CaL scenario



Comparison with yearly household energy in Europe

Baseline ▾
Tail-end CaL high integration ▾

3,966 MJ eq / t cement
7,390 MJ eq / t cement

Baseline energy utilisation equivalent for 1 M t of cement:
493,000
hours of household electricity consumption

Tail-end CaL high energy utilisation equivalent for 1 M t of cement:
709,000
hours of household electricity consumption

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Acknowledgments

Thanks for your attention!

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