West Coast
Cement
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Conference

**October 16-17, 2025
the Hellenic Center in Lancaster, CA**.
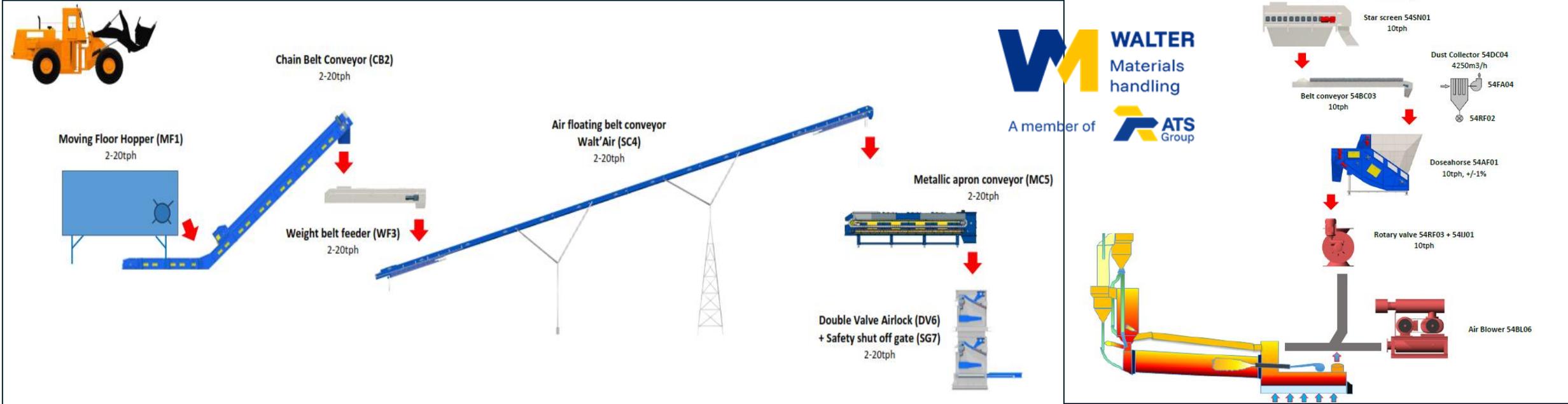
Alternative Fuels, Boosting TSR and Efficiency in Cement Plants Using CFD-Based Engineering

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aix process   The ModelING Company

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Many AF substitution projects in the US/Canada

- What kind and how much solid alternative fuels [SAF] total substitution rate **[TSR]** could be expected,

    a/ with the plant as is,

    b/ with minor adjustments,

    c/ to reach 100%?

- Where are the optimum injection point(s) in the calciner, also for the main burner or / and satellite burner?

- The impact on emissions, ID fan, Riser velocity, … the need for a by-pass?

Introduction

The benefits and drawbacks of alternative fuels (AF) **high thermal substitution rates (TSR)** are known.

Equipment originally designed for fossil fuels requires adaptation to accommodate altered flow and combustion dynamics.

Advanced Computational Fluid Dynamics (CFD) is a critical and effective tool offering predictive capabilities to analyse heterogeneous flow fields, temperature distributions, and chemical reactions within kilns, calciners, and preheaters.

➜To Identify performance-limiting phenomena and develop targeted process modifications.

Meal is not well distributed and mixed in a pot calciner, it tends to form strands with high & low concentration regions. it also accumulate at the bottom leading to pumping effects of the gas flow.
Consequently, energy sink (meal to be calcined) and energy source (fuels) as well as combustibles and oxygen are always segregated.
This leads to in-homogeneous and in-complete calcination, CO formation, unequal split of the meal into the two chambers and process instabilities.
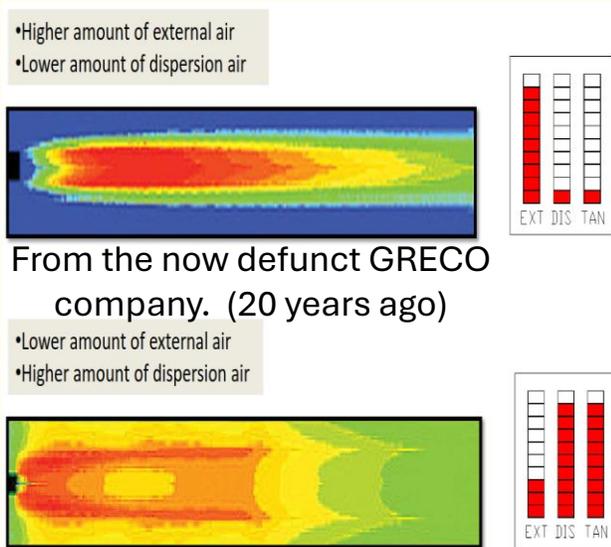*Meal clusters may also drop from the calciner into the kiln inlet .*
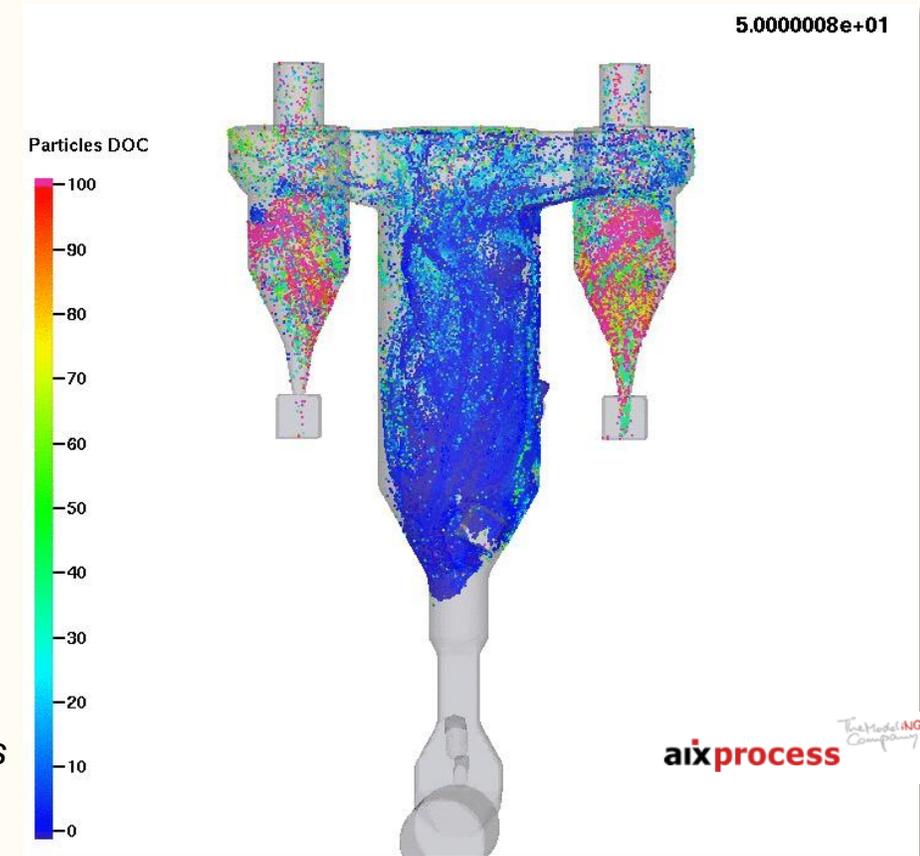
DOC, degree of Calcination
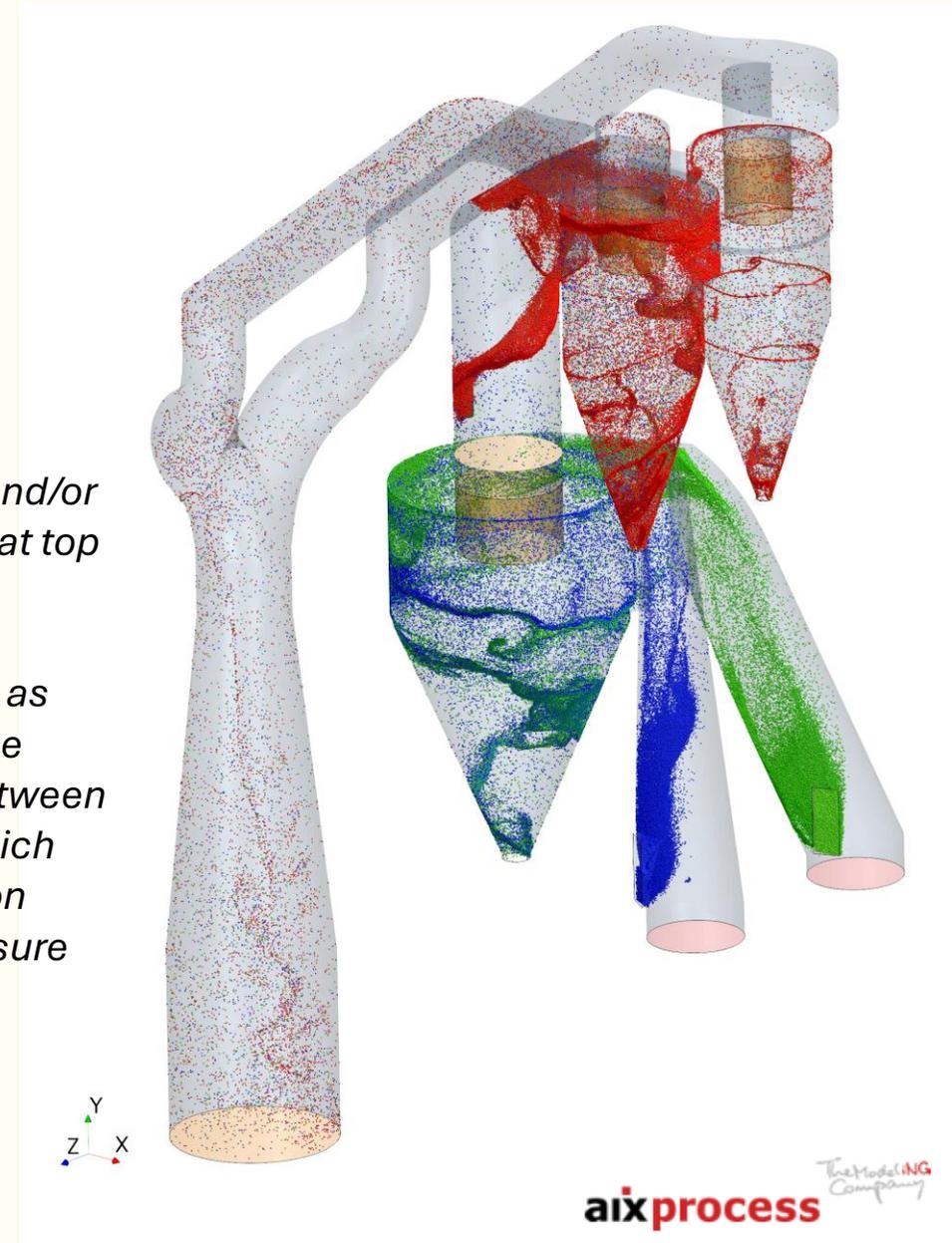
Not your dad / mom CFD anymore!

Opposite to conventional calculations, advanced CFD works on **interconnected phenomena** that are acting simultaneously within each computational cells. It is three-dimensional and **consider transient states**. It numerically solves set of highly complex equation.

•Higher amount of external air
•Lower amount of dispersion air

EXT DIS TAN

From the now defunct GRECO company. (20 years ago)

•Lower amount of external air
•Higher amount of dispersion air

EXT DIS TAN

How to reduce pressure drop and/or increase separation efficiency at top stage.
Cyclone below the one under investigation must be included as inflow is rotating and may cause maldistribution of meal/gas between the two top stage cyclones, which has a huge detrimental effect on separation efficiency and pressure drop of the top stage.

Y
Z X

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Motion of the meal at the top of a preheater, Colors distinguish the origination of splash boxes.

Cement process knowledge + many references and a waste data base + a large experience in combining various CFD software ➔ Advanced CFD for the Cement Industry

Advanced CFD, focuses on the calciners, especially with SAF firing

Years ago, when CFD started to be used in the cement industry, it was primarily by OEMs looking at "prototyping" burners, by-pass, calciner designs.

Many calciner designs exist each with associated known issues, yet each one is unique. Past CFD modeling gave limited insights

The first simulation concerned two basic designs of burner position of alternative fuels:

- In axis of chamber
- Out of axis of chamber

The burner in axis of the chamber shows narrow fuel flow (fig. 23) which is realized quickly in the centre of chamber without intensive mixing with air and that is why we were afraid of insufficient burning of fuel.
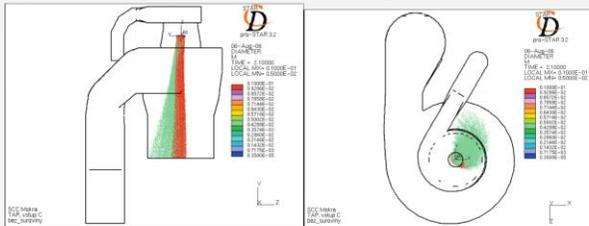
On the other hand the fuel dosed tangentially results in better distribution of fuel in the section of chamber, better mixing with combustion air, and longer material stay in chamber and assumption of better burning.

Separation of material along side chamber walls can have a negative effect.

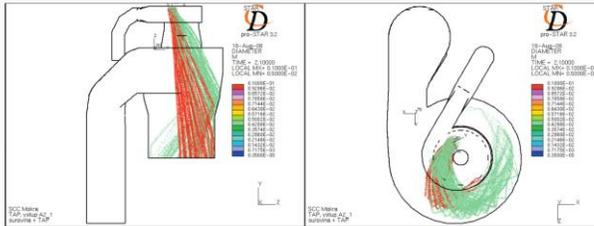The final position of burner marked as A2_1 and corresponding trajectory of fuel are on fig. 24.

The final design of chamber with constant diameter and theoretical trajectory of alternative fuel is in fig. 25.

Advanced CFD modeling also help plants solve "design" problems due to:

- production levels beyond design,
- increase TSR,
- lowering of emissions,
- raw meal variability,
- Multiple cement types, ...

Cement Intl. Conf. 2009
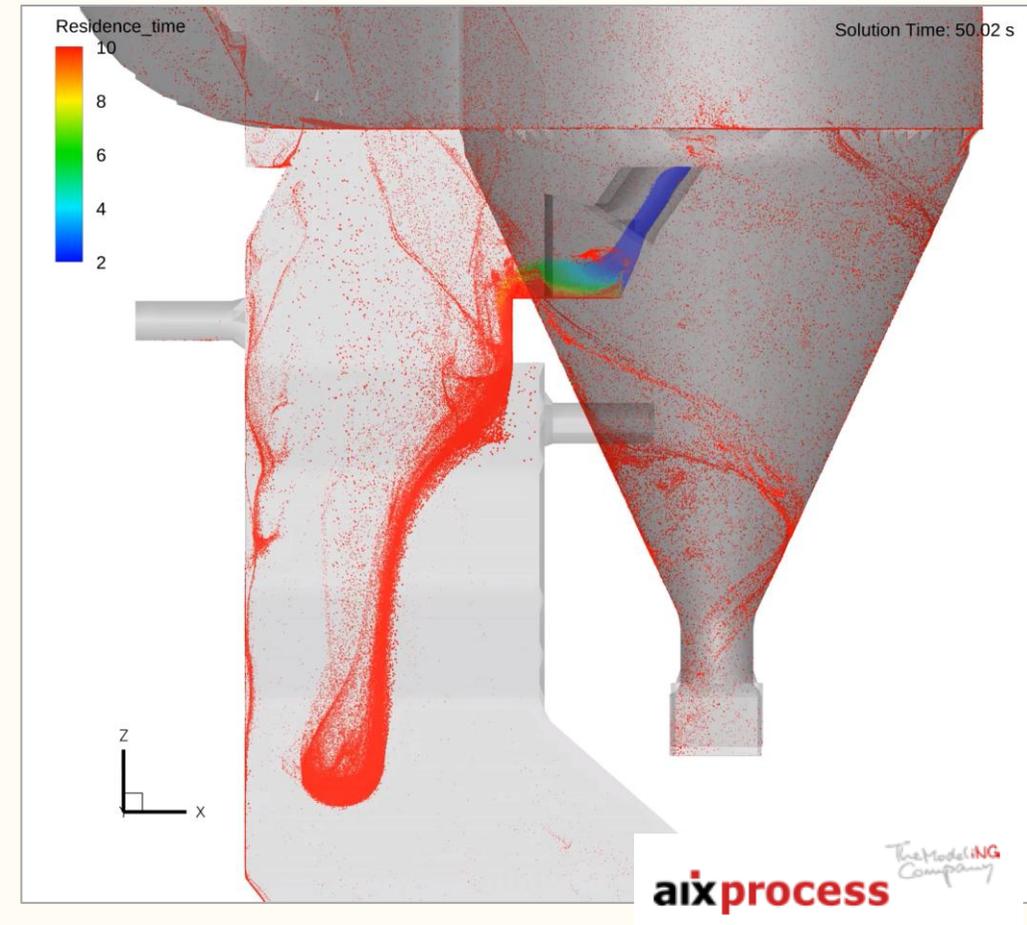
The videos here show the motion of the meal, which is entering the right meal box. The colour shows the residence time.
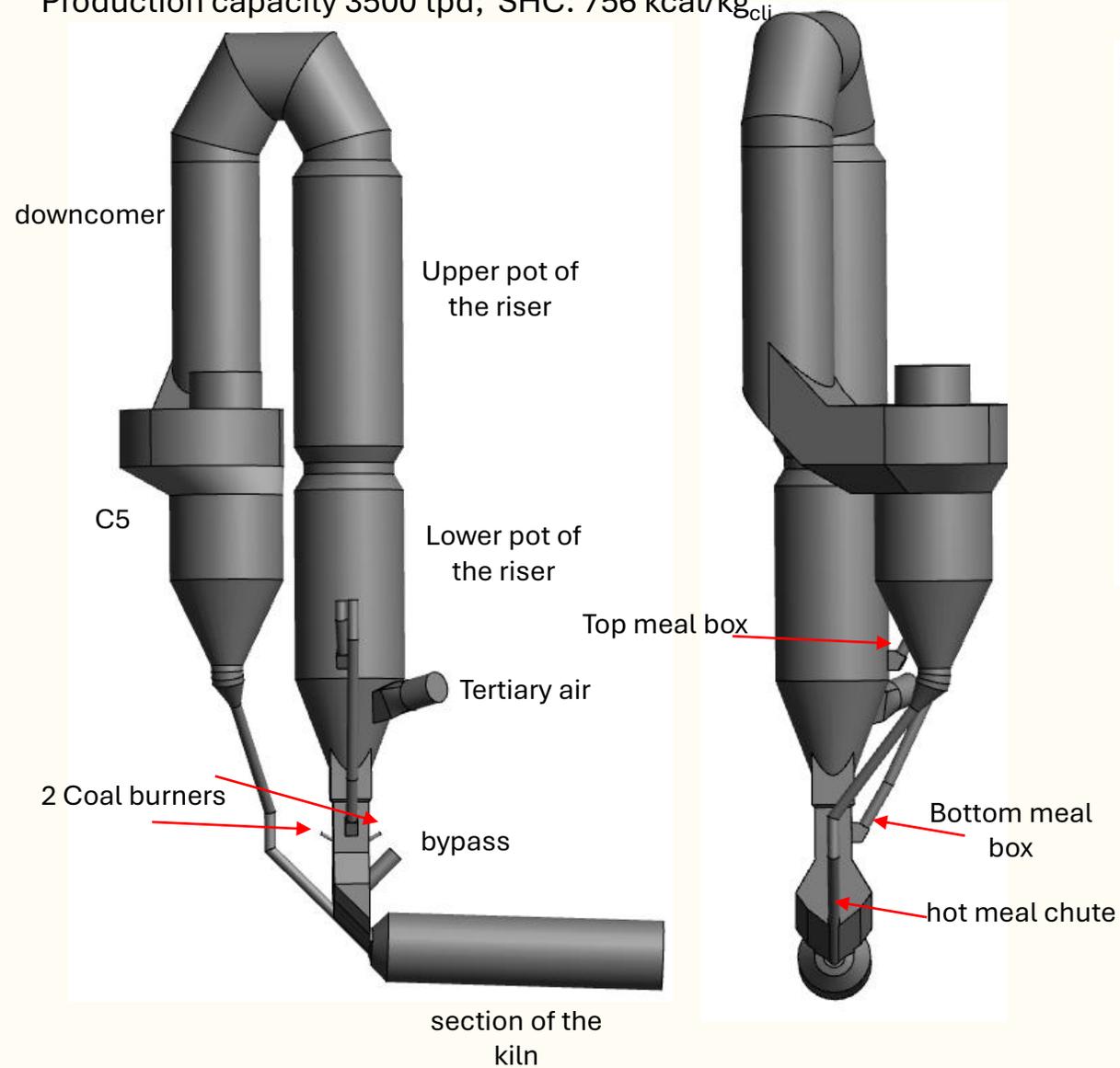
The key parameters for advanced CFD Computational Fluid Dynamic

- Setting clear objectives and getting necessary information
  - Drawings to establish the **geometry** ; Heat & Mass balance; Fuels & Raw Meal characteristics, Process & emissions data.
- Designing the **mesh structure**, usually not uniform, finer or coarser depending on the location and project objectives.
- Defining the **boundaries** in a way that the upstream and downstream limits are not impacting the region to be studied, searching for homogeneity.
- **Validating the model** by running it with the" as is" parameters and comparing the outcome with the process data. Calculations can't be wrong.
- Selecting the **right combination of tools**. AIXprocess uses 4 proprietary softwares + some open sources ones: CCM, Fluent, Fluidized bed, Baracuda, in addition to its own library of parameters on the combustion of SAF.
- Inputting all the data using a tree structure and import libraries and pre-calculated tables,
- Running simulations until a **steady state** is reached; in the calciner it can be up to 60 seconds due to the transient phases (heat transfer, calcination, combustion, …).
- Resulting in obtaining the **key process values** such as O2, temperature, CO, gas composition in general, pressures (pressure drop), particles concentration, reaction rate, volatile, velocities & flows, recirculation zones, species distribution.
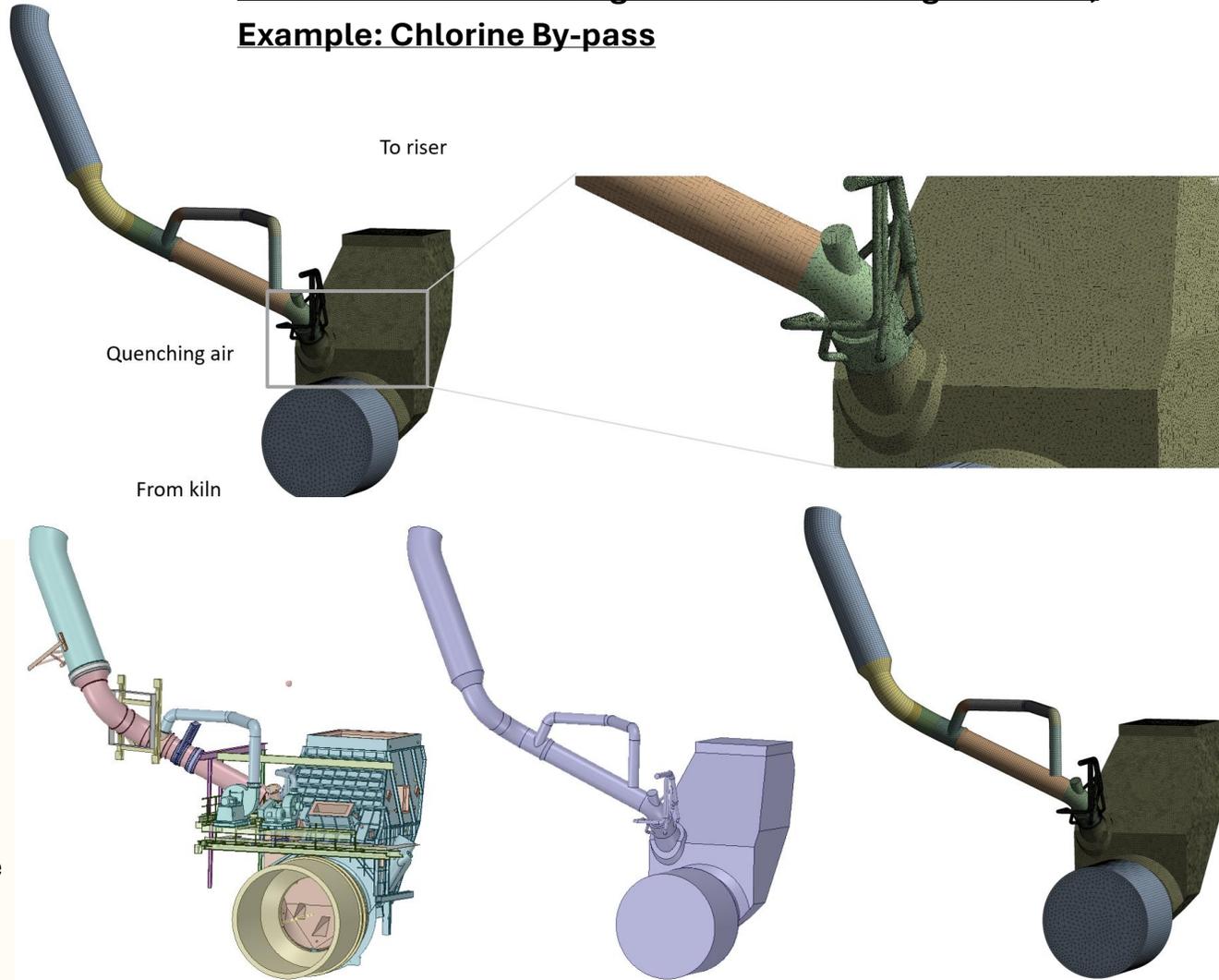- Presenting the **options** with recommendations and saving estimates.

The basis of advanced CFD – The Geometry & The Mesh

Preheater: 1-string, 5-stage; Calciner: ILC with CC
Production capacity 3500 tpd; SHC: 756 kcal/kg$_{cli}$

downcomer

Upper pot of the riser

C5

Lower pot of the riser

Top meal box

Tertiary air

2 Coal burners

bypass

Bottom meal box

hot meal chute

section of the kiln

"Discretization" into single volumes – mesh generation;
Example: Chlorine By-pass

To riser

Quenching air

From kiln

The basis of advanced CFD – Run Time

Calciner geometry
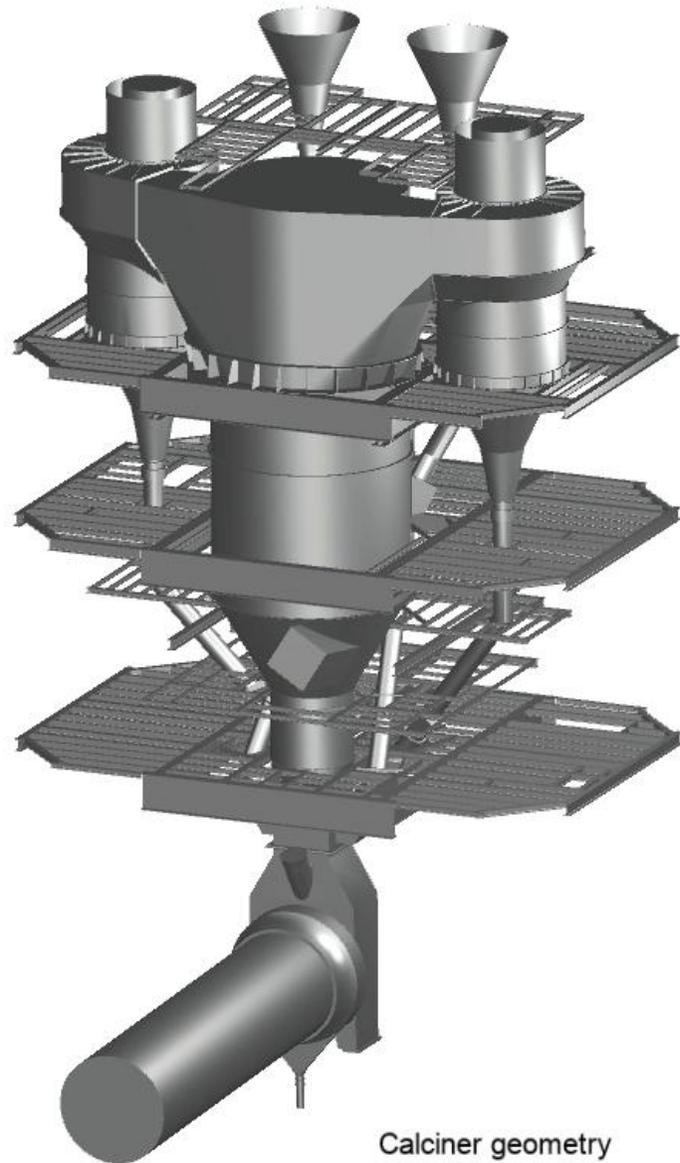
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Combustion and Modeling multi-physics

- Conservation of mass,
- Conservation of momentum (forces)
- Conservation of species
    - Reaction among all reactants
- Conservation of energy
- Heat transfer (radiation, conduction, convection)
- Calcination reaction,
- Combustion reaction, emissions
- Change of P-V-T
- Impulse transfer
    - Particles-gas interaction
    - Particle to particles interaction
- Turbulences
- Changes of shapes, properties and aerodynamic behavior of particles
- Drag forces by the fluid,
- Centrifugal, buoyancy forces
- Particles to wall & particles to particles collisions

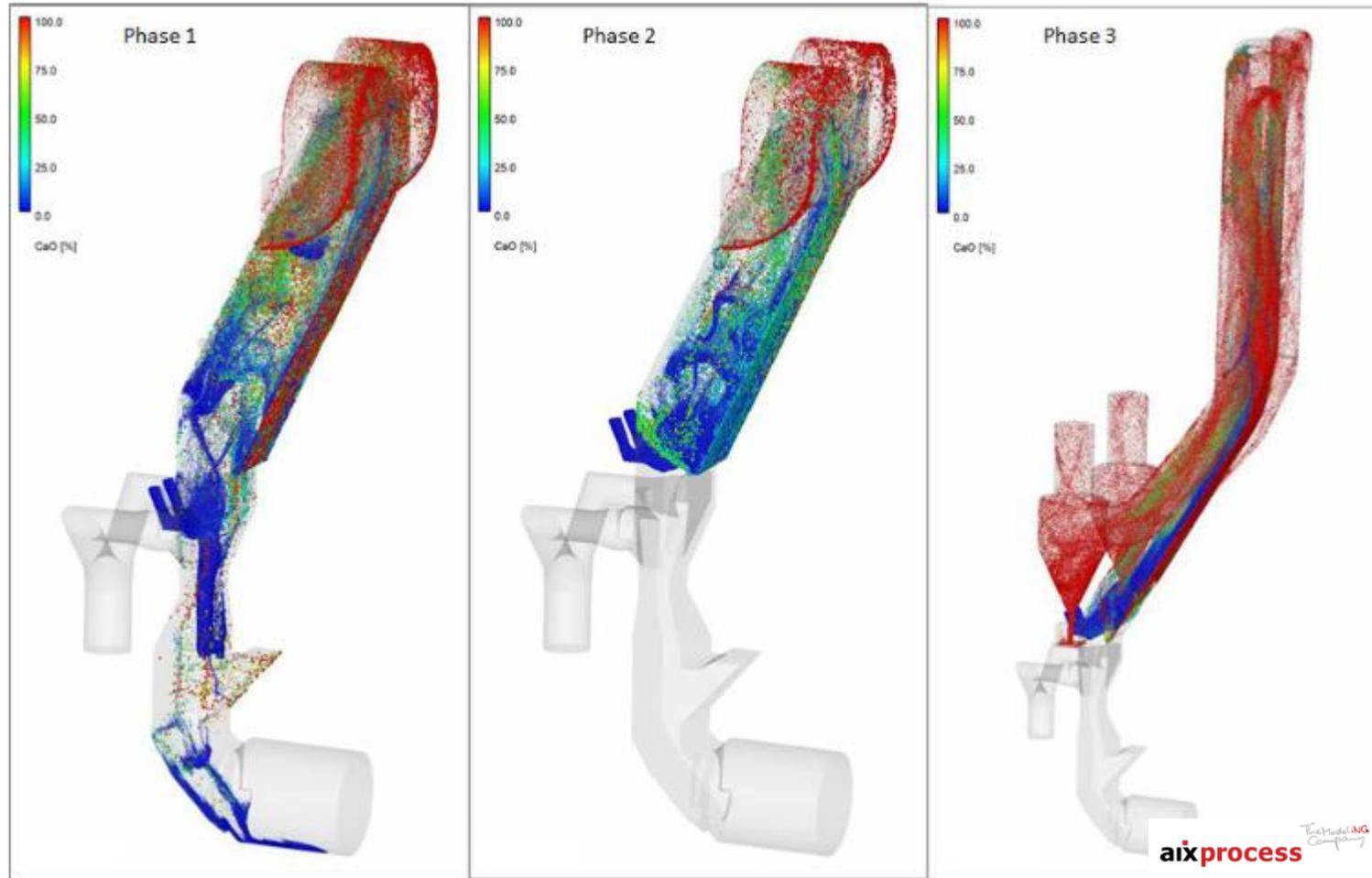# Increasing Total Substitution Rate [TSR] with Advanced CFD, a phase approach

Figure 1: Meal motion and calcination improvement for the three phases of the stepwise TSR ramp-up

PHASE 1 TSR ~15–20%, - PHASE 2 TSR ~30–35%, - PHASE 3 TSR up to 50%

PHASE 1
- Stabilize existing AF feeding to minimize fluctuations.
- Optimize process parameters (O_2 levels, kiln speed, calciner temp).
- Increase TSR incrementally
- Perform baseline CO/NOx measurement.

PHASE 2
o Relocate meal feed (splash) boxes to optimize material flow.
o Reconfigure coal burners to enhance flame and combustion zone.
o Install a new AF dosing system with precision metering and continuous feed to the calciner.

PHASE 3
- Calciner elongation to allow longer residence time.
- Post Combustion Chamber (PCC) for complete burnout.

# "Regular" vs. Advanced CFD, based on actual examples

TO & NOT TO:

- Not To **exclude splash boxes, meal boxes, meal pipes.** the motion of the meal on the splash table and the splash effect. (see illustration)
- Not To define **too small a model region**. If limited to the riser section it does not allow to evaluate the performance of the calciner. Significant burnout, CO- formation and calcination activity still happens up to the bottom stage cyclone.
- To consider any **dynamic effect**, which are very dominant in calciner flows; steady state should be achieved.
- To consider Dense particle flows with particle-particle interactions and **deflection of the gas by the material,** Particle in cell approach (PIC) considering inter-particle interactions (collisions, grouping, bouncing, ...)
- Not To Ignore **AF particle characteristics** (density, dimensions, volatile content,...)
- To take into accoount parameters such as refractory wear, false air, ...

*Splash boxes may not be the biggest part of the preheater – but they play an important role. **KHD** adjustable splash box are equipped with an adjustable dispersion plate, allowing customization to specific process for optimum control & uniform distribution of raw meal into the hot gas flow.*

Advanced CFD – Dealing with solid particles

Fully **accounting for the solid particles** and not just considering gas flows as the primary driver of the preheater/calciner behavior,
Choosing proper CFD software(s) for instance for **fluidized bed simulation**, added to a set of precalculated combustion, chemical, and physical reaction as input into the models,

Analysis of a representative sample – Sphericity vs. Mass of the RDF sample
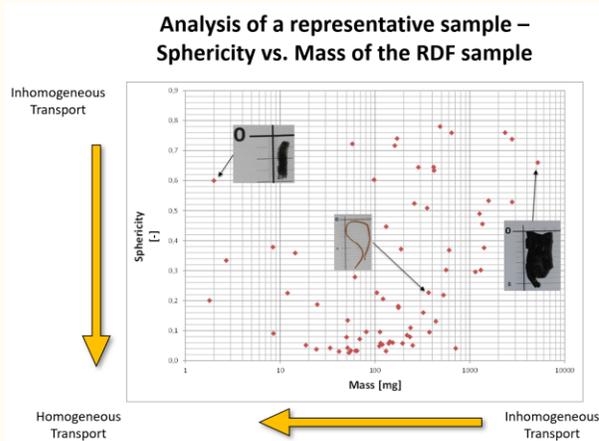
Utilizing a **library of fuels (fossils & SAFs)** taking into consideration PSD,
2D vs 3D/, Volatilization,
Ash formation,

Grouping the SAF particles in classes depending on their characteristics. The solid side of the simulation is given by millions of clouds of particles each with thousands of particles. This is key as **high particle load dictates how the gas/air flow behaves.** The clouds of solid particles displace the gas.

Time = 30.000
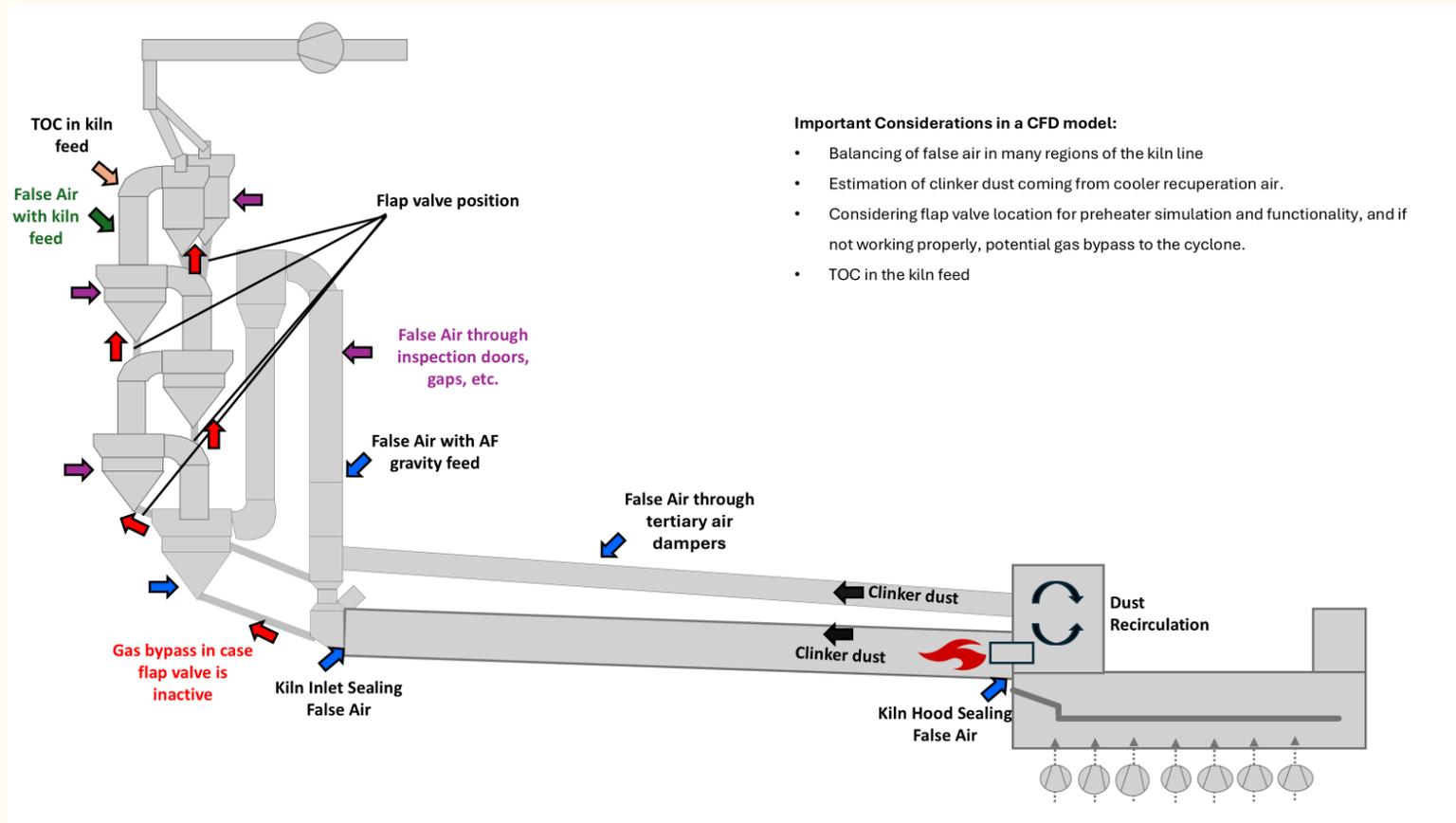
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DOC

1

0.75

0.5

0.25

0
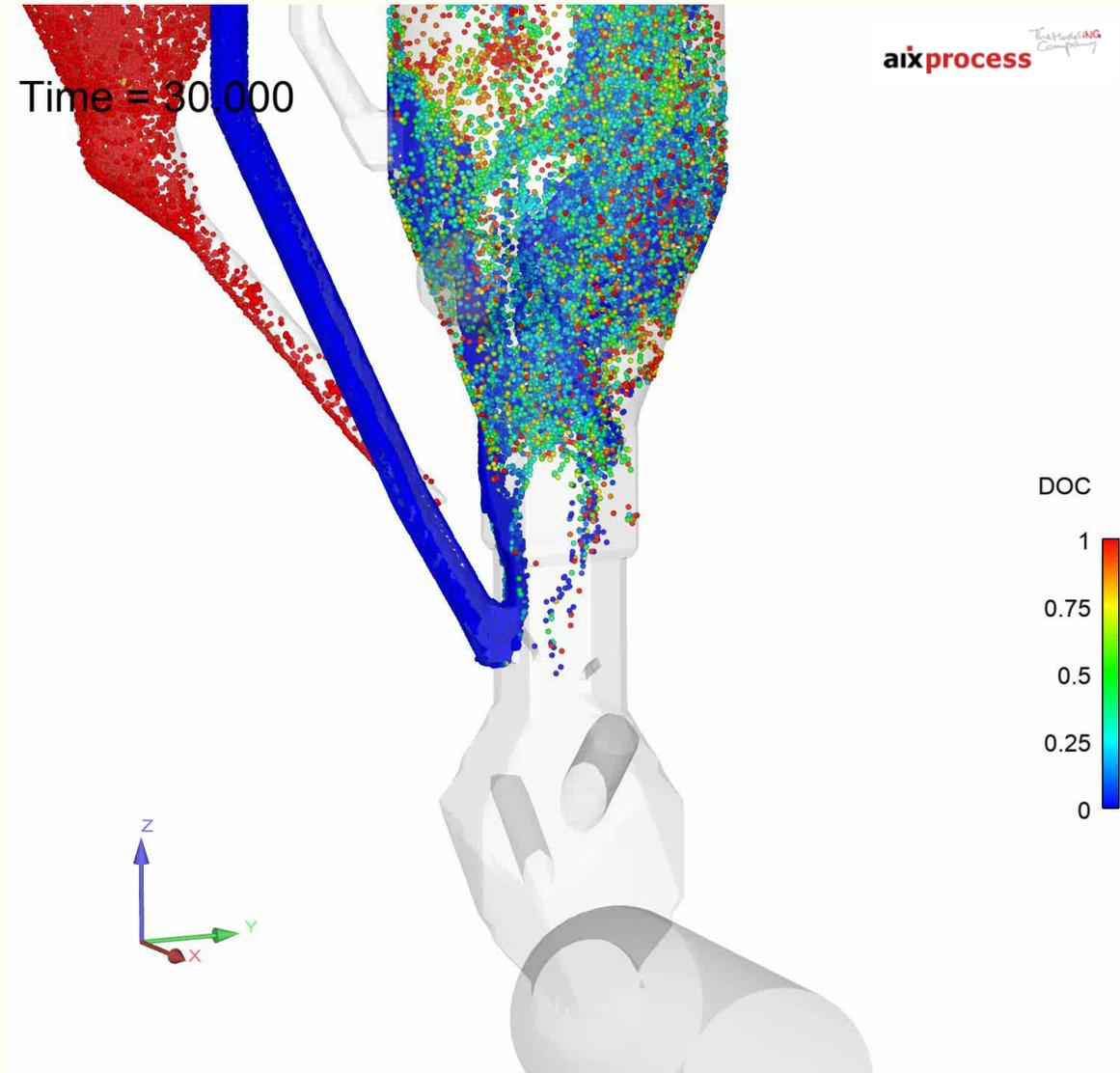
Motion of the hard coal from the burner on the front side – Zoom to bottom. Scale: DOC Degree of Calcination.

Advanced CFD – Dealing with the Air leakages

Air in-leakage is a true issue (various costs associated, thermal and electrical energy, increase maintenance, production limitation, ...) Even if being out of sight and rarely a plant priority.

Also, the cold air being injected into a calciner when using a **pneumatic transport system** for the SAF injection instead of a mechanical one. Often the chosen solution during initial trials at 1 or 2 t/h, it is sometimes requested even when firing 10t/h is foreseen (i.e. 3 to 4 t/h of cold air! It brings additional oxygen for the SAF combustion but at a cost.

TOC in kiln feed

False Air with kiln feed

Flap valve position

False Air through inspection doors, gaps, etc.

False Air with AF gravity feed

False Air through tertiary air dampers

Clinker dust

Clinker dust

Dust Recirculation

Gas bypass in case flap valve is inactive

Kiln Inlet Sealing False Air

Kiln Hood Sealing False Air

Important Considerations in a CFD model:

- Balancing of false air in many regions of the kiln line
- Estimation of clinker dust coming from cooler recuperation air.
- Considering flap valve location for preheater simulation and functionality, and if not working properly, potential gas bypass to the cyclone.
- TOC in the kiln feed

This air in-leakage, the most common being both kiln seals is taken into consideration in advanced CFD modeling.

AF substitution – Also through the main (kiln) burner

Advanced CFD modeling is not just about the main burner design (with or without satellite burner) and adjustment. Upstream and downstream spaces impact the level (quantity, type) of achievable substitution rate
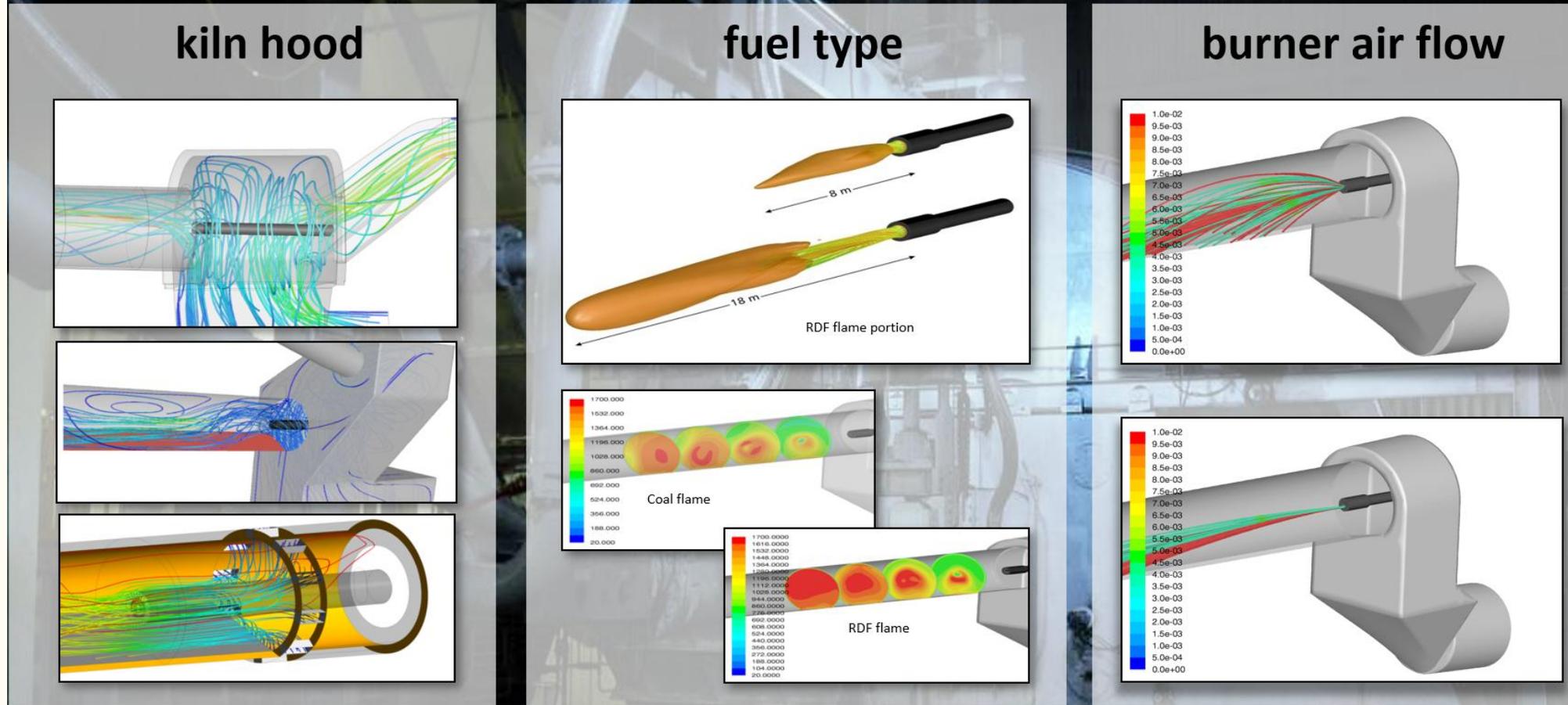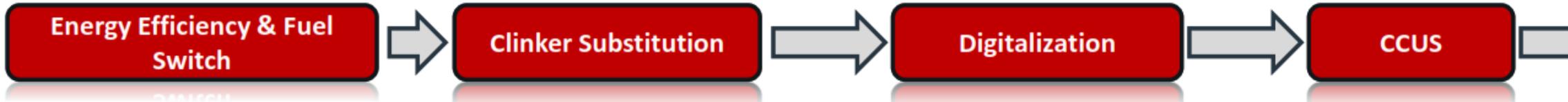

Illustration of the many parameters to be considered for a successful simulation of the firing at the main (kiln) burner

Advanced CFD Modeling, Digital Twins, APC (Advanced Process Controls) & RTO (Real Time Optimizer), Expert Systems


- Process knowledge gained from experiences,
+known physical & chemical models,
+on-line H&M balances,
+advanced CFD modeling extended to Digital Twins of some portions of the cement making process,
+Machine Learning [ML],
are independent bloks which together are the **foundation for APC / RTO / Expert Systems**.
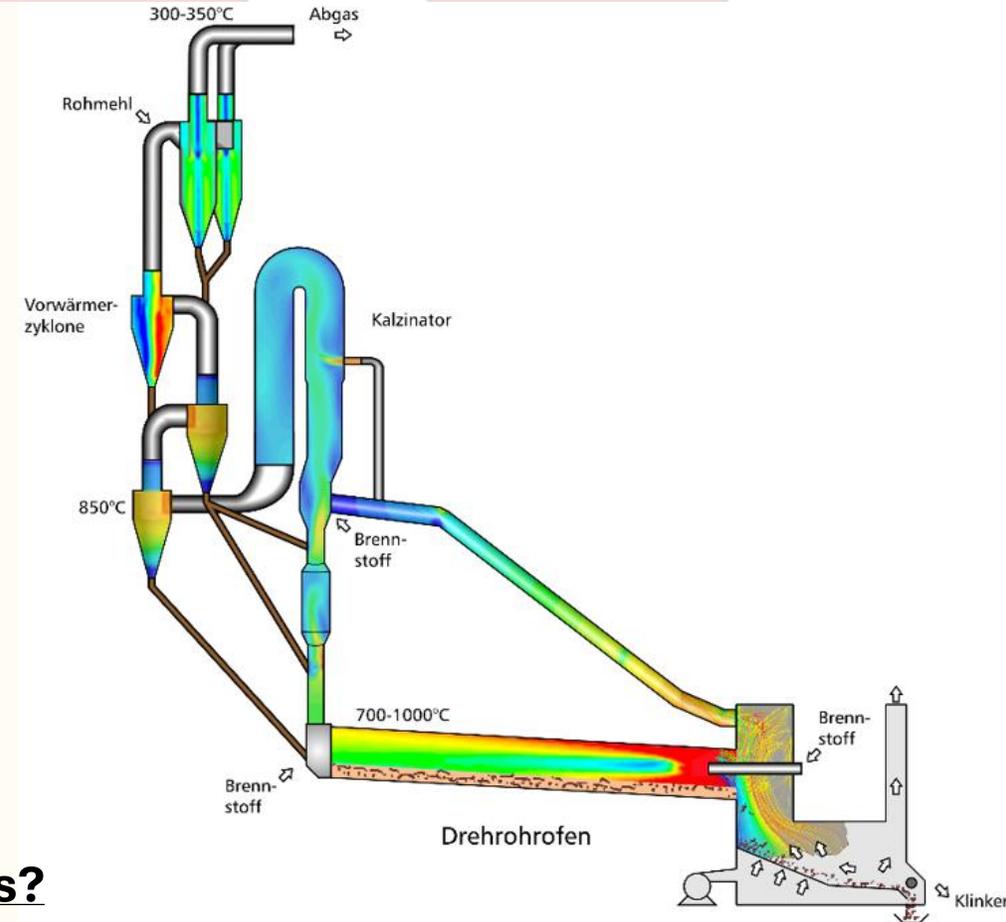
Limits to CFD modeling / Digital Twins?

Digital Twins

On-line advanced measurement systems are needed in cement plants: air flow, LOI, Free Lime, C&S, vibration, moisture, … and should be integrated to Expert Systems.

Online FLA w/ clinker sampling at kiln dischage

Online Air Flow measurement – Finish Mill
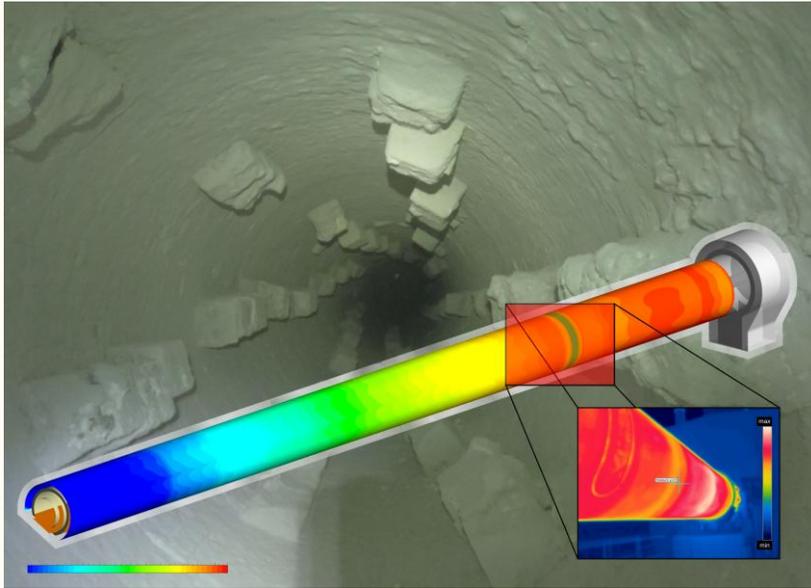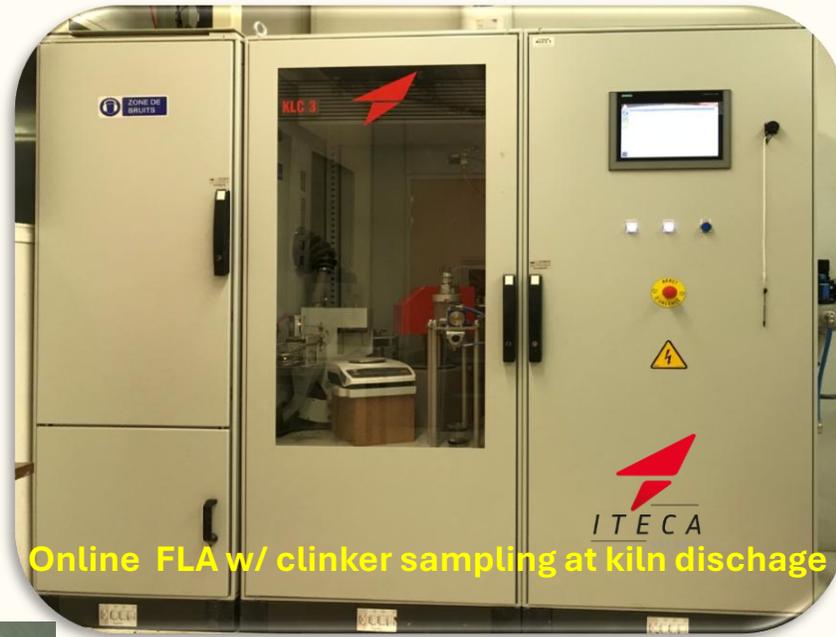
Real-time digital replicates a physical process in the virtual environment(with its functionality, features, and behavior).
E-data / smart sensors complement the hard data

A digital model of a cement plant obtains fast, frequent, and reliable information that would be impossible or too costly to get physically. It provides 3D visualization, and the interpretation of the dynamics of phenomena's.

Both types of live/online/frequent additional information serve as the adjusting set points for advanced control loops.

Advanced CFD one tool used to implement APC / RTO / Expert Systems

Plant & Data
Audits

Optimisation
Consulting

Pyro & Milling
Processes

Integrated Heat & Mass
Balances

Sort, equalize, manage data, AI as a tool for large data processing
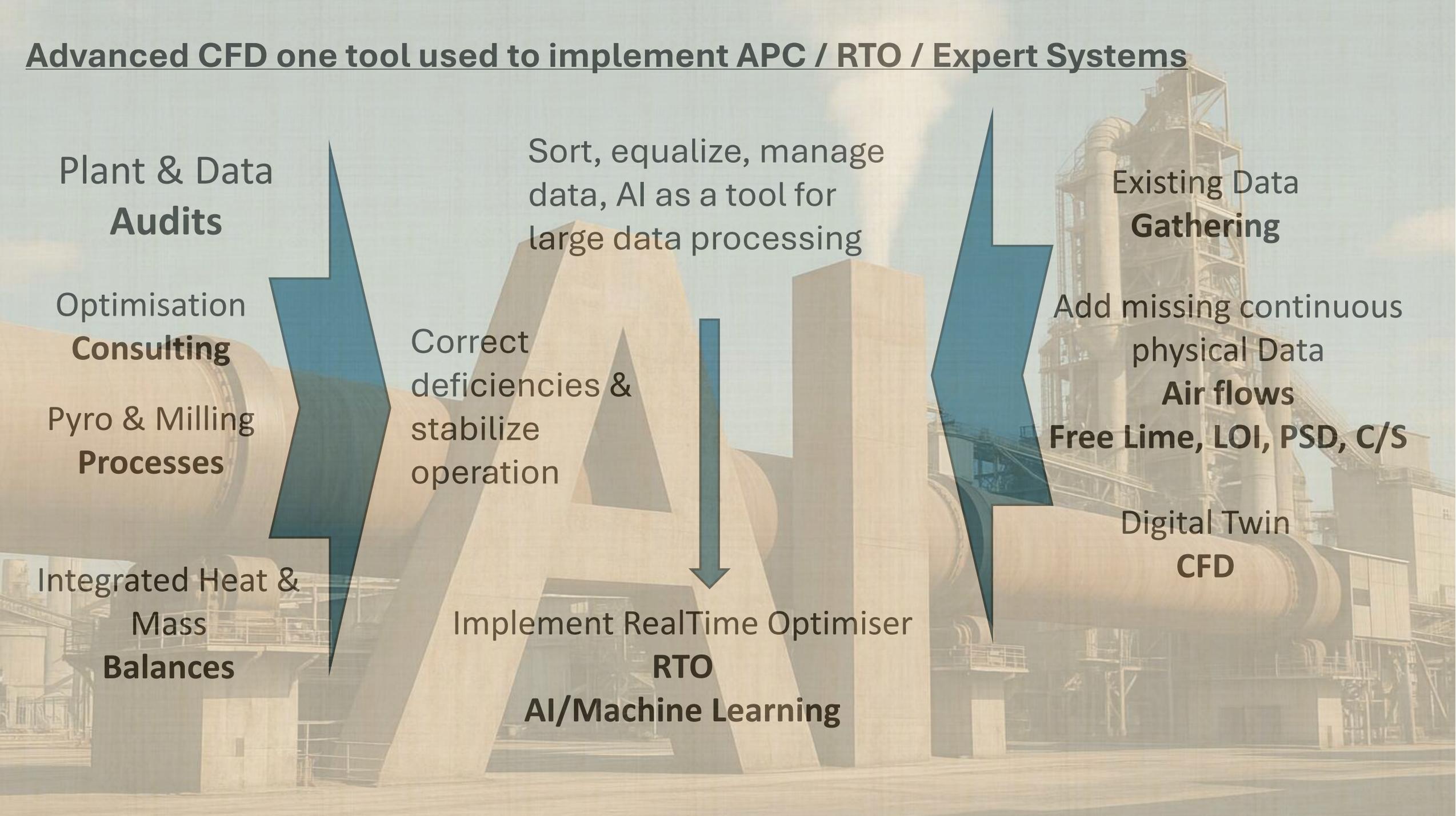
Correct deficiencies & stabilize operation

Implement RealTime Optimiser
RTO
AI/Machine Learning

Existing Data
Gathering

Add missing continuous physical Data
Air flows
Free Lime, LOI, PSD, C/S

Digital Twin
CFD

Conclusion

- Advanced CFD-Based Engineering is to be considered as **an insurance policy, a way to de-risk important projects**, such as the introduction or the increase of alternative fuels TSR.

- It must be conducted by companies having **in depth cement making process experience**, using the **right software** – i.e. a combination of several for each application (there is no one size fits all), and with the capability of simulating dynamic effects.

- In particular, the software should be able to **simulate the impact of the meal on the gas flow**, which is very relevant in case of highly laden gas flows, which is necessary for instance to be able to predict meal spillage in a calciner.

- The **upstream work** in a CFD based project is key, data gathering and evaluation, geometry, mesh, boundaries, selection of CFD software, data input, … and understanding root causes, being able to discuss options and ideas with the plant, …

- **Models can be re-used later** when new issues/projects arise… extra or new AF, oxygen enrichment, use of gaseous fuels (hydrogen, biogas)

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THANK YOU!

Alternative Fuels, Boosting TSR and Efficiency in Cement Plants Using CFD-Based Engineering

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