Carbon^Re

AI FOR MATERIAL IMPACT

AI for plant control

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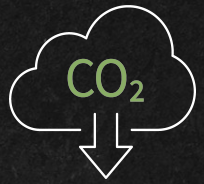
OUR PURPOSE

We’re in business to apply intelligence that reduces the harm of human civilisation on our planet

OUR VISION

Play our part in creating a climate-stable world by enabling zero carbon materials

OUR MISSION



Reduce industrial carbon emissions by gigatonnes every year

Our core technology and expertise

At Carbon Re, we use various kinds of machine learning and deep learning:

– we learn to predict using **supervised learning**;

– we learn to understand data about our processes using **unsupervised learning**;

– we learn to make decisions about our processes using **reinforcement learning**.

The combinations of all of these allow us to learn to interact with complex systems and solve problems requiring sophisticated strategies.

Some definitions

Artificial intelligence (AI): a broad discipline with the goal of creating intelligent machines, as opposed to the natural intelligence that is demonstrated by humans and animals.

Machine learning (ML): a subset of AI that often uses statistical techniques to give machines the ability to "learn" from data without being explicitly given the instructions for how to do so. This process is known as “training” a “model” using a learning “algorithm” that progressively improves model performance on a specific task.

Reinforcement learning (RL): an area of ML in which software agents learn goal-oriented behavior by trial and error in an environment that provides rewards or penalties in response to their actions (called a “policy”) towards achieving that goal.

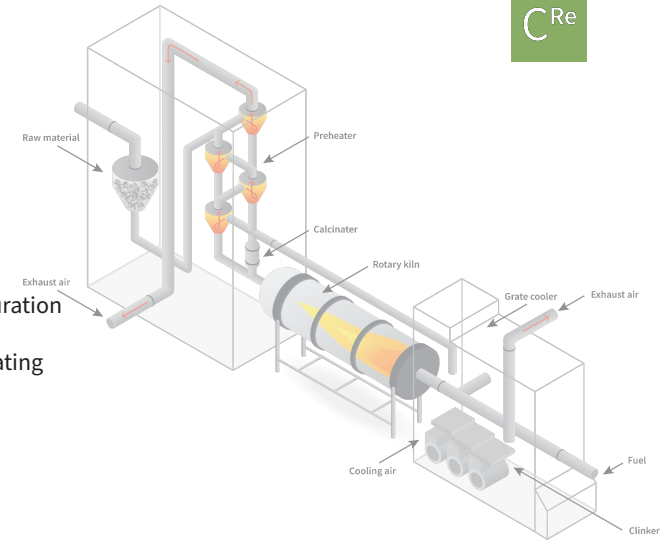
Deep learning (DL): an area of ML that attempts to mimic the activity in layers of neurons in the brain to learn how to recognise complex patterns in data. The “deep” refers to the large number of layers of neurons in contemporary models that help to learn rich representations of data to achieve better performance gains.

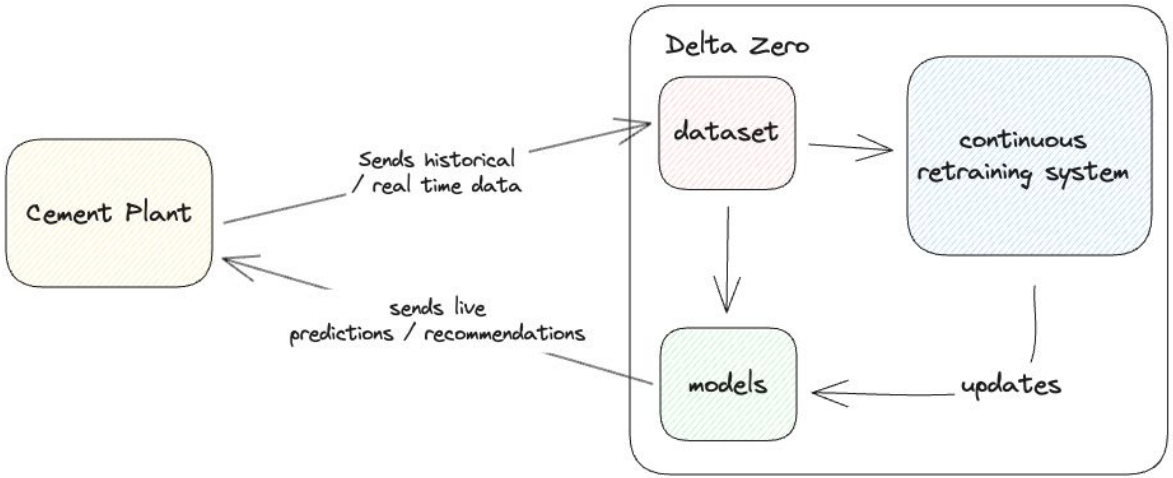
Model: once a ML algorithm has been trained on data, the output of the process is known as the model. This can then be used to make predictions.

Introducing Delta Zero

Pyroprocessing optimization with machine learning

- AI models learn how each cement plant operates from the data, evolve and adapt to changes in the plant configuration
- They take into account quality metrics (Clinker Free Lime and Degree of Calcination) and customer defined operating limits (pre-calciner temperature lower & higher bounds)





Optimizations can be changed according to need, for example:

- **Maximize** throughput then **minimize** cost, whilst **maintaining** clinker quality and plant in control limits
- **Minimize** cost whilst **maintaining** throughput, whilst **maintaining** clinker quality and plant in control limit
- Recommendations and soft sensor data can be **directly** fed into the kiln control system or expert optimizer.

Holistic models assessed by engineers

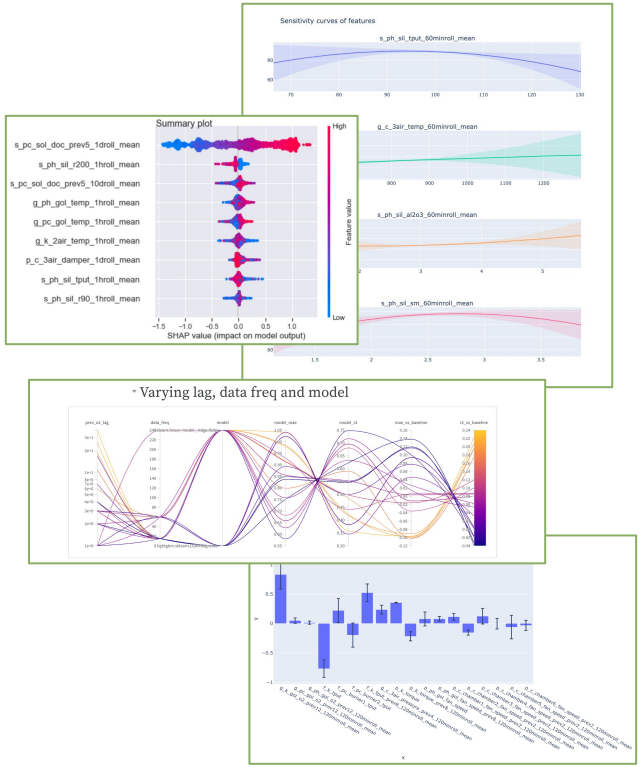
Model baselines are developed and assessed with cement plant engineers

When building each model, **our cement process engineers ensure the performance** of each model matches real world plant operations.

We create **a single model** for each of the three main process stages: pre-heater or pre-calciner; kiln; and, cooler:

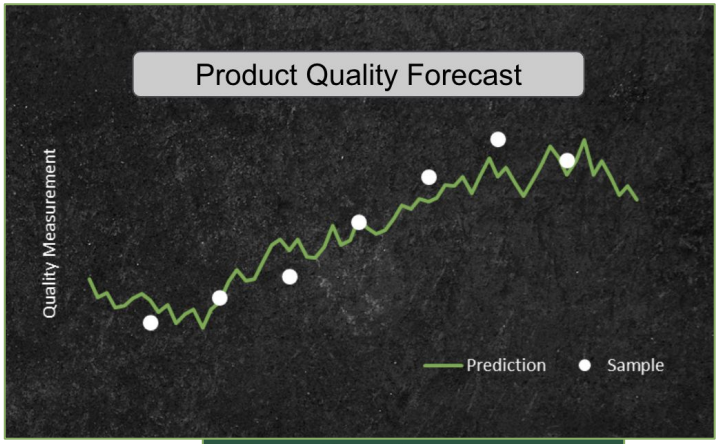
- Our models are not single simple relationships between specific variables, they are full models of all variables for each process stage. This allows us to scale our platform quickly.
- We check that the model behaves like a real plant would.
- It is not a ‘physics-based model’, instead it is a model that respects physical laws, chemical reactions and thermodynamics.

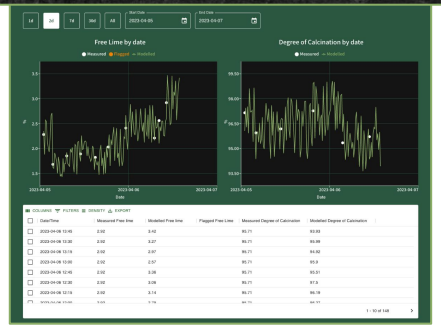
We build confidence in each model by reviewing sensitivity curves to key variables and feature importance for each model.



Forecasting quality parameters

Delta Zero forecasts two key quality parameters: Free Lime (%) and Degree of Calcination (%)





Optimization of production throughput and fuel consumption depends on a good understanding of calcination of the raw meal entering the kiln, and of free lime levels in the cooler. These parameters are important for the system control loops both for expert optimizers and manually controlled kilns:

- Pre-calciners typically consume 60% of the thermal energy required in clinker production. Controlling Degree of Calcination help us to optimize the fuel split between kiln and pre-calciner.
- Free Lime is the most important quality metric for the finished product, and we aim to reduce both under burning and overburning.

Delta Zero's quality predictions enhance control system performance, removing 1 to 2 hour delay in capturing the value of Free Lime arising from the time for cooling, sampling, testing and to feedback the results. This allows kilns to go from reactive to proactive quality control.

These parameters are generated every 15 minutes.

Sampling errors can throw off process control. Delta Zero flags samples for retest if they significantly deviate from the predicted value, reducing the impact of erroneous sampling.

Quality process evolution

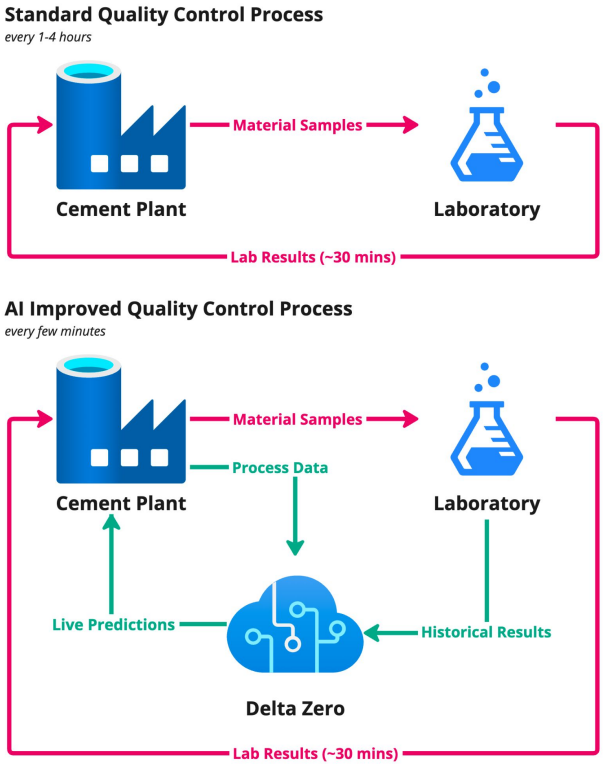
Delta Zero uses soft sensors to improve plant control

Delta Zero's quality predictions enhance control system performance, removing the delay in capturing the value of clinker free lime arising from the time for cooling, sampling, testing and to feedback the results. This allows kilns to go from reactive to proactive quality control.

- Leading clinker quality sampling programs typically only provide results every hour, with a time delay from sampling to measurement of at least 30 minutes
- Our models use live process data, and the most recent lab data to make clinker free lime predictions
- This allows the operators to make decisions on adjusting kiln operation faster and more frequently

As a result, cement plants with free lime predictions can ensure improved control of free lime variability:

- Reduced underburnt clinker (enhanced product quality)
- Reduced overburning clinker (lower fuel consumption)



Core energy optimization

Delta Zero works with manual-controlled kilns or alongside an expert optimizer to maximise performance:

Good forecasting enables the kiln to work at its full potential:

- Under current systems, there is a delay of at least an hour between clinker being quenched, fixing free lime, and sampled values being used to adjust control settings. In addition, sampling frequency might be once every few hours. **This results in controlling of the kiln based on data that is at least an hour out of date**.
- Using a forecasted value of free lime allows control of the burning zone temperature based on the current plant conditions.

Integrating a Degree of Calcination (DoC) soft sensor turns a simple loop control into a dynamic system:

- PC temperature is typically controlled using a loop control setpoint by the operator to maintain a target DoC.
- Modelling the relationship between temperature setpoint, DoC and Free Lime allows Delta Zero to recommend PC temperature target setpoints: optimizing the target DoC for raw material and fuel conditions.

The resulting system delivers both cost and quality benefits:

- Real-time dynamic control of the free lime system reduces over and under-correction errors due to out-of-date sample values.
- Eliminating inaccurate sampling results using the retest-flag feature reduces erroneous correction for inaccurate values.
- This reduces both under and over-burning of clinker, reducing fuel consumption and improving product quality.

Improved quality control also allows for a higher target free lime value without increasing the proportion of high free lime clinker. This reduces fuel consumption still further.

The system is equally beneficially for Expert Optimizer run kilns and for manually controlled kilns.

AI Launchpad programme

Core Capabilities

- **Pre Calciner Temperature target** recommendation
- Live **Free Lime** soft sensor
- Live **Degree of Calcination** soft sensor
- **Open or Closed loop integration** with the kiln control system
- Online **dashboard** with unlimited number of authorized users
- Daily **heat balance** analysis
- **Visualization and analytics** on plant metrics
- **Live connection** to secure cloud hosting platform

DeltaZero

AI Launchpad programme

The AI Launchpad programme provides early access to the core capabilities of Delta Zero.

Join the Carbon Revolution

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