Cost-efficient strategies for sustainable cement production

Driving precise process control with real-time elemental analysis

thermo scientific

Sustainable and cost-efficient cement can be one and the same

Cement, the active binder in concrete, is essential for modern life. Second only to water with respect to global consumption, it underpins our ability to build durable structures, from roads and cities to dams, sea defenses and wind farms. However, cement production is also responsible for up to 8% of global CO_2 emissions[1] providing a significant opportunity to improve environmental output.

Decarbonizing cement manufacture is an increasingly pressing environmental goal that also presents an opportunity to improve production economics. Lower energy consumption and cement's unique potential within the circular economy can be highly beneficial for the bottom line. The Global Cement and Concrete Association (GCCA) roadmap to carbon neutral concrete by 2050[2] is already in place. By achieving breakthrough levels of efficiency, reliability and plant utilization, and embracing new technologies, we can accelerate the journey.

Sustainable solutions for carbon neutrality

Carbon capture and storage are key elements of long-term plans to reduce the environmental footprint of cement production. But easier and potentially lucrative short and mid-term wins can be made through operational changes within the circular economy. Substantial CO_2 reduction is anticipated from the use of such cost-saving opportunities as:

- **Alternative fuels** – replacing fossil fuels in the kiln with waste materials such as old tires
- **Alternative raw materials** such as fly ash and blast furnace slag
- **Clinker substitutes or supplementary cementitious materials (SCMs)** such as calcined clays, burnt shale/shale oil and silica fume, in addition to fly ash and blast furnace slag[3]

Cement manufacturers can reduce production costs by taking advantage of cheaper alternative fuels, raw materials and SCMs. However, successful implementation of these alternatives relies on both understanding and controlling their impacts on the cement production process. Market leaders are measuring key information and using the data to drive efficient bulk materials handling and blending via responsive automated controls. Integration, seamless communication, and exceptional reliability are the hallmarks of the greenest, most efficient cement operators.

[1] https://psci.princeton.edu/tips/2020/11/3/cement-and-concrete-the-environmental-impact
[2] GCCA report https://gccassociation.org/concretefuture/wp-content/uploads/2021/10/GCCA-Concrete-Future-Roadmap-Document-AW.pdf
[3] https://gccassociation.org/cement-and-concrete-innovation/clinker-substitutes

Our proven solutions for the cement industry include on-line elemental analysis and dedicated cement control software. Together they allow cement manufacturers to access and use valuable compositional information to help them compete effectively in the production of cost-efficient and low carbon cement. See figure 1.

Read on to find out how our solutions can:

- Extend quarry life, reduce reliance on costly corrective materials and enable the optimal use of alternative raw materials
- Reduce variability across the plant making it easier to produce high-quality products while reducing kiln energy consumption and extending kiln life
- Deliver sustainability gains in combination with a healthy return on investment (ROI)

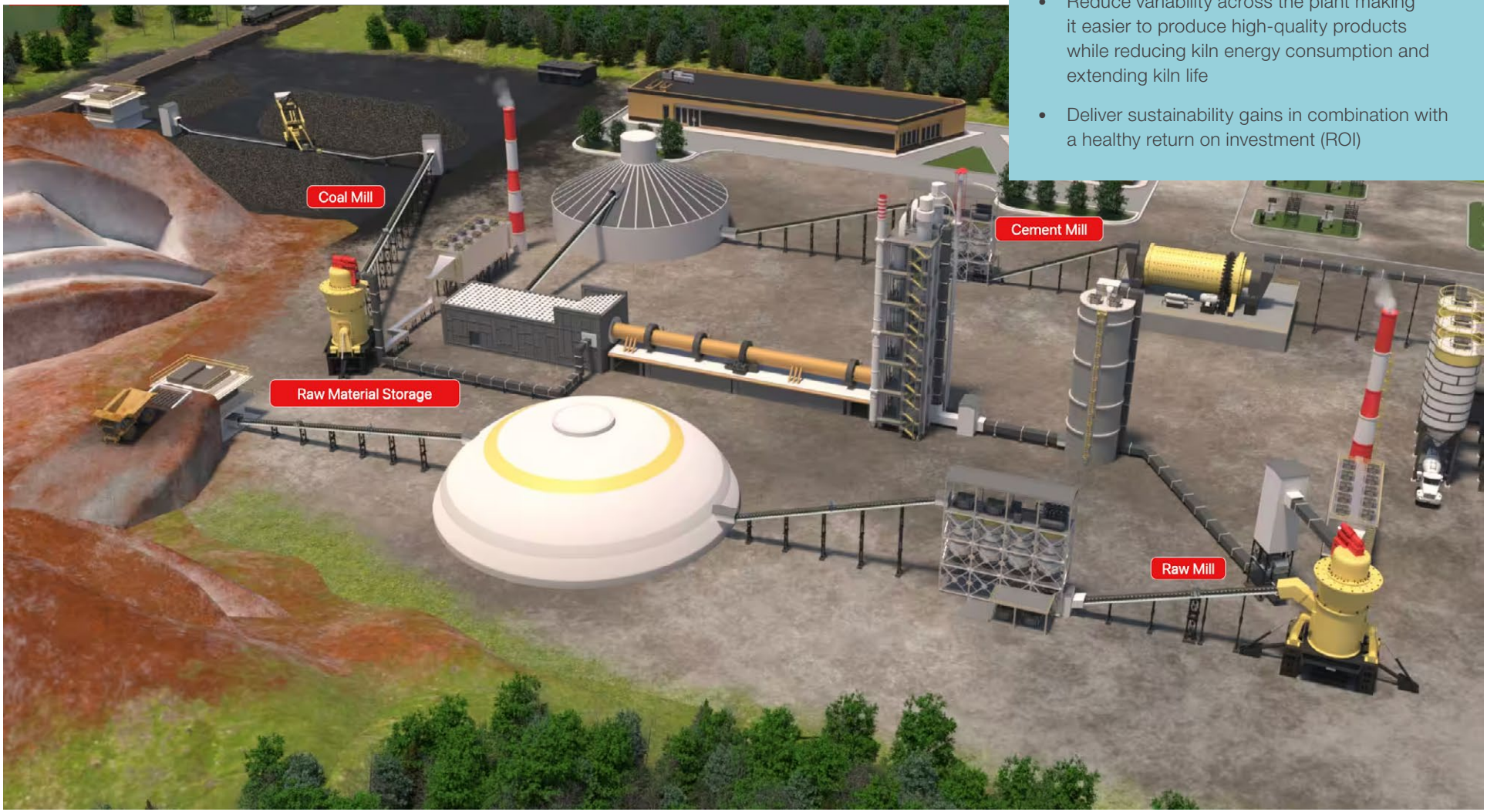


Figure 1: Our technology and solutions work across the cement manufacturing process to deliver higher quality product, at lower cost, with reduced environmental impact

Don’t estimate, measure.

Real-time elemental analysis from quarry to kiln

Quantify and control cement chemistry to drive improvements

The robust control of cement composition safeguards key cement performance characteristics such as strength. Such control begins at the quarry and extends through the kiln to clinker blending. It relies on having timely and precise information about the composition of raw materials and blends.

Prompt gamma neutron activation analysis (PGNAA) and pulsed fast thermal neutron activation (PFTNA) are well-established process control technologies for real-time elemental analysis of cement.

Collectively referred to as neutron activation analysis, these techniques determine elemental composition by capturing and analyzing the secondary or prompt gamma rays released by bombarding materials with neutrons. Individual elements produce a ‘fingerprint’ allowing rapid and accurate compositional analysis. A defining difference between PGNAA and PFTNA is the neutron source which is matched to individual applications; see our dedicated ebook – *A Guide to PGNAA and PFTNA for Non-Scientists* – for further details of these powerful techniques.

For cement manufacturers, neutron activation analysis is a particularly compelling technique because of its ability to:

- Directly measure key compounds of interest, including Ca, Si, Al, and Fe oxides as well as other important elements such as MgO, Na_2O, TiO_2, K_2O, SO_3, Cr and Cl
- Calculate industry standard parameters, such as lime saturation factor (LSF), C_3S, silica modulus, and iron modulus, among others

See figure 2.

Neutron activation analysis for cement

Direct measurement

- CaO
- SiO_2
- Al_2O_3
- Fe_2O_3
- MgO
- Alkalis (K & Na)
- Sulfur
- Chlorine
- Chromium
- Phosphorus
- Moisture

Main elements: 20 Ca Calcium; 14 Si Silicon; 13 Al Aluminum; 26 Fe Iron; 16 S Sulfur; 12 Mg Magnesium

Alkali: 11 Na Sodium; 19 K Potassium

Other elements of potential interest: 17 Cl Chlorine; 24 Cr Chromium; 15 P Phosphorus

Computed parameters

- LSF
- Silica modulus
- Iron modulus
- Burnability index
- C_3S
- C_4AF
- Custom targets

Excellent (<0.01%)
Very good (0.01% to 0.1%)
Good (0.1% to 0.3%)
Moderate (0.3% to 1%)

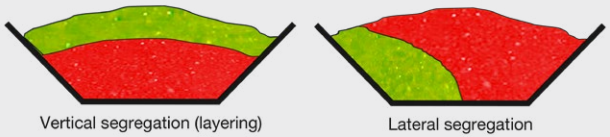
Figure 2: PGNAA and PFTNA capabilities in cement production

The capabilities of neutron activation analysis are combined with practical appeal. PGNAA/PFTNA are readily implemented in either new or existing systems in the form of a cross-belt online analyzer. Online implementation means rapid, high frequency analysis with no sampling requirements, and the technology has been proven reliable to industrial standards.

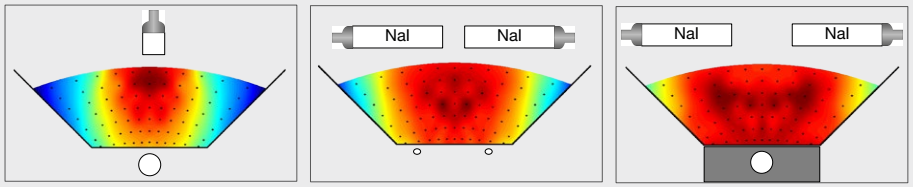
Take a closer look at what online elemental analysis can deliver…

Not all neutron activation analysis technology is equal; know the difference.

PGNAA/PFTNA online analyzers vary principally with respect to source type/strength and detector size/quality. These differences influence measurement uniformity across the belt and have a defining impact on data quality, relevance, and value.



Typical conveying segregation behaviors



Higher neutron output ----------> Better gamma ray capture

- Multiple and/or more powerful sources deliver higher neutron counts

- Multiple, larger and/or better-quality detectors increase gamma capture

The key point: The specifications and configuration of the source and detector determine the analyzer's ability to detect non-uniformity and directly impact measurement success.

The Thermo Scientific™ CB Omni Agile™ Cross-belt Analyzer is one of the world's leading neutron activation analysis solutions for cement manufacture. Light, compact and easy to install, it is a flexible system that is fully customizable with respect to:

- Number of detectors, between 1 and 4 high efficiency sodium iodide (NaI) detectors with NaI selected for speed, resolution, and stability.
- Neutron source, californium isotope (CF-252 for PGNAA) or electronic neutron generator (for PFTNA); sources may also be changed as required
- Configuration, which can be optimized for repeatability or uniformity
- Source quantity

The flexibility of the CB Omni Agile analyzer allows us to offer all cement manufacturers an online elemental analyzer well-matched to their needs.

Reaping the rewards of real-time analysis

At the quarry

Manage stockpiles effectively to extend quarry life

Reducing the variability of raw material stockpiles carries through to lower variability across the plant. However, quarry output changes over time as different stands are mined and depleted. As quarries mature, waste levels can become particularly high, hastening the end of productive mining.

Online elemental analysis enables the precise control of stockpile LSF

With real-time elemental analysis in place, the LSF variability of stockpiles can be substantially reduced relative to performance with offline X-ray Fluorescence (XRF) measurements (see figure 3). LSF is a ratio of lime to Si, Al and Fe oxides and a performance-defining metric for cement.

This ability to continuously monitor and control pre-blend feedstocks means:

- Longer quarry life
- Lower stockpile-to-stockpile variability and the elimination of pre-homogenization silos
- More cost-effective material management

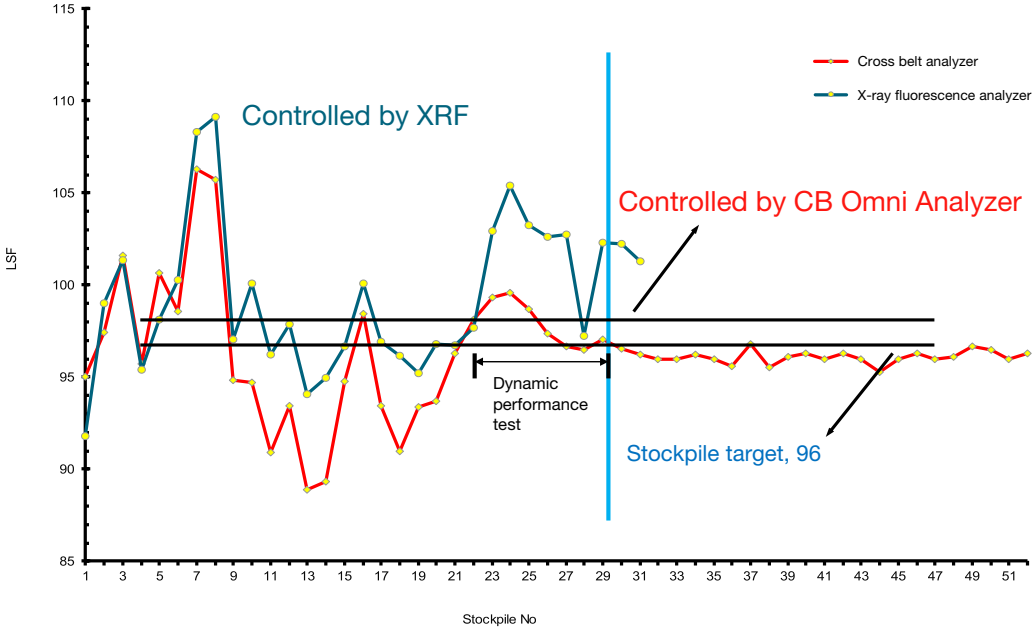


Figure 3: Variability reduction with real-time elemental analysis

Real-world returns: Lower operating costs, longer quarry life

By installing a Thermo Scientific cross-belt online analyzer immediately after the primary crusher, a European cement producer was able to reduce pre-blending stockpile-to-stockpile variability by a factor of four. This improvement delivered **savings on corrective material spend** and **lower kiln energy consumption**. By re-routing quarry material previously sent to waste, **the life of the quarry was extended.**

At the kiln

Take control of LSF to make low carbon cement, cost-efficiently

Raw mix optimization is another area of opportunity for fine-tuning the kiln feed to control cement chemistry. Proportioning the output from the mine with materials such as corrective lime and iron is essential to produce a consistent raw mix. Introducing alternative raw materials such as fly ash, blast furnace slag, catalyst fines (a chemical waste stream) at this point reduces reliance on expensive correctives while simultaneously improving sustainability.

Online elemental analysis enables precise control of the LSF of the kiln feed

Implementing online PGNAA can bring the LSF of the raw mill feed under tight control (see figure 4). Reductions in LSF variability of around 50% are routinely observed.

The ability to achieve tighter control of the LSF of the kiln feed means:

- Lower, more stable kiln energy consumption
- Raw material savings
- Longer kiln brick life
- Higher throughput
- More consistent clinker quality

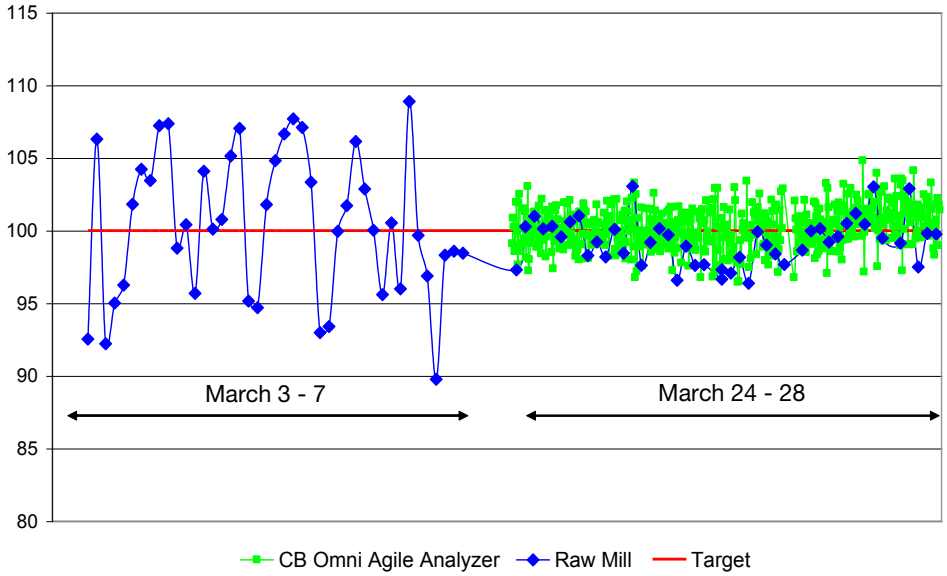


Figure 4: LSF measurements before and after online PGNAA implementation

The Thermo Scientific analyzer and RAMOS software have allowed “an improvement in the standard deviation to about half of what it was coming out of the raw mill” compared to prior to installation.

Quality Control Manager at US cement manufacturer

Minimize variability, optimize production

Use real-time data to drive the process

Switch from reactive to proactive with integrated solutions that deliver precise process control

Real-time elemental analysis enables statistical process control (SPC) so you can proactively manipulate process variables to meet operational goals in real-time. How does that differ from traditional offline analysis? Routine offline analyses in a cement lab are essential for QA/QC and a critical element of statistical quality control (SQC). They confirm the quality of finished products. However, the time lags associated with such analyses limit their value for proactive process control. An analysis that reveals an operational status in the plant an hour go allows only for reactive control.

By making effective use of real-time data, manufacturers can control and drive down variability across the plant (see figure 5).

Automated, integrated process control solutions maximize the value of real-time data

Taking stockpile control as an example, we can see the requirements and benefits of automated control (see figure 6). With manual control, data from the elemental analyzer is fed through to the plant control system. The operator combines the resulting information with mass flow rate data from the weigh scale to adjust the flow rate of raw materials to control the composition of the blending bed.

With automatic control, the feeders for three different materials are manipulated in real-time – with no manual input – to meet a target LSF for the blending bed. Feed rate changes become more frequent but smaller, and as a result, the bed composition is more consistent.

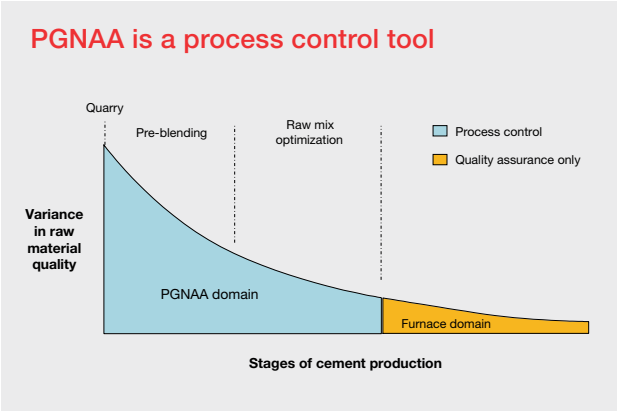


Figure 5: Real-time analysis impact on variability

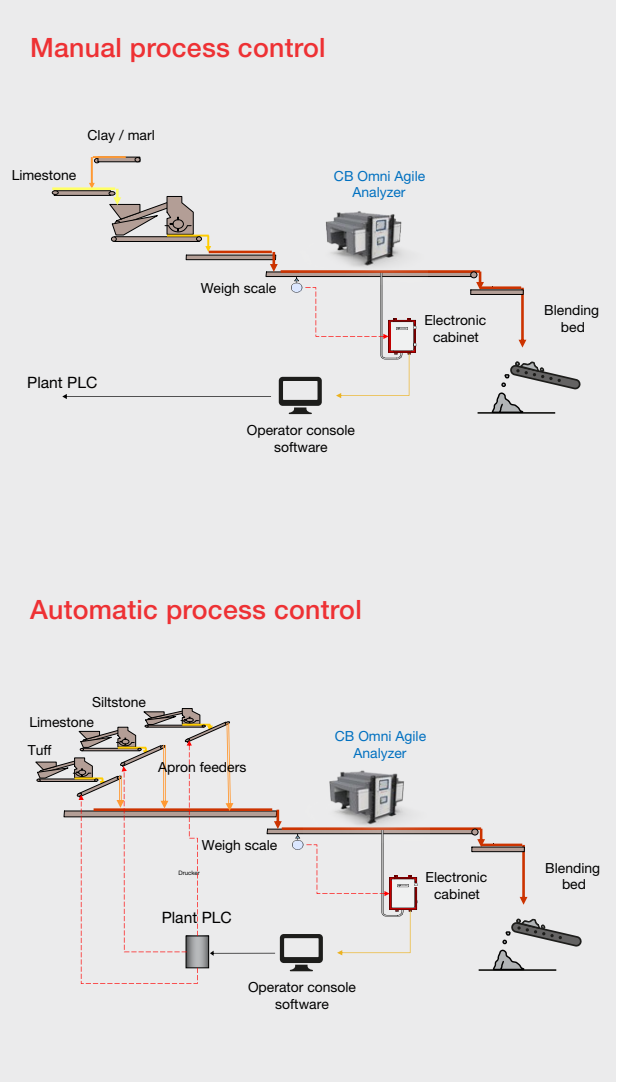


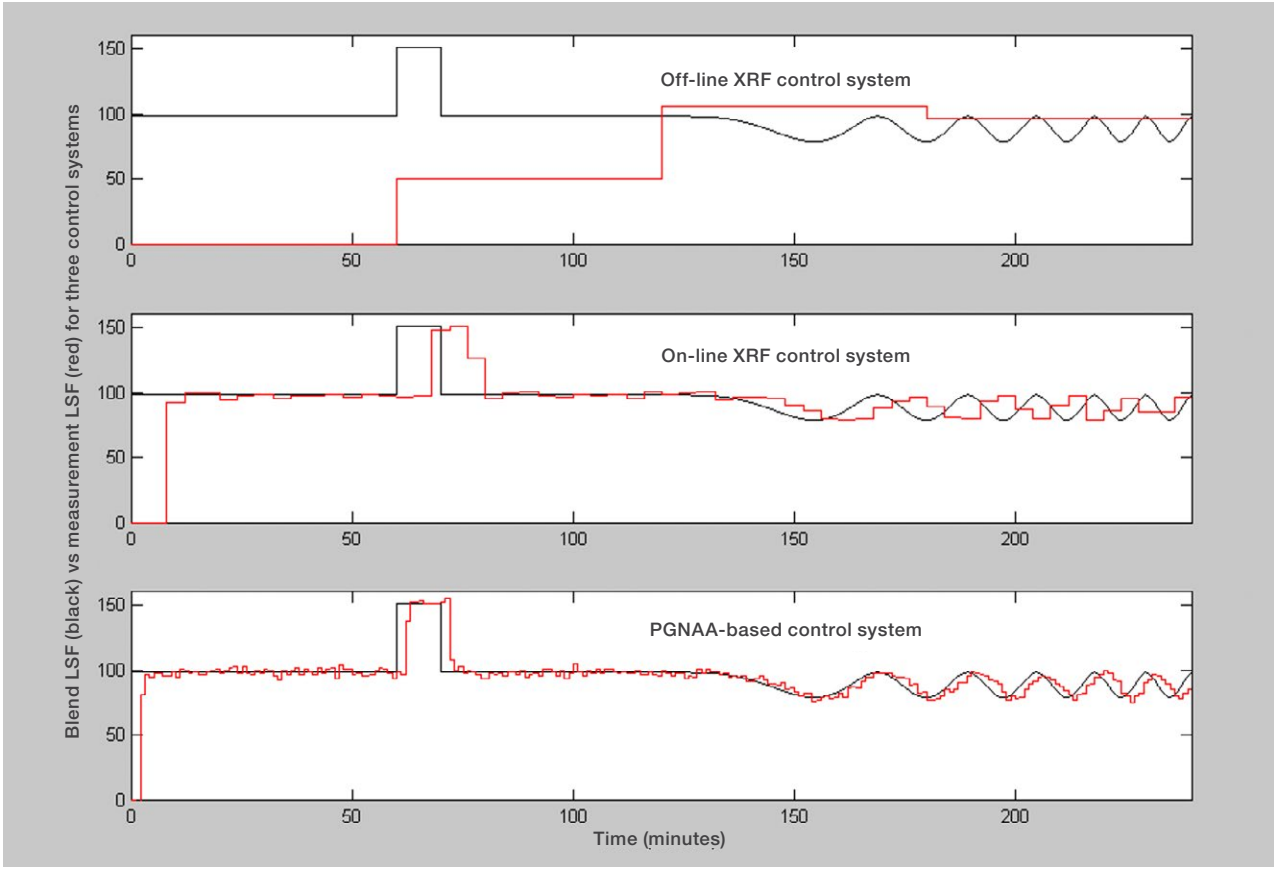
Figure 6: Manual versus automated process control

Real-time process monitoring: the key to successful control

The chart below illustrates the value of rapid, real-time measurement. With offline measurements (XRF – upper plot), infrequent measurement makes it impossible to track LSF variability. Online XRF (middle plot) is better, but the time lag is still significant because online XRF has an appreciable measurement time. In contrast, PGNAA measurement (bottom plot) is rapid, and the online analyzer closely tracks fluctuations with no delay. In this way it provides a secure foundation for responsive and efficient process control.

Real-world returns: Establishing a benchmark for green, intelligent mine operation

In Zhejiang Province, China a Thermo Scientific cross-belt online analyzer has been used to develop a green, intelligent limestone mine for Zhejiang Chengyu Environmental Protection New Materials Co., Ltd. Data from the analyzer provides a foundation for the implementation of advanced automation and digitalization and has proven instrumental to transforming operational practice. Key gains range from **a reduction in SiO_2 fines and product returns to improved production efficiency, better resource utilization and lower mine transportation costs. Environmental and safety risks have also been reduced and product quality enhanced** in a project that sets a benchmark for future development of efficient, green cement operations in the province.



Build a solution that works for you

We offer the software required to build effective manual and automated control solutions that capitalize on the inherent value of real-time data. These include solutions that:

- present the elemental analysis in a relevant form and drive SPC for cement operations such as pre-blending or raw mix optimization.
- enable automatic online analyzer calibration.

Using these solutions you can steer cement manufacturing into the ‘sweet spot’ where product quality is assured, sustainability goals are met and costs are minimized.

Choose PREBOS or RAMOS software for customized cement plant control

Thermo Scientific™ Pre-blending Optimization Software (PREBOS™) is a dedicated software for stockpile management. It works with a cross-belt online elemental analyzer to minimize stockpile variability. Figure 7 shows PREBOS software automatically manipulating the feed rate of four different materials to build a stockpile with an LSF of 98.

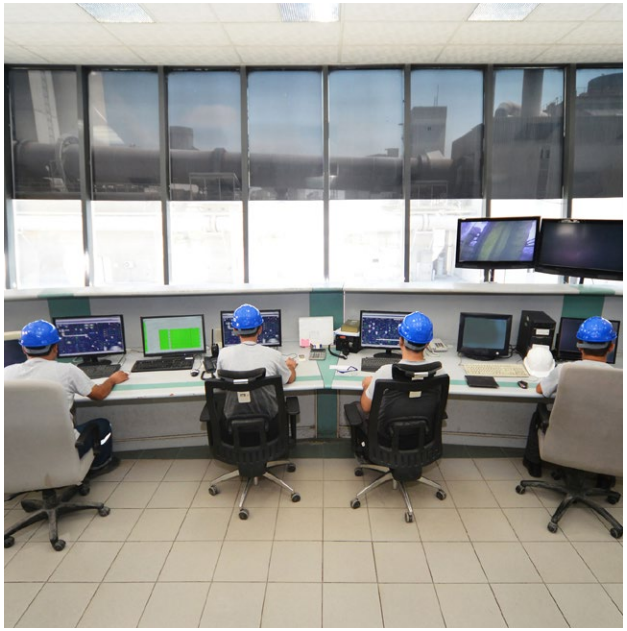
Figure 7: PREBOS software managing feed rate for four different materials

Raw material optimization software (RAMOS) is analogous software for optimizing the kiln feed. It works with a cross-belt online elemental analyzer to control blend proportionately in the kiln feed and maintain consistent composition. Figure 8 shows RAMOS software manipulating the feed rate of four different materials to control raw mix composition in real-time (upper trend plot); control on the basis of hourly XRF data is shown in the lower trend plot. RAMOS makes more frequent changes but keeps LSF under more precise control (note the differences in the y-axes), reducing the LSF standard deviation from 5.1 to 1.8.

PREBOS and RAMOS software are flexible with respect to plant connectivity, easy to configure, and produce charts and trends aligned with industry norms. Either can integrate seamlessly into your overall plant control system to deliver critical control functionality. Both can:

- Automatically control the feed rate of multiple raw materials
- Optimize blend quality
- Prioritize targets to minimize costs while meeting QC constraints

Figure 8: RAMOS software manipulating the feed rate of four different materials



Building solutions that are lean and green

An automated, integrated solution delivering efficiency and sustainability in raw mix control is shown in figure 9.

The automated, integrated system shows raw materials flowing from ten hoppers:

- Three contain limestone
- Three contain catalyst fines (a chemical waste material)
- One contains iron ore
- One contains shale
- One contains silica
- One contains feed slag (a second waste material)

These feeds are automatically used at a controlled rate to meet economic and sustainability targets within the constraint of delivering a consistent LSF. A two-speed belt conveyor supplies both ball mills, and it works at a lower speed when a single mill is in operation. This set-up has immense flexibility with respect to alternative feed usage, and at the same time delivers the consistency and efficiency required for competitive cement production.

Immense options to change material feed

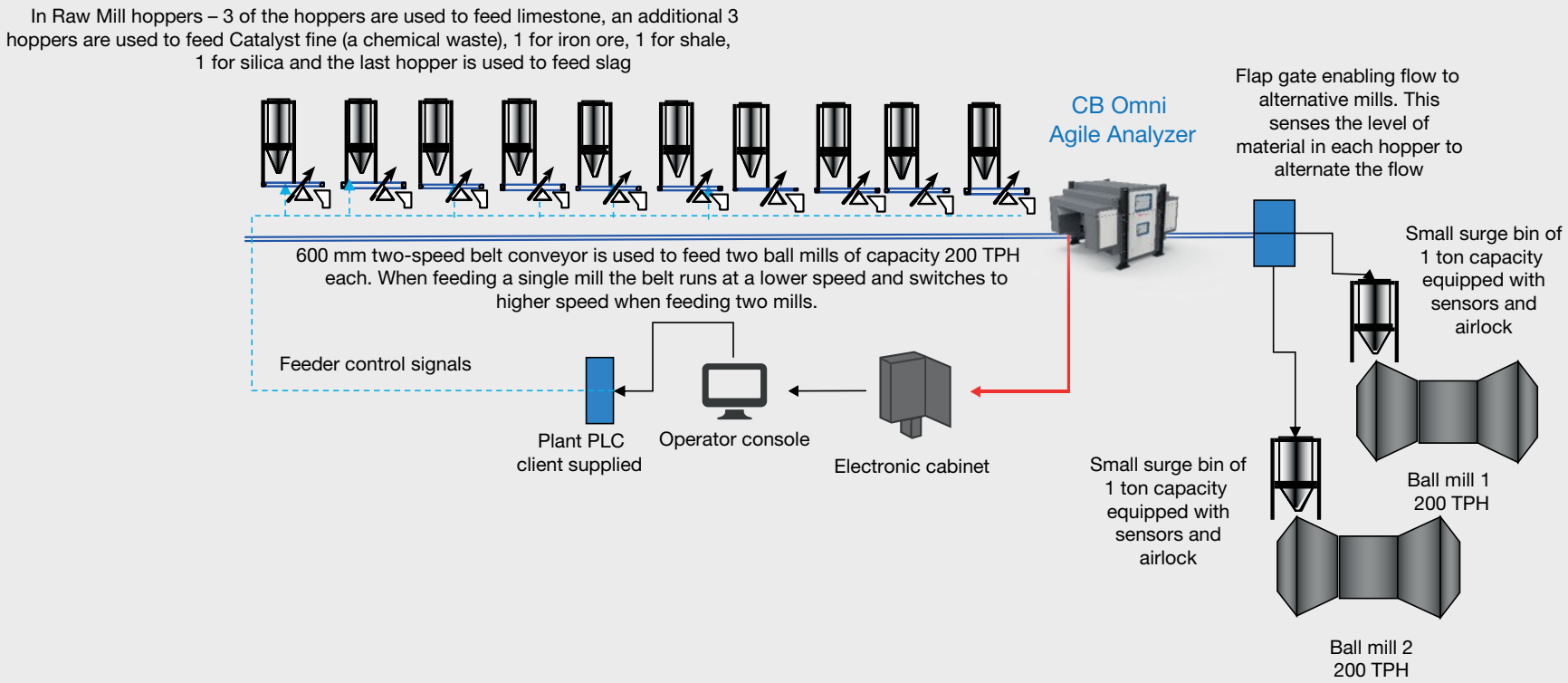


Figure 9: Depiction of an automated, integrated solution that is both efficient and sustainable

Thermo Scientific™ AccuLINK™ Software for automatic online analyzer calibration

For cement production, offline XRF analysis remains the benchmark for QC. AccuLINK software keeps your online elemental analyzer as close as possible to this benchmark by continuously comparing online data with results from your site's laboratory. It generates statistical and graphical information for data comparison to maintain the accuracy of the online system via automatic calibration. A powerful diagnostic tool, AccuLINK software essentially ensures laboratory levels of accuracy with minimal manual input, thereby delivering significant gains in LSF consistency (as shown in figure 10).

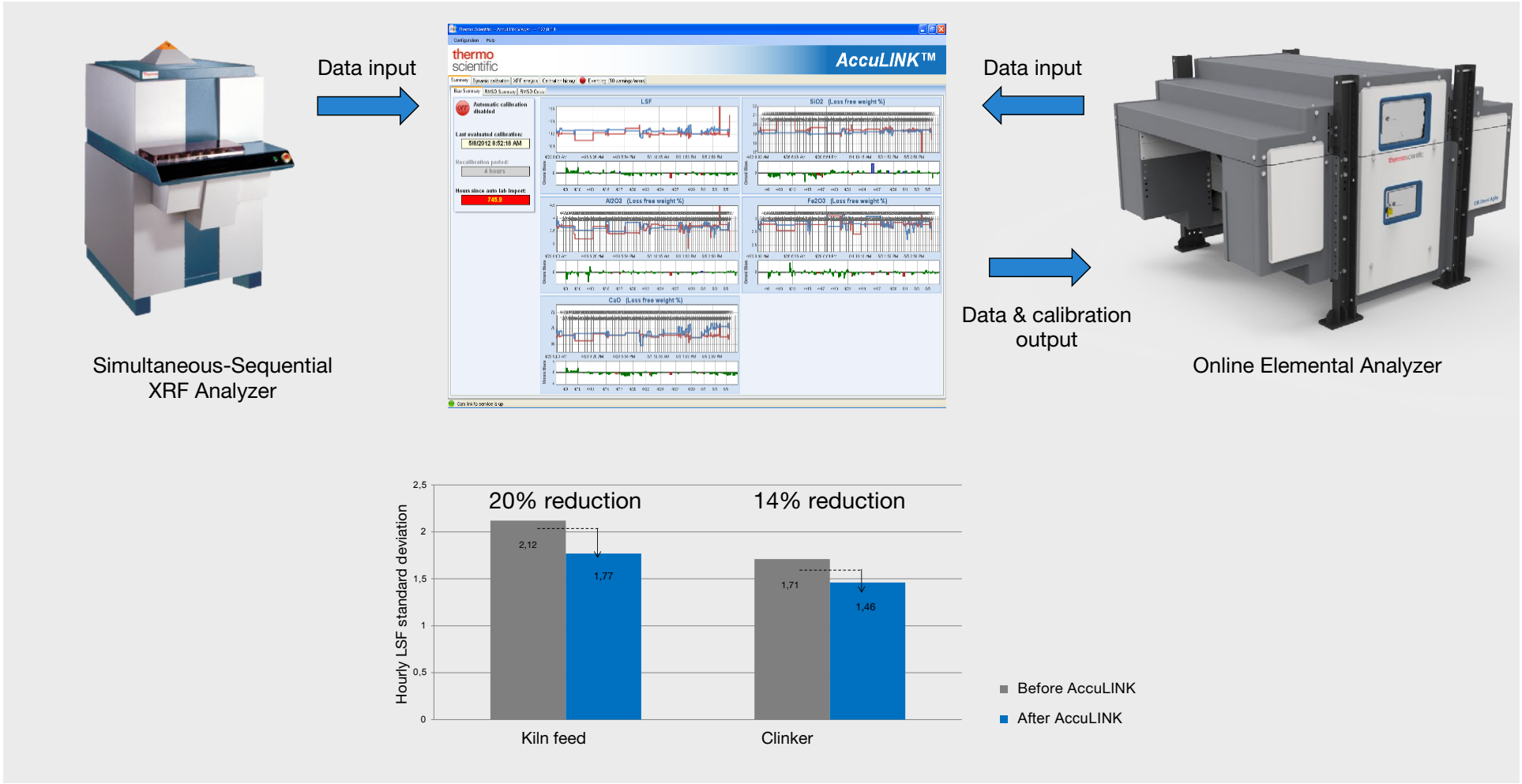


Figure 10: By ensuring lab standard data from an online analyzer, AccuLINK software maximizes gains in LSF consistency

Saving through stability

Track the route from real-time measurement to ROI

Stability and consistency are the hallmarks of highly efficient processes. Such agile processes minimize waste and energy consumption while optimizing profitability. Variability, in contrast, can be directly linked with inefficiency. A closer look at the correlation between variability in LSF and fuel usage in the kiln exemplifies this effect.

The kiln converts the raw mix to clinker via pyroprocessing at an appropriate temperature of ~ 1300 – 1450 °C. Fuel input is automatically controlled to ensure the correct conditions, typically with reference to process variables such as temperature profile of the kiln and compositional analysis of the exiting exhaust gas. If the LSF of the feed is consistent, then this complex control system simply needs to transition to an optimal fuel input and remain there. Deviations from the optimal operating condition will therefore be minimal.

In contrast, if the LSF of the raw mix is variable then the control system must work much harder to control multiple effects. In this scenario, the specific heat required to bring the feed to the appropriate temperature is continuously shifting, and so is the heat required for pyroprocessing because composition affects the chemical reactions taking place. The net result is a constantly moving fuel input target. However good the control system, variable LSF makes it much harder for optimal conditions to be identified and maintained. Fuel input will therefore be sub-optimal for a larger proportion of the time, negatively impacting production economics.

But the fuel story doesn't stop there. Many cement manufacturers use a cocktail of highly calorific waste materials to drive the kiln since this is financially and environmentally attractive.

Similar to raw mix variability, fuel variability can also potentially lead to inefficient operation though the impact tends to be less noticeable. Agile fuel usage is much easier with an otherwise steady kiln than when it accentuates the fluctuations of a less stable plant. Add in the extension to kiln brick life that also comes from consistent operation, and you have a truly compelling case for online elemental analysis.

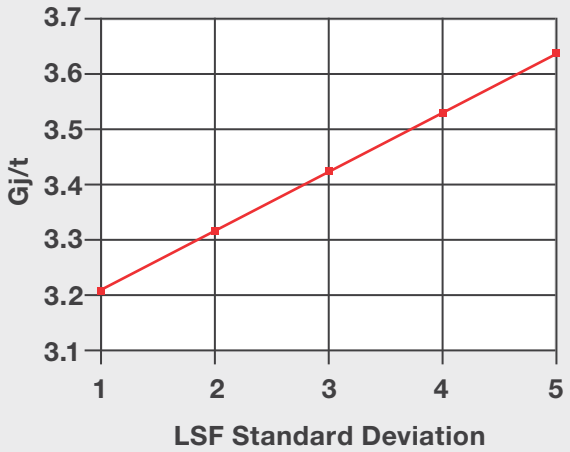


Figure 11: LSF stability in terms of fuel savings

Figure 11 quantifies the impact of LSF variability and shows how much LSF stability is worth in terms of fuel savings. These savings alone deliver an attractive ROI on the implementation of real-time elemental analysis and are typically sufficient to justify an investment.

The support you need to succeed

With precise, automated control in place, it is much easier to steer cement manufacture into the ‘sweet spot’ where product quality is assured, sustainability goals are met, and costs are minimized.

We offer complete service and support options with access to a global network of technical support, factory-certified engineers, consultants, and industry professionals. Partnering with us simplifies the maintenance of your instrument and controls service costs.

Our service team is:

Knowledgeable: We understand cement production, what our products are capable of and how they support economic and sustainability initiatives. We bring expertise to complement yours, and we’re invested with you for the long-term.

Experienced: We’ve pioneered the industrial application of PGNAA and PFTNA, and our market-leading products reflect that.

Comprehensive: Our comprehensive service offering extends from technical evaluation, through installation and commissioning, to maintenance, calibration and training, responsive diagnostics and repair. Your operations will benefit from a service plan that is designed to match your needs as well as efficient parts supply wherever you’re working, around the globe. We can help you minimize downtime and maximize the return on your assets.

Proven: For cement manufacturers the road to carbon neutrality is a challenging one, but there are solutions with a proven ability to simultaneously deliver economic and sustainability gains. The world’s largest, most innovative cement producers already rely on our technology to ensure product quality and operate safer, cleaner plants with high profitability. Talk to us and find out more.

Look to us for all the tools needed to build automatic, integrated solutions that can transform the efficiency and sustainability of your cement manufacturing operations.

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Learn more at **thermofisher.com/cement**

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