

ONLINE SEMINAR 2022

Production of High-Performance Cement at Lowest Costs enabled by Latest Analytical Technology

Dr. Kai Behrens

Dr. Adrian Fiege

Dr. Rainer Schmidt

Frank Portala

Renata Janjic





Outline

01 Bruker's Solutions for the Cement Industry

02 Applications of XRF

03 Live-from-the-Lab: Automation

04 Applications of XRD

05 Live-from-the-Lab: Benchtop XRF Solutions

06 Q&A Session with our Experts

Our Speakers



Dr. Adrian Fiege
Product Manager XRF



Dr. Rainer Schmidt
Market Manager Automation Solutions



Frank Portala
Product Manager XRF



Renata Janjic
Application Specialist XRF



Dr. Kai Behrens
Head of XRF Product Management

PRODUCTION OF HIGH-PERFORMANCE CEMENT AT LOWEST COSTS ENABLED BY LATEST ANALYTICAL TECHNOLOGY

Applications of XRF

Dr. Kai Behrens
Dr. Adrian Fiege

What are the Analytical Requirements in the Modern Cement Industry?

Accuracy and Precision

- For Process Control: Raw Mix, Clinker
- For Quality Control: Cement

Speed and Sample Throughput

- Immediate feedback for process optimization
- Short time for product release

Analytical Flexibility

- From raw materials to final product; incl. alternative fuels and environmental protection

■ Reliability

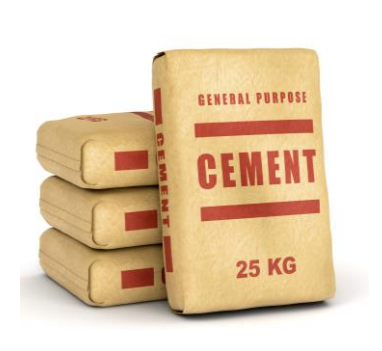
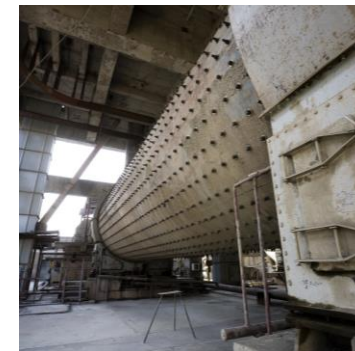
- Instrument uptime
- Long-term analytical stability

■ Simple Operation

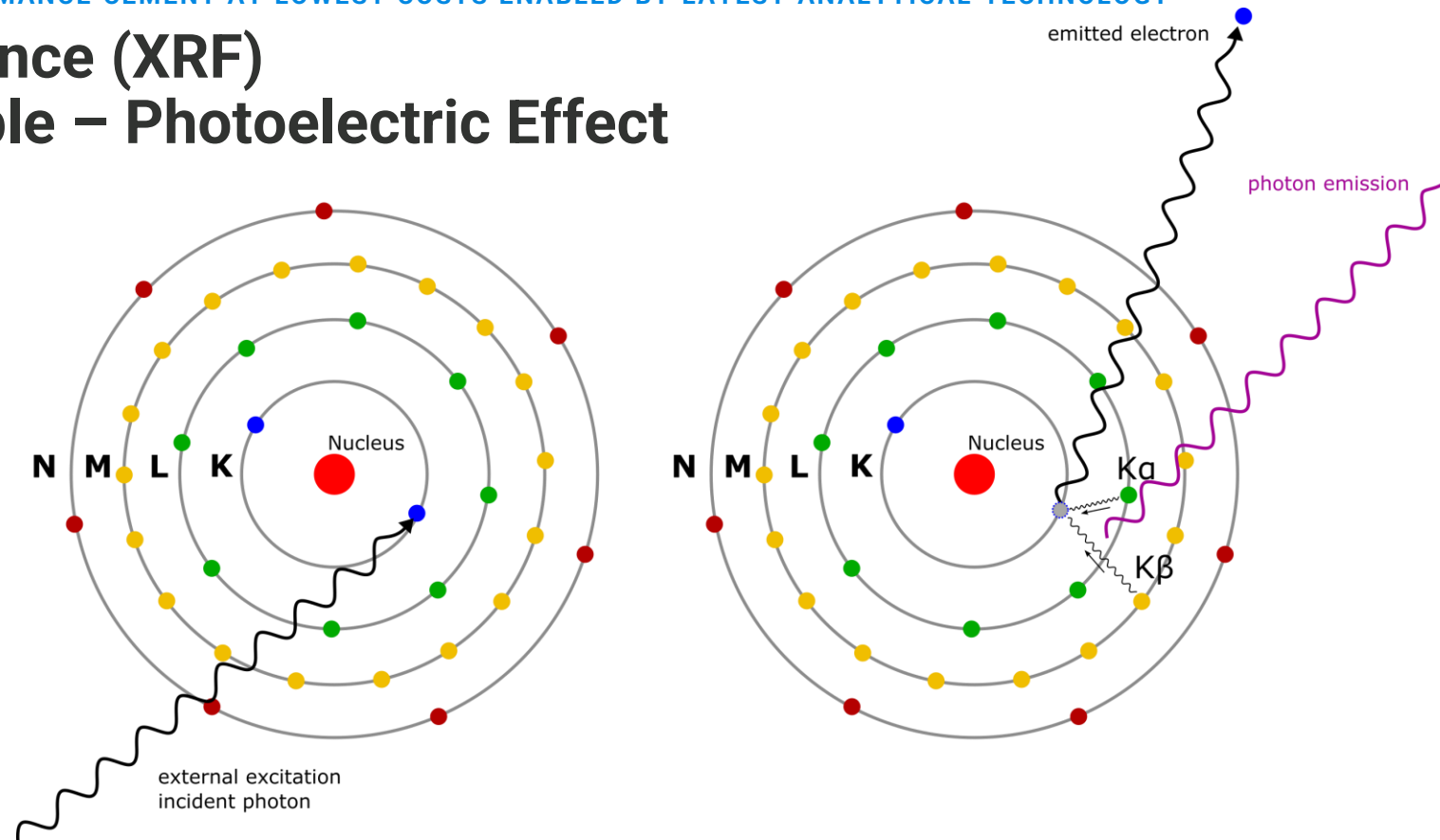
- For cost effective operation and involvement of all employees

■ Compliance

- GLP compliant workflow
- Data integrity
- Norm compliance



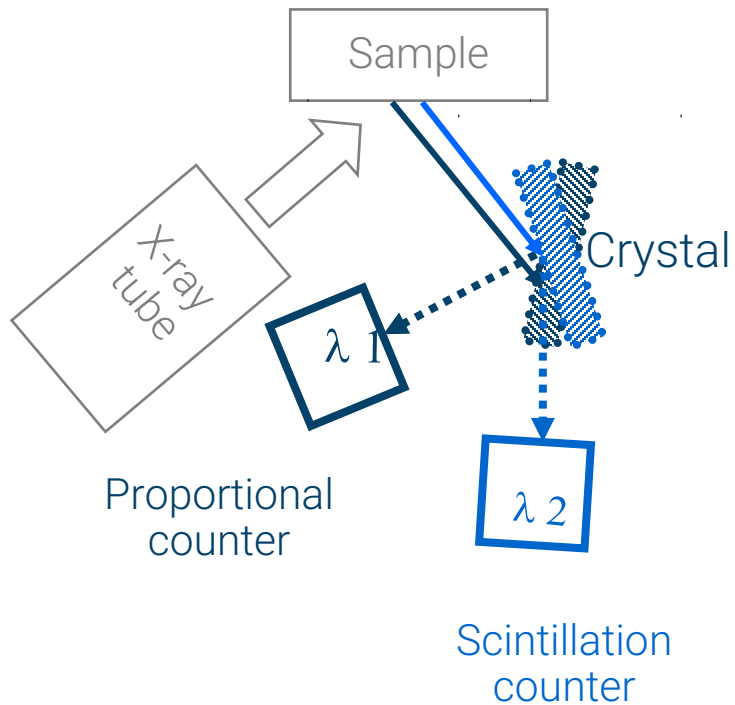
X-ray Fluorescence (XRF) Analysis Principle – Photoelectric Effect



- Sample excited with an X-ray beam causing fluorescence
- Electron ejected from an inner shell of its atom
- Electron from a shell farther out falls into the vacancy

- Energy difference is emitted as an X-ray photon
- Discrete energy and wavelength is characteristic for the emitting element / transition
- Intensity of characteristic radiation is proportional to concentration of the element in the sample

Wavelength-dispersive X-ray Fluorescence (WDXRF)

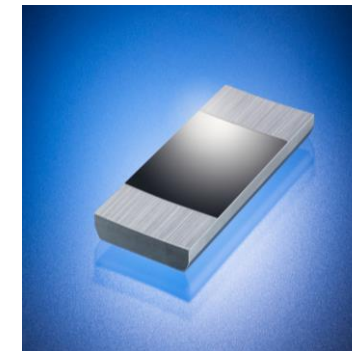


An analyzer crystal is used to separate the different wavelengths λ (energies)

The detector records the number N of X-ray photons at a given wavelength (energy)

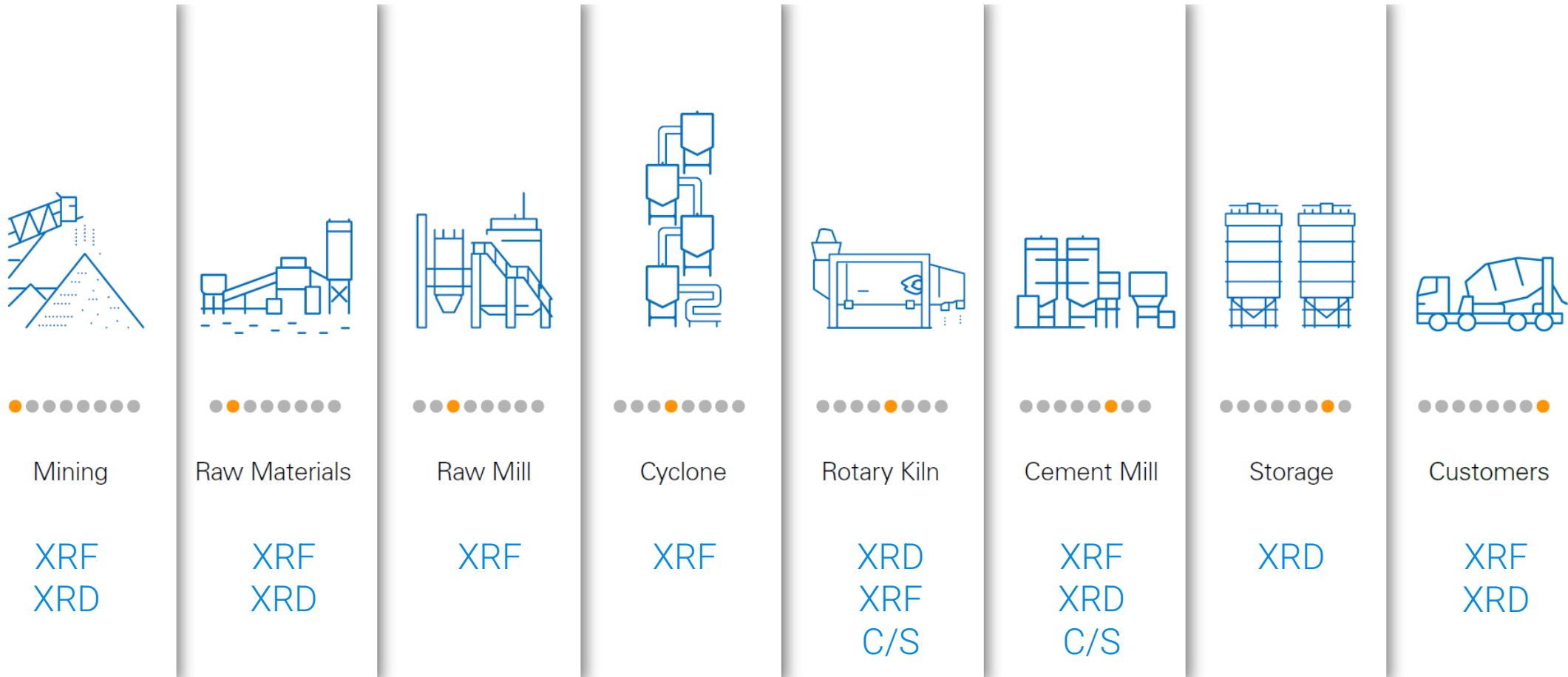
Two detectors are used to cover the entire element area

- Proportional counter: B to Cr
- Scintillation counter: Mn to U



The Cement Production Process

Where to Use XRF, XRD, and Combustion Analysis (C / S)



XRF Applications during Cement Production



Grade Control at the Mine and during mineral beneficiation (limestone, dolomite, sands, iron ores)



Quality Control of raw materials (limestone, dolomite, clays, sands, slags, fly ashes, iron ores, ...)

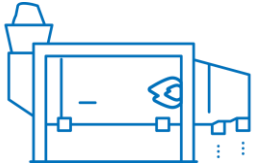
Process Control: Raw Meal analysis



Process Control: Hot Meal analysis

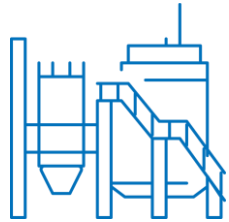


XRF Applications during Cement Production

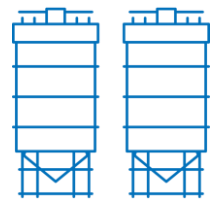


Process Control: Clinker analysis

Quality Control of (secondary) fuels (rubber, fuels, coal, plastics, ...)



Quality Control of the milled cement



Quality control of the final cement products

- Before storage & shipment
- Upon receipt / by customs or local authorities



XRF Applications during Cement Production

Environmental Tasks

- Heavy metal contents in secondary (alternative) fuels
- Waste control: Effluents, sewage, filters, metals, slurries...



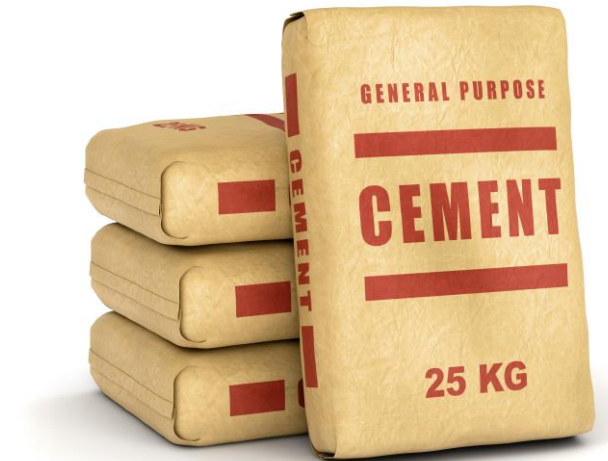
Multielement analysis

8 traditional cement elements

- Na_2O
- MgO
- Al_2O_3
- SiO_2
- SO_3
- K_2O
- CaO
- Fe_2O_3

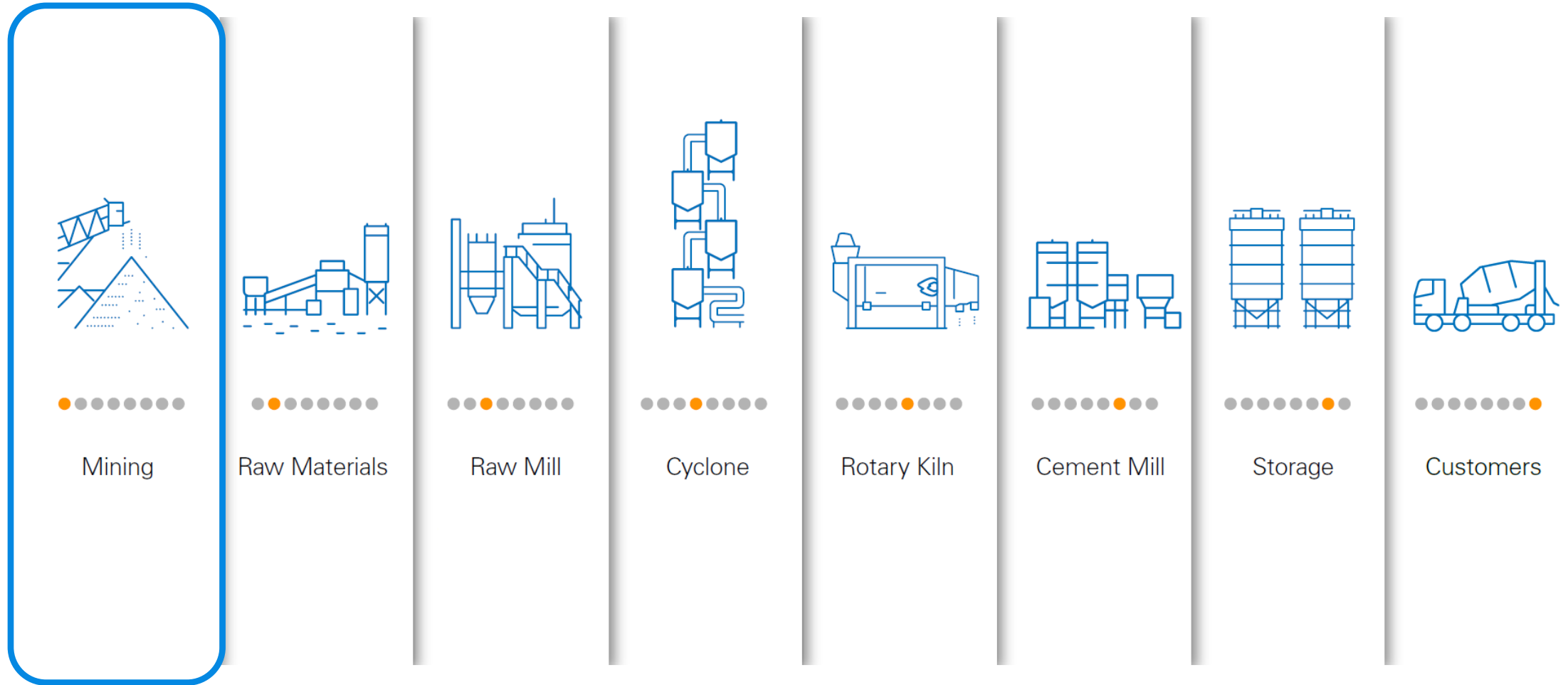
further plant specific elements

- Mn_2O_3 , TiO_2 , Cl , Zn , P_2O_3 , F , C , Cd , Hg , etc.



The Cement Production Process

XRF Application



Limestone Grade and Quality Control with benchtop XRF

- Raw material analysis for
 - Hardness (SiO_2)
 - Color (Mn, Fe)
 - Hazardous elements (Cr)

EDXRF S2 PUMA:

- Very good precision (~7 min)

WDXRF S6 JAGUAR:

- Similar precision in 5 min
- Better performance for F and Na (and low Mg)



Raw material analysis at cement plant



Pressed powder pellets



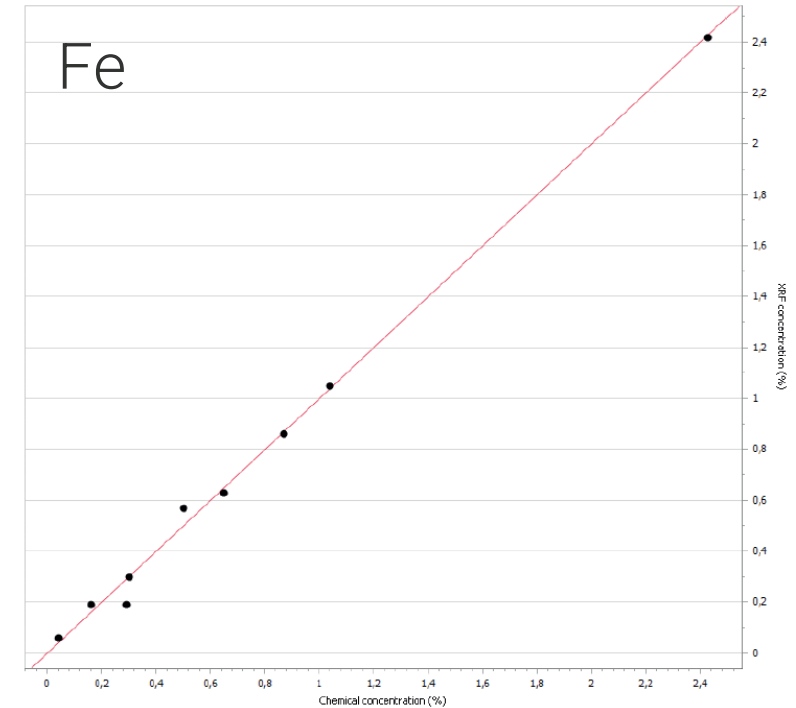
Limestone Grade and Quality Control

S6 JAGUAR (benchtop WDXRF)

wt%	Concentration range	R ²
Na ₂ O	0.003 – 0.46	0.991
MgO	0.24 – 17.88	0.999
Al ₂ O ₃	0.05 – 2.4	0.972
SiO ₂	0.45 – 12.4	0.999
P ₂ O ₅	0.013 – 0.117	0.970
SO ₃	0.016 – 0.13	0.981
K ₂ O	0.001 – 0.96	0.993
CaO	38.46 – 55.15	0.984
TiO ₂	0.03 – 0.15	0.992
MnO	0.007 – 0.28	0.999
Fe ₂ O ₃	0.04 – 2.43	0.996

- Quick sample preparation with 8 g sample and 2 g binder (wax)
- High accuracy and precision of Fe
- Optimal detection limit for Fe

Specific calibration based on CRM's, alternatively with fused bead preparation and GEO-QUANT BASIC calibration



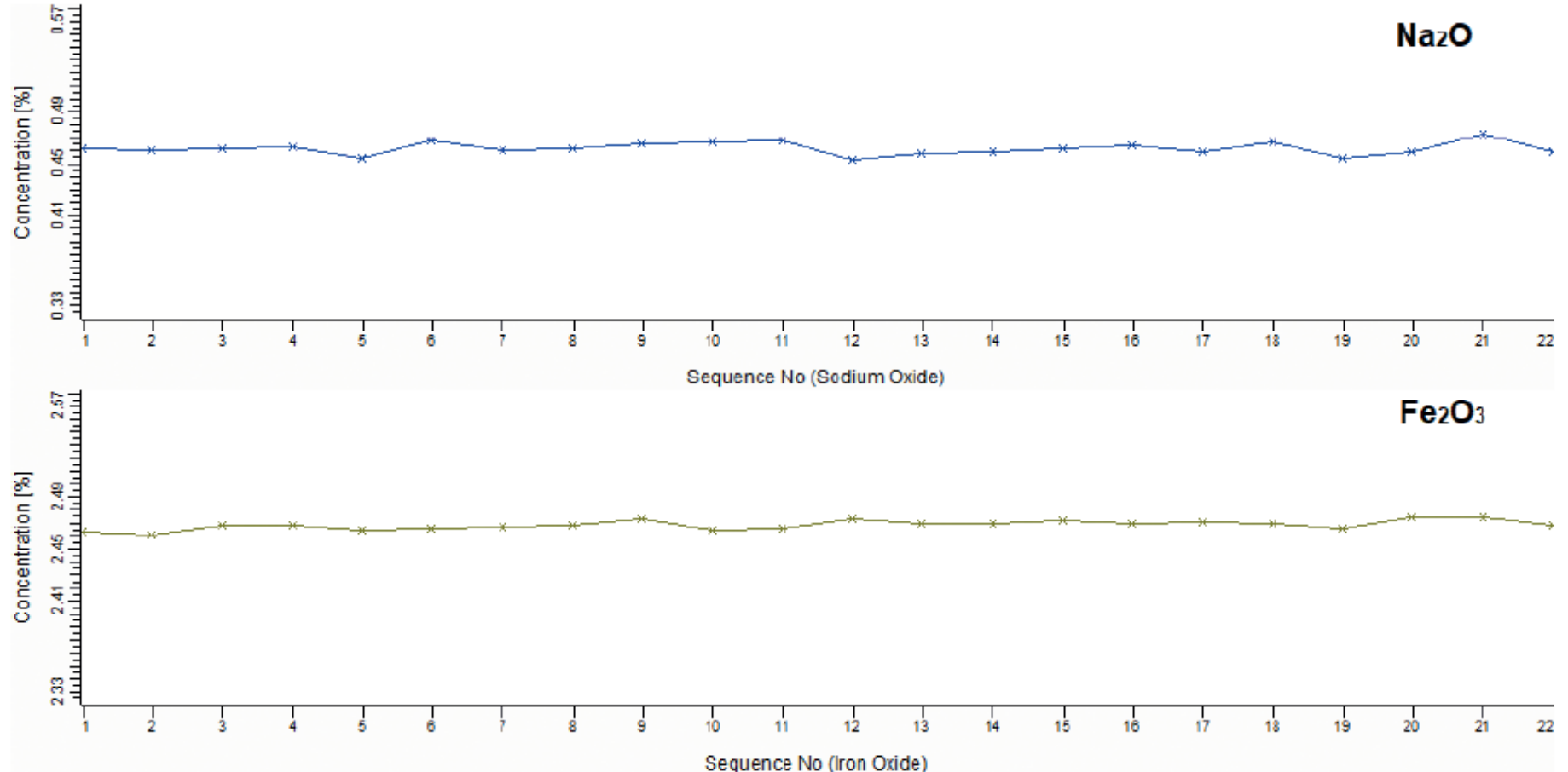
wt%	Na ₂ O	MgO	MnO	Fe ₂ O ₃
Certified	0.460	5.97	0.280	2.43
Measured	0.461	5.87	0.286	2.47
Abs. Deviation	0.001	0.10	0.006	0.04



Limestone Analysis

S6 JAGUAR (benchtop WDXRF)

- High long term stability for traces of light elements (Na) and elements of discoloring (Fe)





“The S6 JAGUAR has become an important tool in our process lab. It works as an ideal backup, based on the same technology than our big instruments. In addition it runs all raw mix samples delivering the same data quality as our main units.”

S6 JAGUAR is now established as alternative backup for S8 TIGER and grinding plants:

- Same technology than first instrument
- Additional capacity for excess samples

GEO-QUANT TRACES

Be prepared for all new tasks

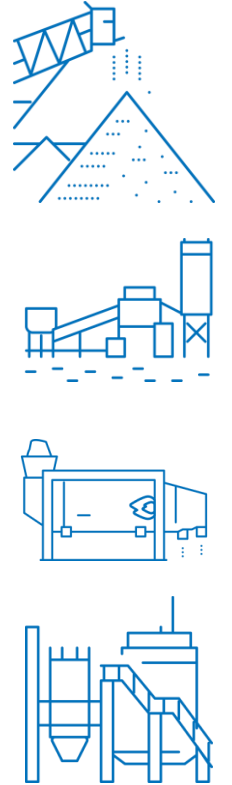
Available for S8 TIGER Series 2 (3 and 4 kW; with LiF220)

Extended element range:

- 51 elements: Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Ge, A, Se, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, In, Sn, Sb, Cs, Ba, La, Hf, Ta, W, Ir, Pt, Au, Tl, Pb, Bi, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, U, S, Cl
- Major elements included: Na, Mg, Al, Si, P, K, Mn, Fe

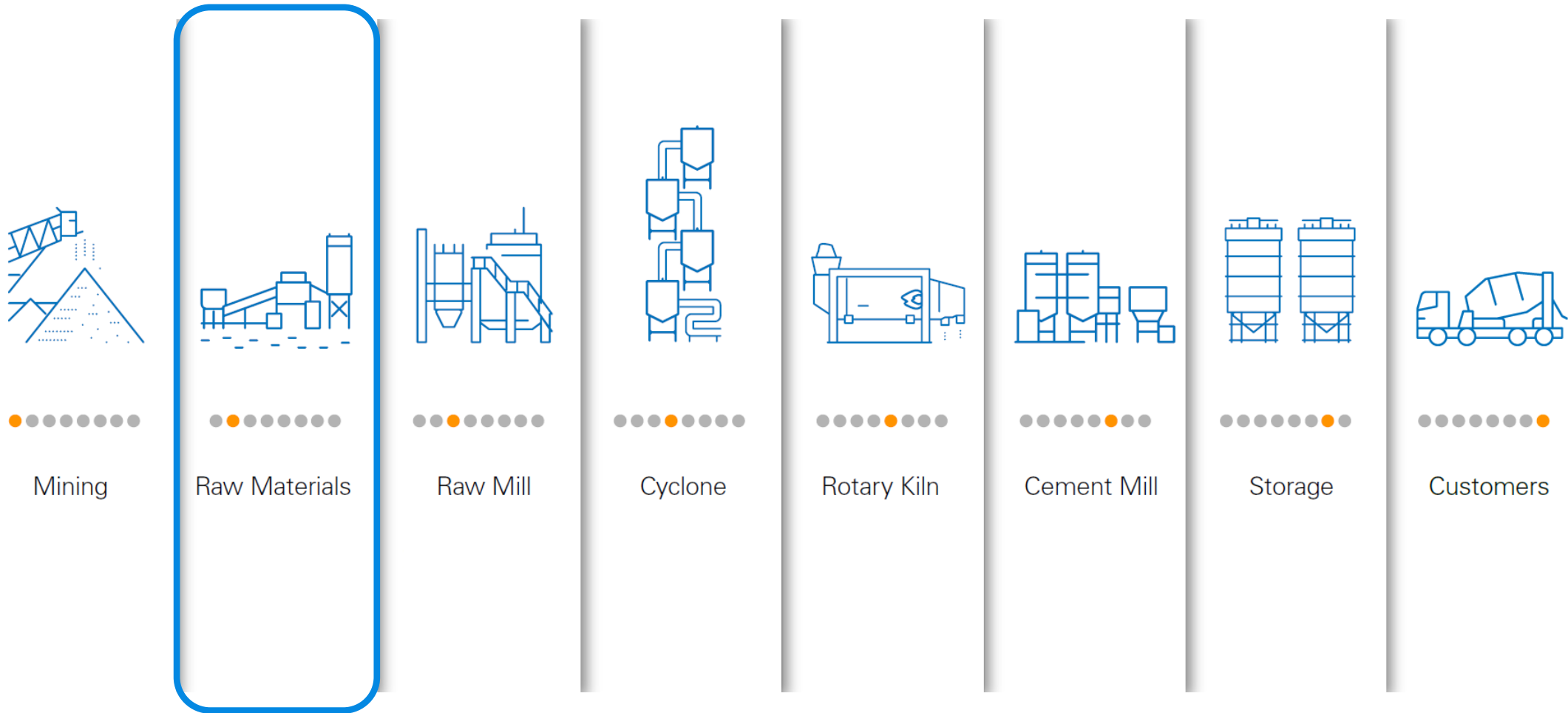
Analytical Flexibility:

- Add / Remove elements
- Fine tuning of calibration lines with customer samples possible
- Change preparation parameters



The Cement Production Process

XRF Application



Solutions for Every Need

S8 TIGER

CEMENT-QUANT

- Complete solution for cement industry, fast analysis of 14 major and minor elements in raw mix, clinker, cement

GEO-QUANT BASIC

- Analysis of major and minor elements as oxides
- Grade control and product quality based on fused beads

GEO-QUANT TRACES

- Analysis of trace elements
- Purity control and geological and environmental mapping based on pressed pellets

PETRO-QUANT





GEO-QUANT BASIC on S8 TIGER For Raw Materials

- Accurate method for measurement of 11 major elements as oxides in geological samples based on certified reference materials (CRM)
- CRMs include cement, clay, feldspar, limestone, dolomite, magnesite, gypsum, bauxite, sedimentary rocks, refractory and others.
- Na_2O , MgO , Al_2O_3 , SiO_2 , P_2O_5 , SO_3 , K_2O , CaO , TiO_2 , Mn_2O_3 , Fe_2O_3
- Fused bead calibration → can create a pressed pellet calibration
- Typically, 7 to 8 minutes
- For optimum results of P and S
 - XS-Ge-C

H																	He																
Li	Be											B	C	N	O	F	Ne																
Na	Mg											Al	Si	P	S	Cl	Ar																
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr																
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe																
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn																
Fr	Ra	Ac																															
																		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
																		Th	Pa	U	Np	Pu	Am	Sum	Matrix	Compton	Rayleigh						



GEO-QUANT BASIC on S8 TIGER

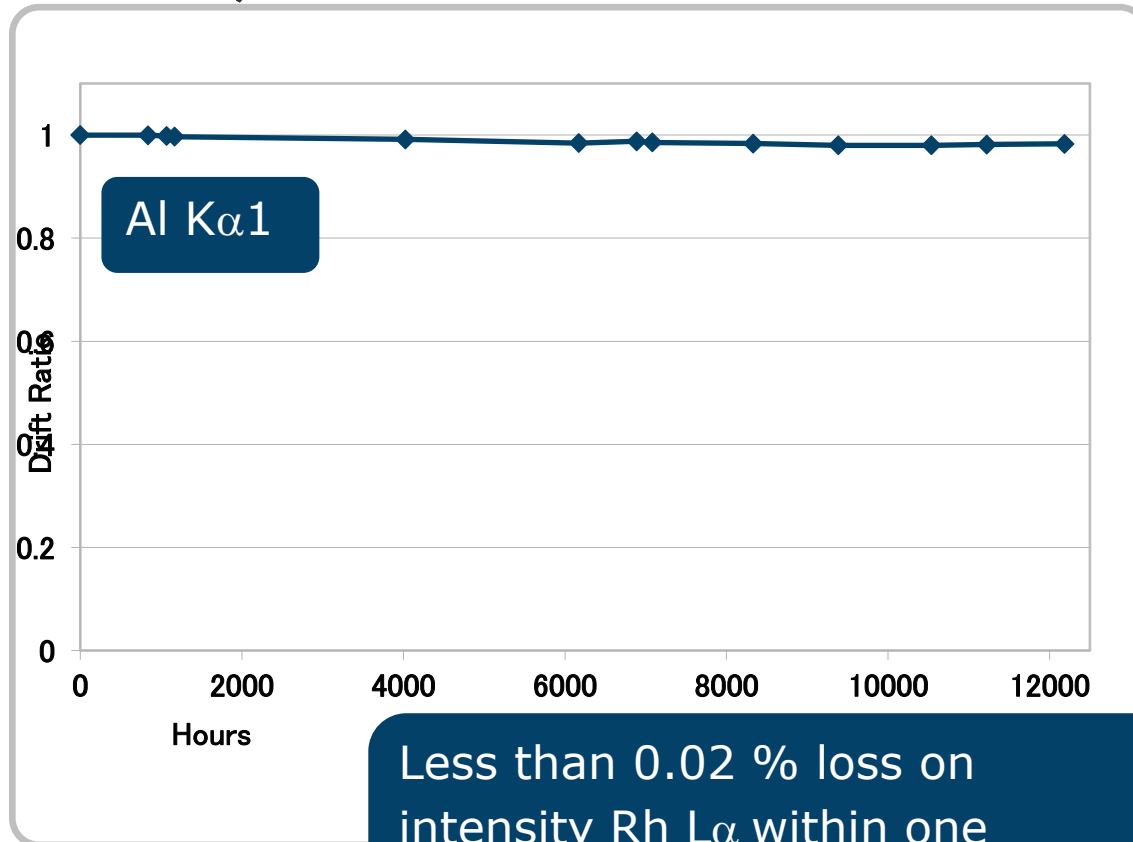
Repeatability test (20 measurements) reveals high Precision and high Accuracy

	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃
Average	1.40	2.49	19.16	63.45	0.18	0.46	3.14	1.91	0.79	0.09	6.95
Min	1.39	2.47	19.13	63.32	0.18	0.45	3.14	1.91	0.78	0.09	6.94
Max	1.42	2.50	19.20	63.52	0.18	0.46	3.15	1.92	0.79	0.09	6.97
Std.Dev.	0.01	0.01	0.02	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Rel.Std.Dev	0.52	0.40	0.10	0.07	<0.01	0.49	0.19	0.19	0.56	<0.01	0.10
	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃
Certified	1.48	2.59	19.18	63.23	0.18	0.41	3.13	2.06	0.80	0.09	7.06

The Zero Drift Instruments with new X-ray Tube Technology

S6 JAGUAR and S8 TIGER

Observation: Zero Drift over one year for light elements, such as Al



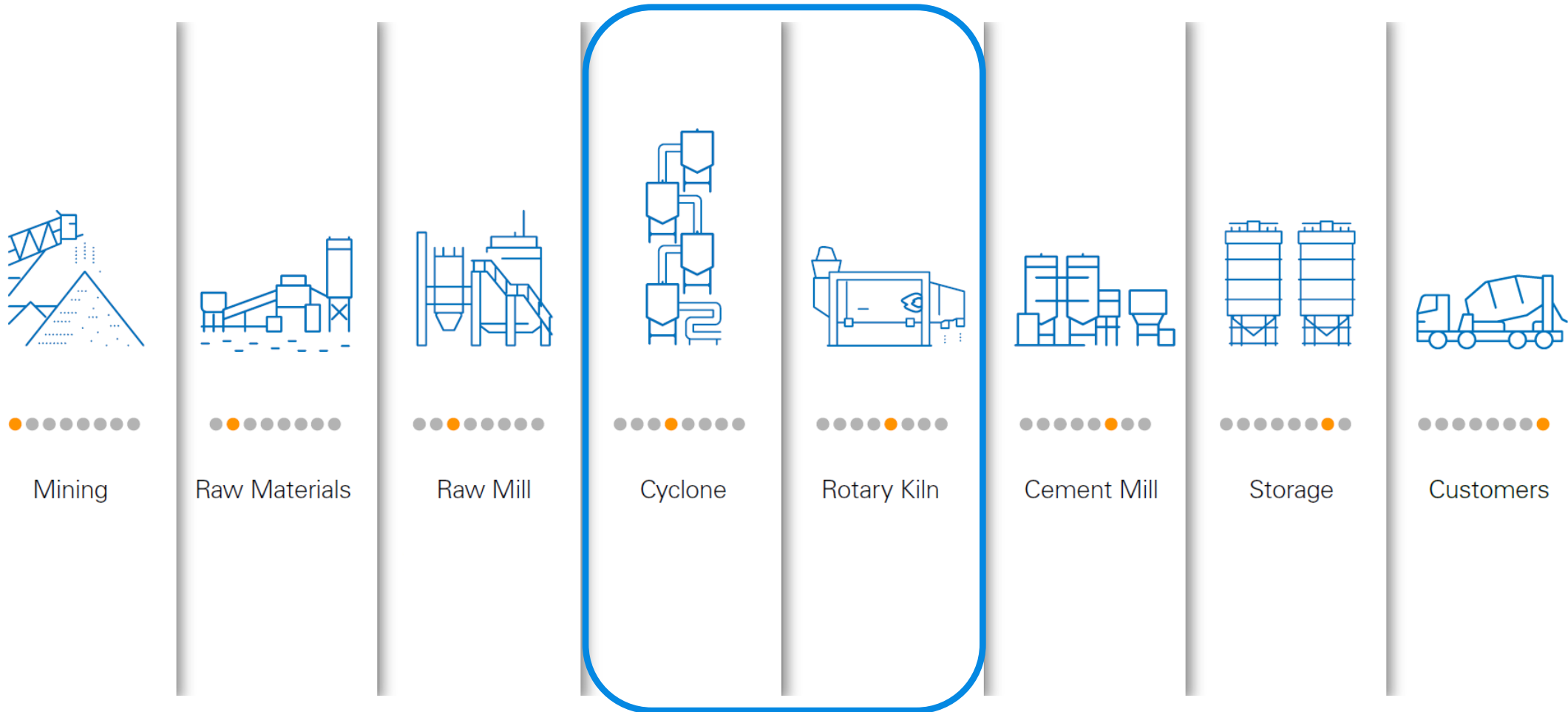
Less than 0.02 % loss on intensity Rh L α within one year (Tube, Crystals, Detector)

Influence parameters on tube drift and recent changes

- Instrument drift depends on aging of components, such as tube, crystals, counters
 - Tube aging was biggest contributor due to W deposition on window (absorption), release from the W filament
 - Change of tube geometry (internal) shadows from free W to the tube window – no deposits, no aging
 - Non aging multilayer optics:
 - O, Na, Mg, F: XS-55
 - Al, Si: XS-CEM
 - P, S, Cl: Ge or XS-Ge-curved

The Cement Production Process

XRF Application



Bruker's dedicated XRF Solutions for the Cement Industry

Sequential WDXRF

- Most advanced XRF Solution
- Fast and Flexible



Simultaneous WDXRF

- For fastest process control



Benchtop EDXRF & WDXRF

- Ideal as back-up or for smaller plants and mines





Cement Production with Net-Zero CO₂ Emmission

The Role of XRF

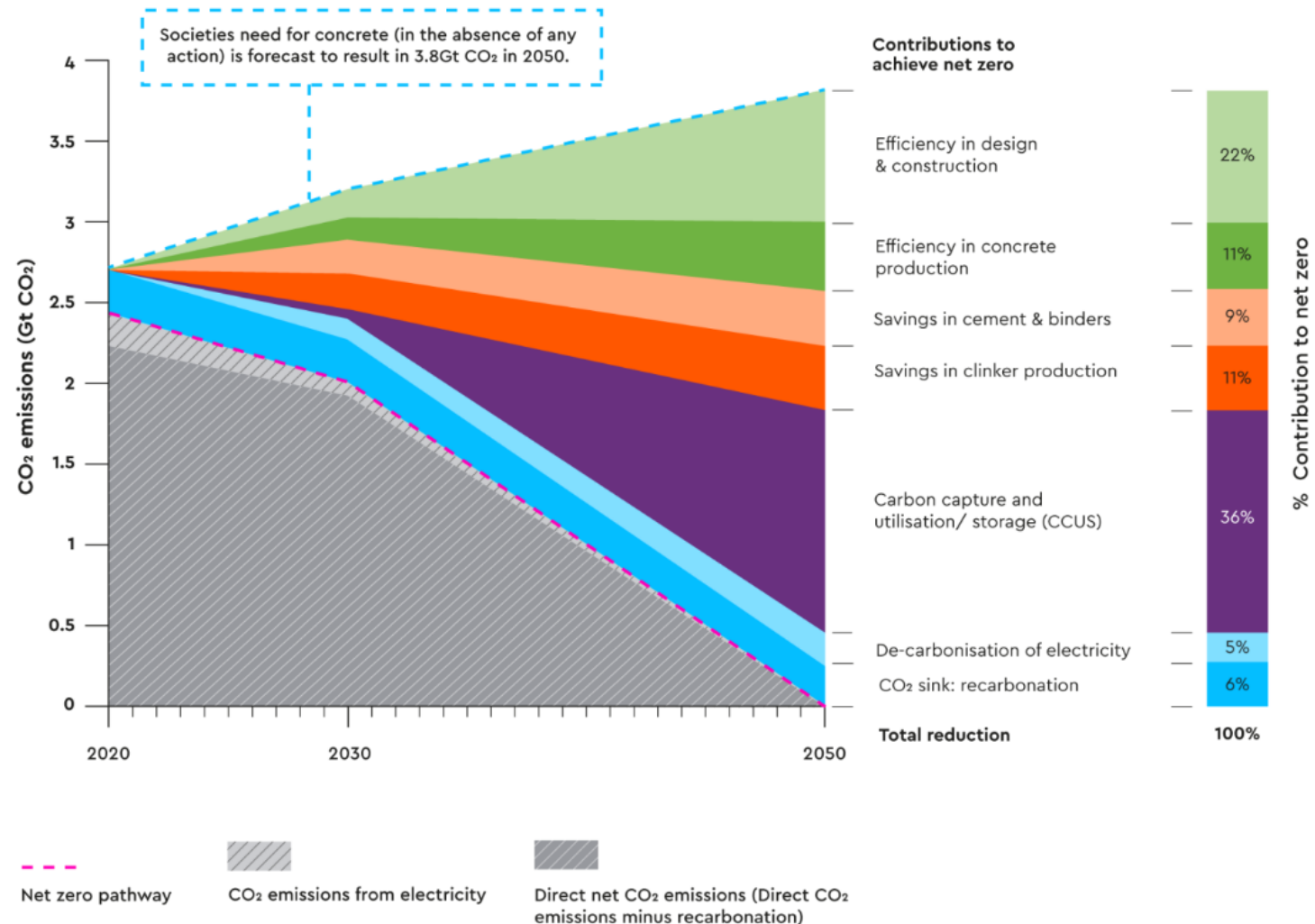
- Clear commitment by Global Cement and Concrete Association (GCCA) to producing carbon neutral concrete by 2050

How to reduce the Net CO₂ emission?

- Overall higher production efficiency
- Replacing some limestone with decarbonated raw materials
- Use of sustainable waste materials (“alternative fuels”) to replace fossil fuels
- and more

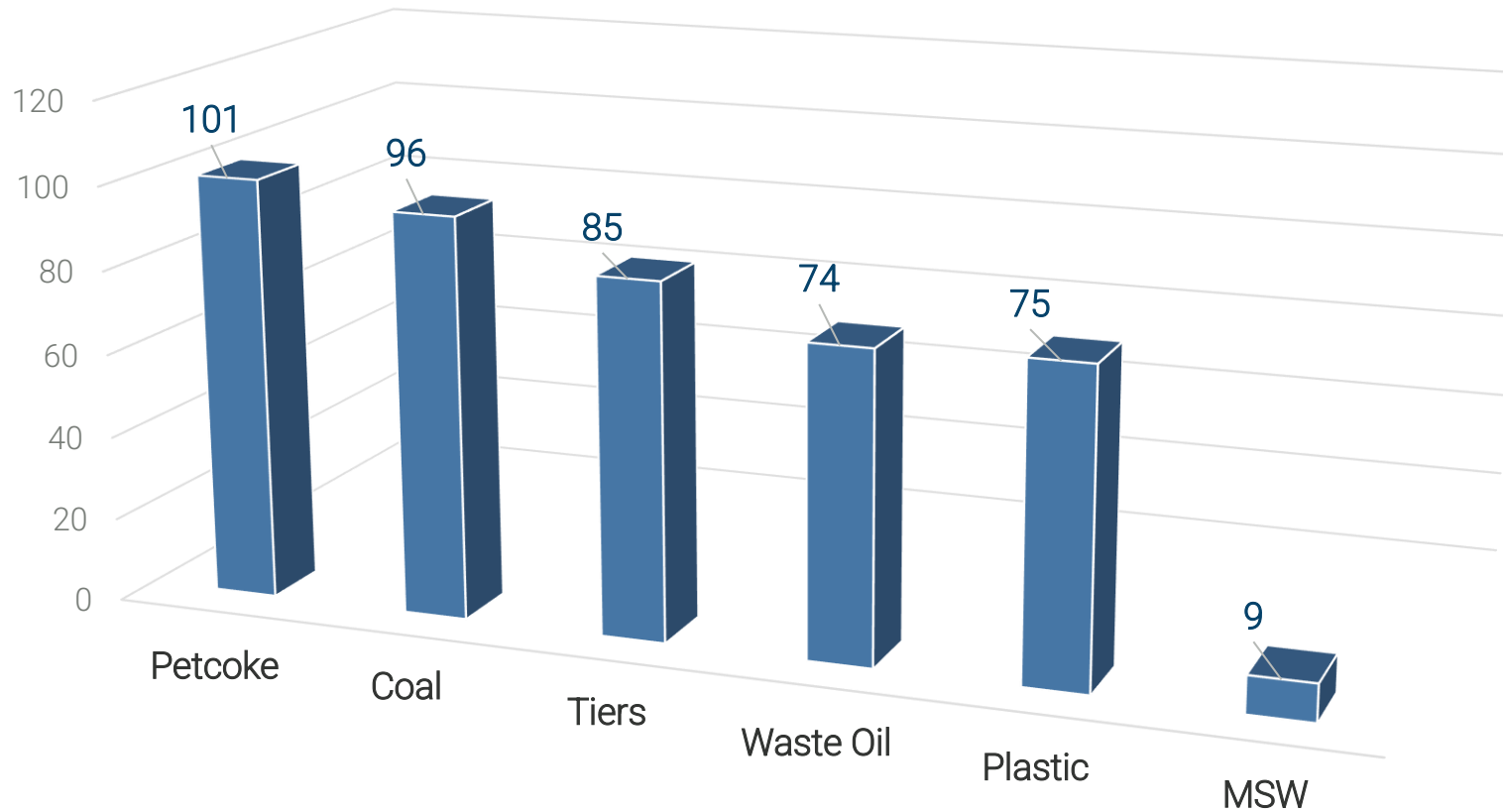
Not possible without XRF

Sources: www.npgroup.com/, www.gccassociation.org/



Burning Waste Alternative Fuel Compared to Coal

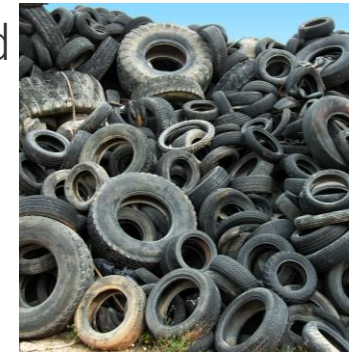
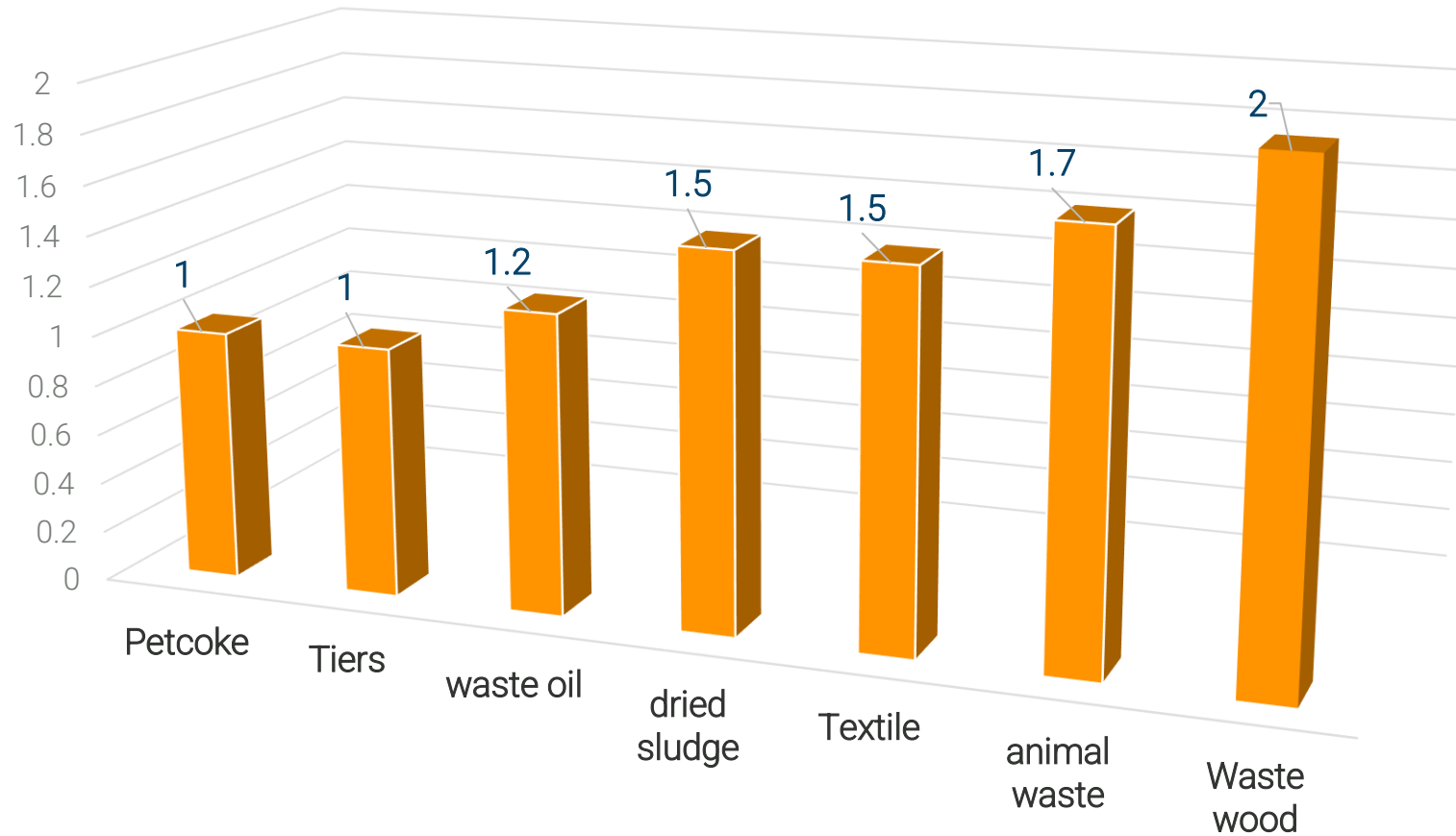
Net CO₂ Emission Factor kg CO₂/GJ



Sources: <https://china.lbl.gov>

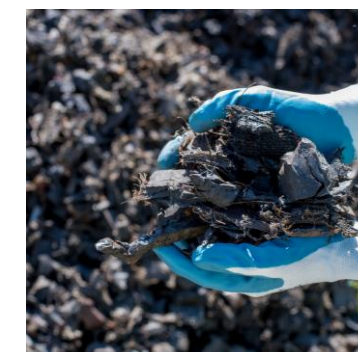
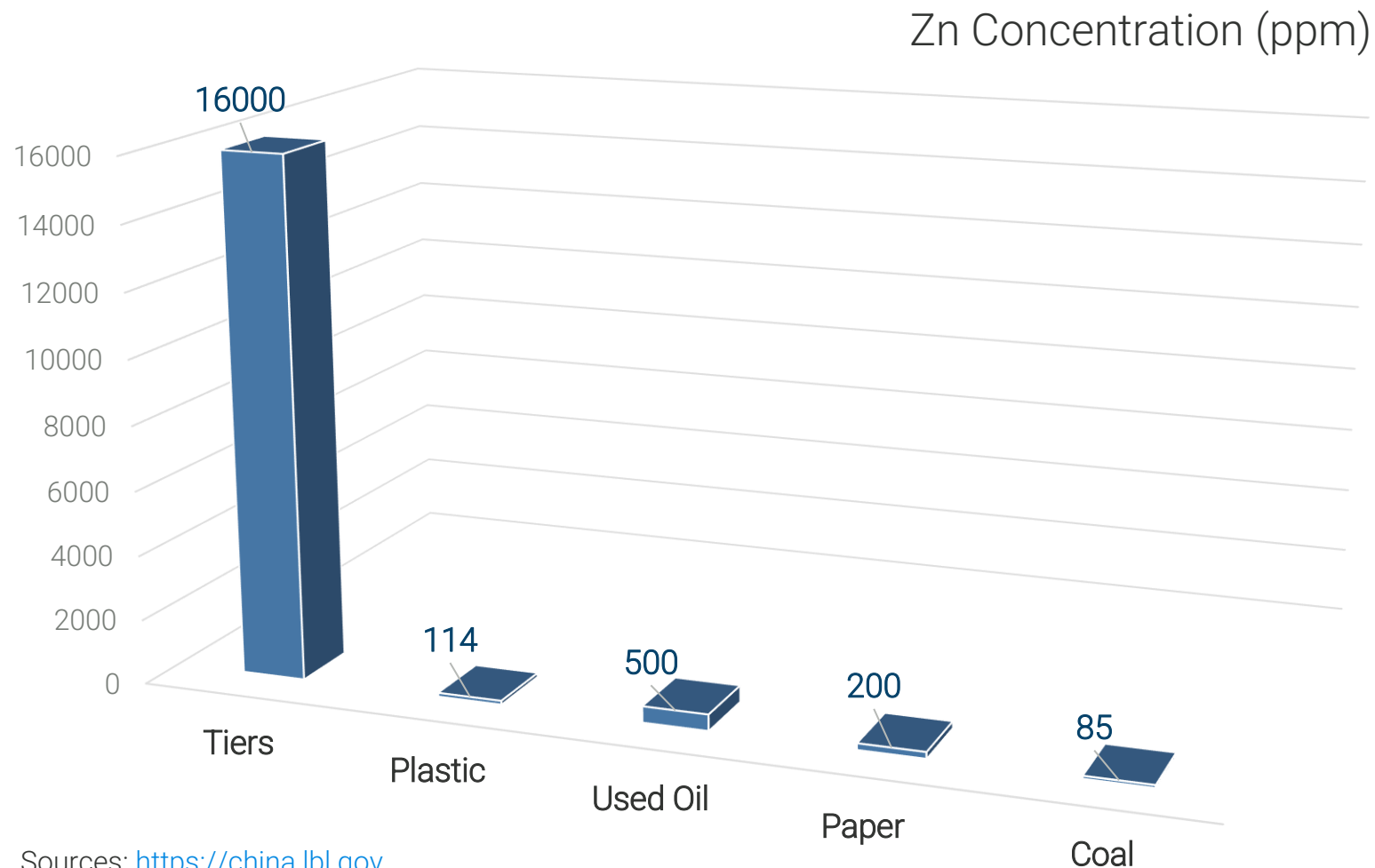
Calorific Value Alternative Fuel compared to Coal

Calorific Values ton/1 ton Coal replaced



Sources: <https://china.lbl.gov>

Trace Element Concentration in Alternative Fuel, Example Zn (ppm)



Sources: <https://china.lbl.gov>



PETRO-QUANT

Elements & Lower Limit of Detection (LoD)

Analyte Element	Concentration Range [mg/kg]	LoD (3 σ ; 12s) [mg/kg]	LoD (3 σ ; 100s) [mg/kg]
Na	LoD – 2000	2.7	1.5
Mg	LoD – 4000	0.8	0.4
Al	LoD – 1250	1.7	0.6
Si	LoD – 2000	1.9	0.7
P	LoD – 5000	0.5	0.2
S	LoD – 1000	0.6	0.2
S*	LoD – 2.50 %	~ 8	~ 3
Cl	LoD – 1500	1.5	0.5
Cl*	LoD – 2.00 %	~ 9	~ 3
K	LoD – 2000	0.5	0.2
Ca	LoD – 10000	0.6	0.2
Ti	LoD – 600	0.6	0.2
V	LoD – 600	2	0.7
Cr	LoD – 600	0.5	0.2
Mn	LoD – 600	0.4	0.1
Fe	LoD – 2000	0.4	0.2
Co	LoD – 600	0.3	0.1
Ni	LoD – 600	0.2	< 0.1



PETRO-QUANT

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Na	LoD – 2000	2.7	1.5
Mg	LoD – 4000	0.8	0.4
Analyte Element	Concentration Range [mg/kg]	LoD (3σ; 12s) [mg/kg]	
S	LoD – 2.5%	~ 8	
Cl*	LoD – 2.00 %	~ 9	
Ti	LoD – 600	0.6	
V	LoD – 600	2	
Cr	LoD – 600	0.5	
Mn	LoD – 600	0.4	
Fe	LoD – 2000	0.4	
Co	LoD – 600	0.3	
Ni	LoD – 600	0.2	
Fe	LoD – 2000	0.4	0.2
Co	LoD – 600	0.3	0.1
Ni	LoD – 600	0.2	< 0.1



PETRO-QUANT

Elements & Lower Limit of Detection (LoD)

Analyte Element	Concentration Range [mg/kg]	LoD (3 σ ; 12s) [mg/kg]	LoD (3 σ ; 100s) [mg/kg]
Cu	LoD – 600	0.2	< 0.1
Zn	LoD – 2000	0.1	< 0.1
As K α As K β	LoD – 600	0.1 1.0	< 0.1 0.3
Br	LoD – 600	0.1	< 0.1
Zr	LoD – 600	0.4	0.1
Mo	LoD – 600	0.5	0.2
Ag	LoD – 600	1.1	0.4
Cd	LoD – 600	1.3	0.5
In	LoD – 600	1.6	0.6
Sn	LoD – 600	1.6	0.6
Sb	LoD – 600	1.9	0.7
Ba	LoD – 8000	2.0	0.7
W L α / W L β	LoD – 1250	0.3/0.5	0.1/0.2
Tl L α /Tl L β	LoD – 600	0.2/0.5	< 0.1/0.1
Pb L α /Pb L β	LoD – 1250	0.2/0.4	< 0.1/0.1
Bi L α /Bi L β	LoD – 600	0.2/0.5	< 0.1/0.2



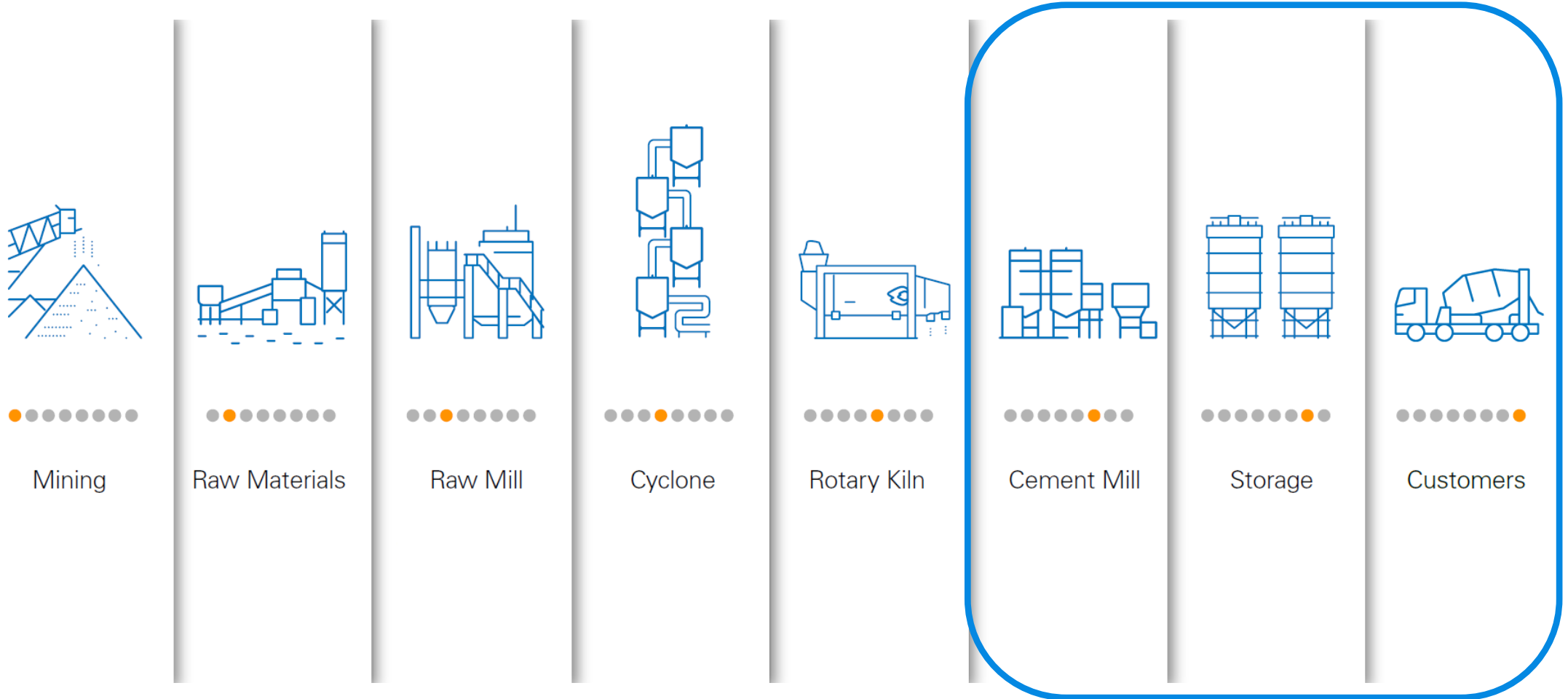
PETRO-QUANT

Elements & Lower Limit of Detection (LoD)

Analyte Element	Concentration Range [mg/kg]	LoD (3σ; 12s) [mg/kg]	LoD (3σ; 100s) [mg/kg]
Cu	LoD – 600	0.2	< 0.1
Zn	LoD – 2000	0.1	< 0.1
Analyte Element	Concentration Range [mg/kg]	LoD (3σ; 12s) [mg/kg]	
Cu	LoD – 600	0.2	
Zn	LoD – 2000	0.1	
As Ka	LoD – 600	0.1	
Mo	LoD – 600	0.5	
Cd	LoD – 600	1.3	
Sn	LoD – 600	1.6	
Sb	LoD – 600	1.9	
W Ti La	LoD – 600	0.2	
Ti Pb La	LoD – 1250	0.2	
Pb La/Pb Lβ	LoD – 1250	0.2/0.4	< 0.1/0.1
Bi La/Bi Lβ	LoD – 600	0.2/0.5	< 0.1/0.2

The Cement Production Process

XRF Application





CEMENT-QUANT

The versatile XRF Solution for the Cement Industry

- Provides a workflow to meet good laboratory practice (GLP)
- Includes a quality check procedure for instrument stability and a repeatability check for the sample preparation
- Pre-defined applications for
 - raw mix
 - clinker
 - cement
 - and more ...
- Available for: S2 PUMA, S6 JAGUAR, S8 TIGER and S8 LION



Oxides	Standard Deviation	Concentration Range
Na ₂ O	0.015	0.02%-1.08%
MgO	0.02	0.78%-5.12%
Al ₂ O ₃	0.03	3.39%-10.7%
SiO ₂	0.05	18.87%-29.3%
P ₂ O ₅	0.002	0.02%-0.4%
SO ₃	0.05	1.91%-4.7%
K ₂ O	0.02	0.09%-1.25%
CaO	0.15	49.2%-69%
TiO ₂	0.004	0.09%-0.73%
Cr ₂ O ₃	6 ppm	24 ppm-598 ppm
MnO	0.007	0.01%-0.61%
Fe ₂ O ₃	0.017	0.15%-4.18%
ZnO	9 ppm	10 ppm-1090 ppm
SrO	0.0014	0.02%-0.65%



CEMENT-QUANT

The versatile XRF Solution for the Cement Industry

Includes a set of international certified reference materials (CRM)

- Allows to create traceable and accurate calibrations in three steps:
- **Step 1** – Preparation of the CRMs as fused beads
- **Step 2** – Measurement of the beads with CEMENT-QUANT
- **Step 3** – Calibration - Ready to analyze! Traceable to NIST!

Makes you ready for ASTM C114 and DIN EN ISO 29581-2



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Na ₂ O	0.015	0.02%-1.08%
MgO	0.02	0.78%-5.12%
Al ₂ O ₃	0.03	3.39%-10.7%
SiO ₂	0.05	18.87%-29.3%
P ₂ O ₅	0.002	0.02%-0.4%
SO ₃	0.05	1.91%-4.7%
K ₂ O	0.02	0.09%-1.25%
CaO	0.15	49.2%-69%
TiO ₂	0.004	0.09%-0.73%
Cr ₂ O ₃	6 ppm	24 ppm-598 ppm
MnO	0.007	0.01%-0.61%
Fe ₂ O ₃	0.017	0.15%-4.18%
ZnO	9 ppm	10 ppm-1090 ppm
SrO	0.0014	0.02%-0.65%

S6 JAGUAR: Full WD performance in a benchtop device! Thanks to HighSense Technology



- 400 W excitation
 - 20 – 50 kV
 - 1 – 17 mA
 - Optimal settings for every single element at full power
- 5 position beam filter (optional) for improved peak-to-background ratio
- 4 sample masks (optional for different sample sizes)
- Vacuum seal for low-cost-of-operation
- Up to 4 analyzer crystals for the entire element range and specific demands
- Flow counter and HighSense XE detector for 2 Mcps count rates for high calibration ranges



Analyzing White Cement on the S6 JAGUAR

[wt.%]	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	Cl [ppm]	K ₂ O	CaO	TiO ₂	MnO [ppm]	Fe ₂ O ₃
Rep-1	0.151	0.659	2.496	15.84	0.018	0.041	435	0.332	44.08	0.088	72	0.162
...
Rep-10	0.155	0.663	2.507	15.86	0.018	0.042	424	0.332	44.06	0.091	73	0.162
Average	0.156	0.665	2.496	15.83	0.018	0.041	429	0.331	44.09	0.091	72	0.162
Abs. Std. Dev.	0.003	0.005	0.005	0.02	<0.001	<0.001	6	0.001	0.02	0.001	1	<0.001
Rel. Std. Dev. [%]	2.1	0.8	0.2	0.1	1.7	1.0	1.4	0.4	0.0	1.5	1.2	0.2
Certified	0.138	0.663	2.51	15.9	0.019	0.048	423	0.334	44.21	0.092	74	0.164
Abs. diff.	0.018	0.002	0.014	0.07	0.001	0.007	6	0.003	0.12	0.001	2	0.002

A 30 hours repeatability tests:

- Excellent Analytical Precision and Accuracy
- High System Stability

Automation in the Box! Only with S2 PUMA & S6 JAGUAR



- Compact container **all-in-one** solution with fully integrated benchtop XRF (WD or ED) – **only possible with Bruker XRF**
- Ideal for raw meal control and at smaller cement plant

HERZOG
AtLineLab 

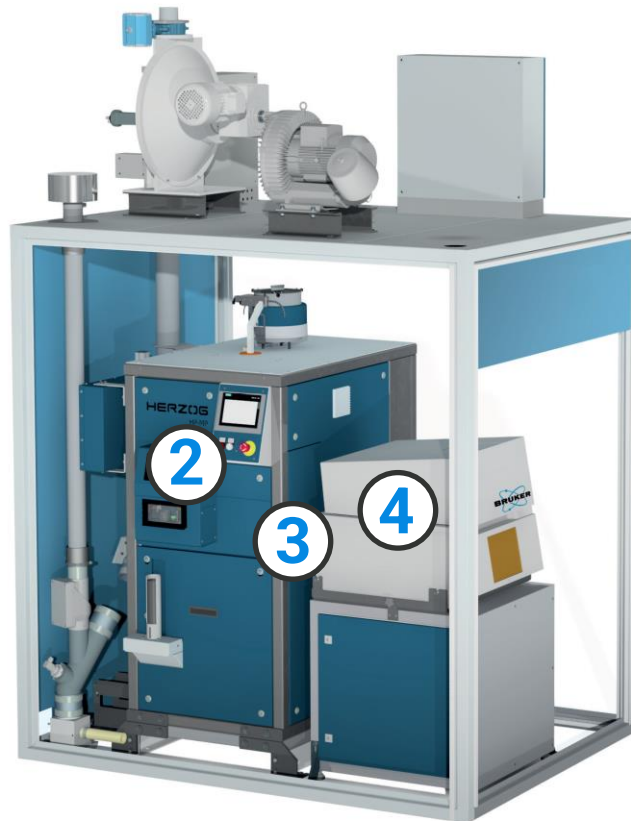


Automation in the Box! Only with S2 PUMA & S6 JAGUAR



1. Sampling
2. Sample Preparation with Herzog HP-MP
3. Sample Transport & Handling
4. XRF Analysis by S2 PUMA
5. Customized Reporting

HERZOG
AtLineLab

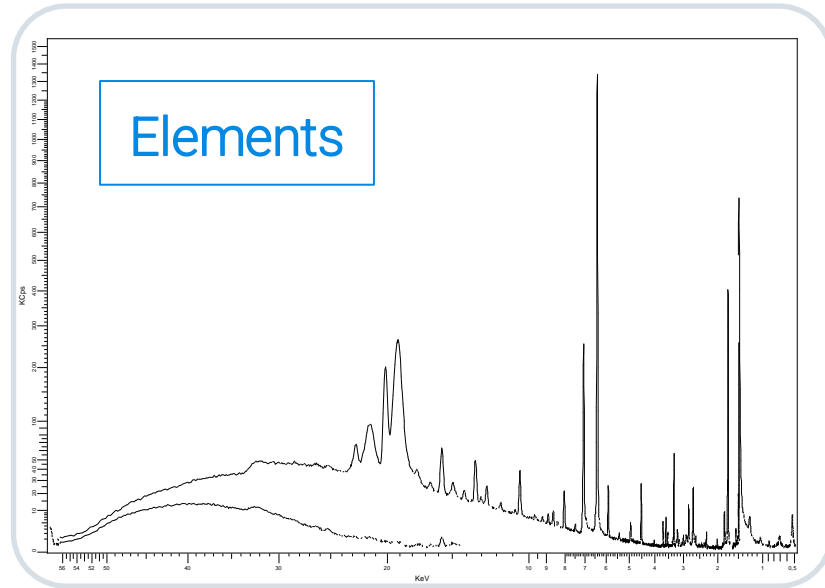


PRODUCTION OF HIGH-PERFORMANCE CEMENT AT LOWEST COSTS ENABLED BY LATEST ANALYTICAL TECHNOLOGY

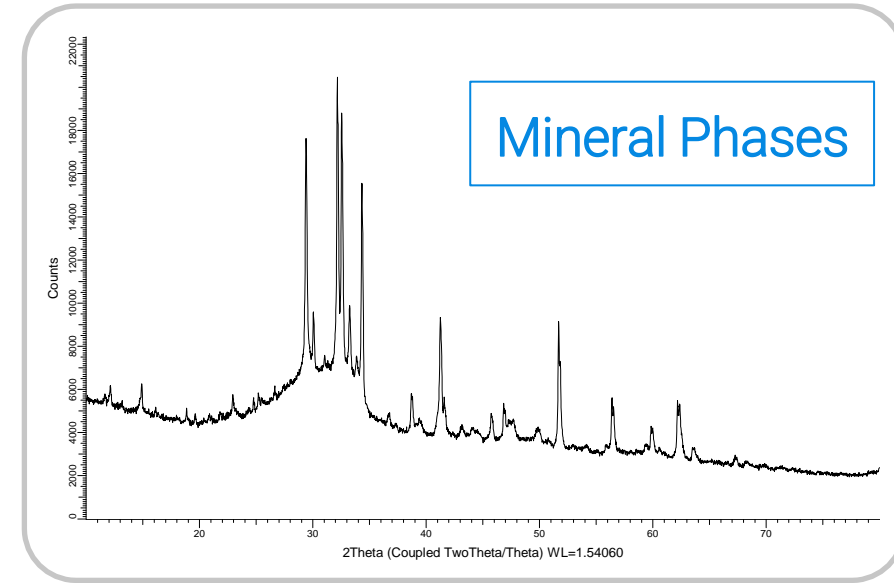
Applications of XRD

Dr. Rainer Schmitt

XRF & XRD in Process and Quality Control



XRF



XRD



XRF & XRD Comparison of Methods

XRF

- Elements only
 - Atom Number
- Single Peaks
- Net Intensity (Height or Area)
- Absolute Intensities
 - Calibration
 - Standards
 - Drift Correction

XRD

- Phases / Minerals
 - Crystal Structure
- Multiple Peaks
- Profile fitting of the whole scan
- Relative Intensities
 - No Calibration
 - No Standards
 - No Drift Correction

X-Ray Diffraction in the Cement Production process

01 Why using XRD

02 Where: Cyclones

03 Where: Clinker

04 Where: Cement



XRD in Process & Quality Control

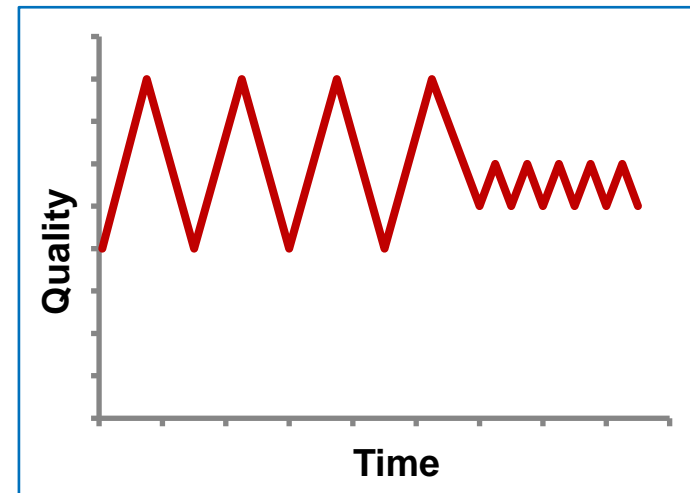
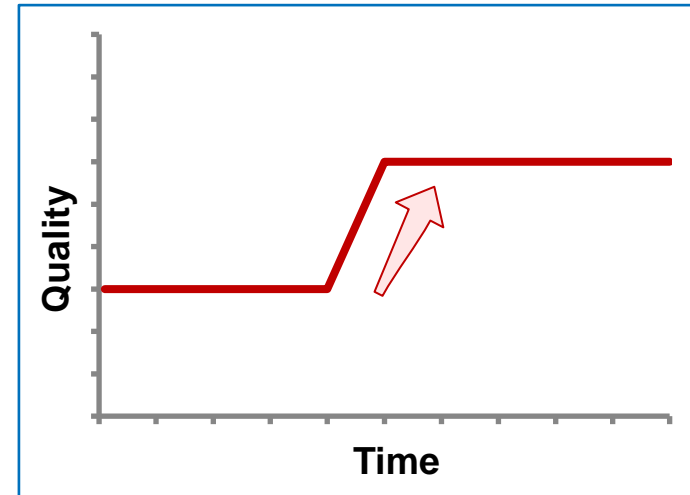
Why XRD?

- Monitoring and Predicting the physical properties
 - Setting
 - Strength development
 - Water consumption
 -
- the physical properties are mainly governed by
 - Phase composition
 - Fineness

XRD in Process & Quality Control

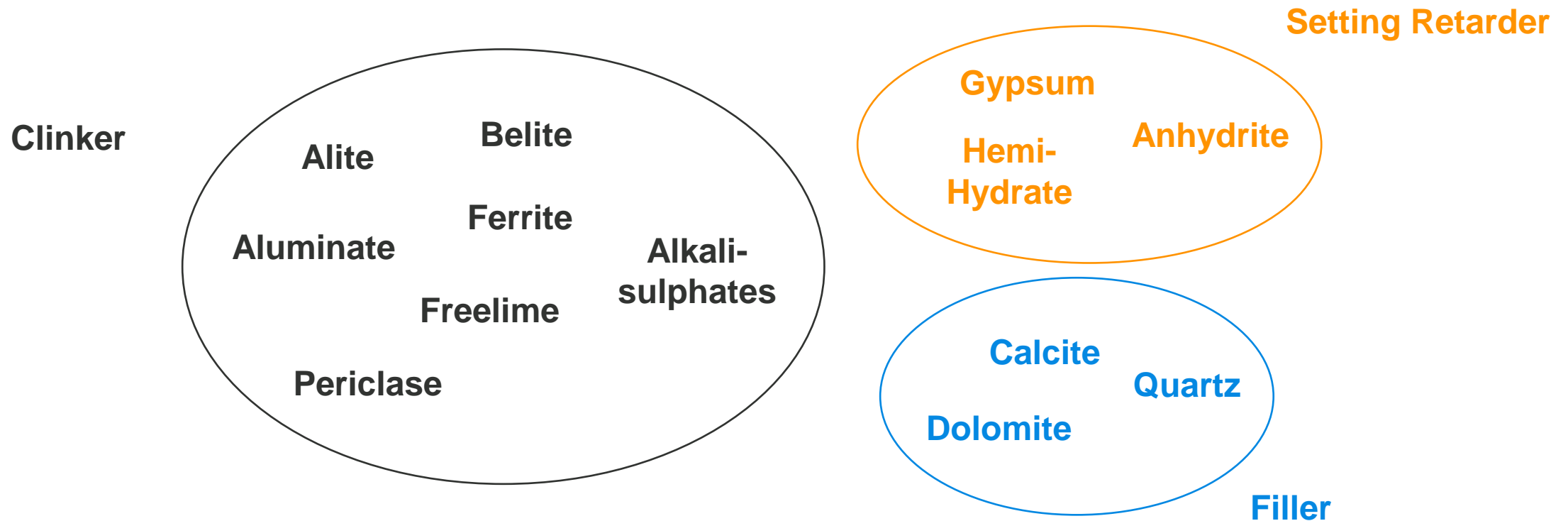
Knowing the true phase composition allows

- Monitoring and prediction of clinker and cement quality
- Establishing of stable production conditions

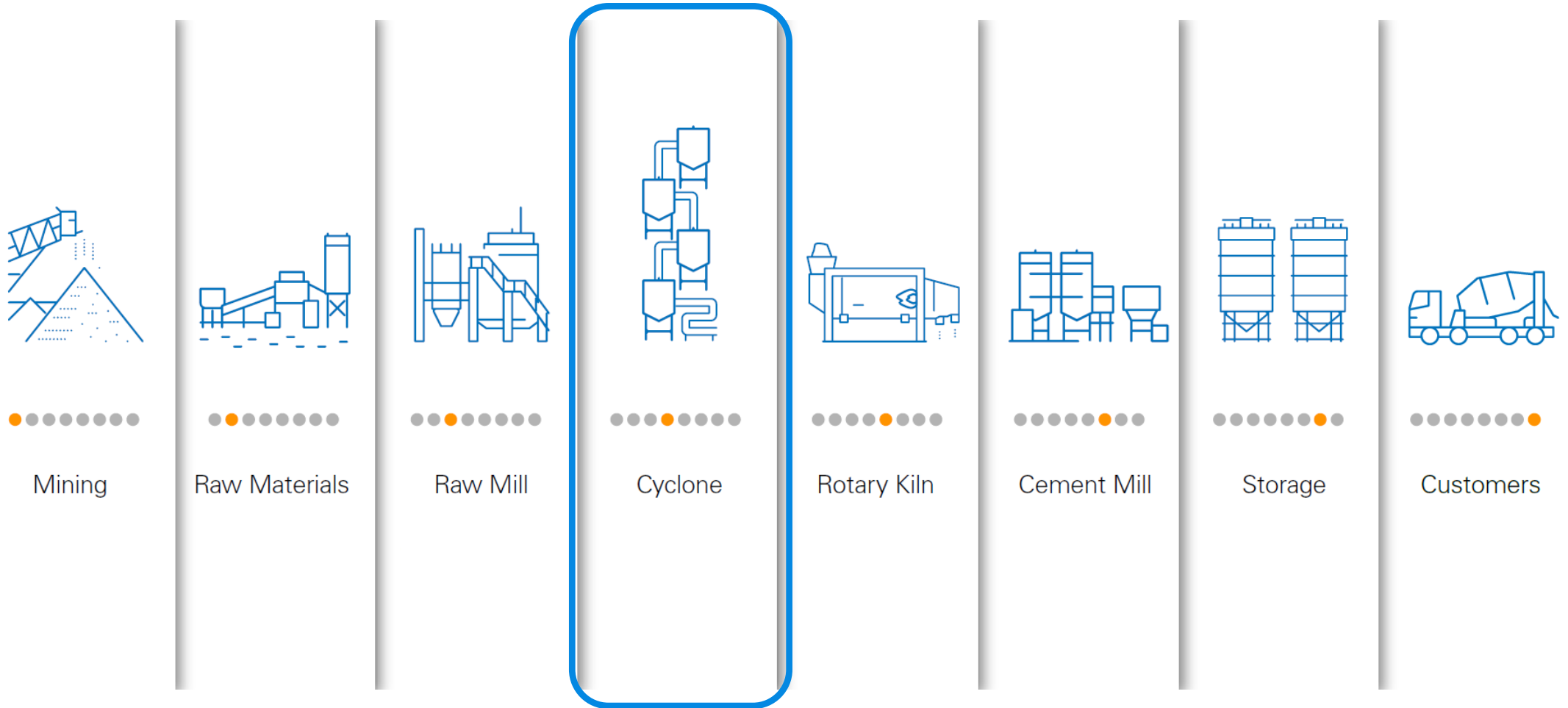


XRD in Process & Quality Control

Phase Composition and properties: Example CEM I

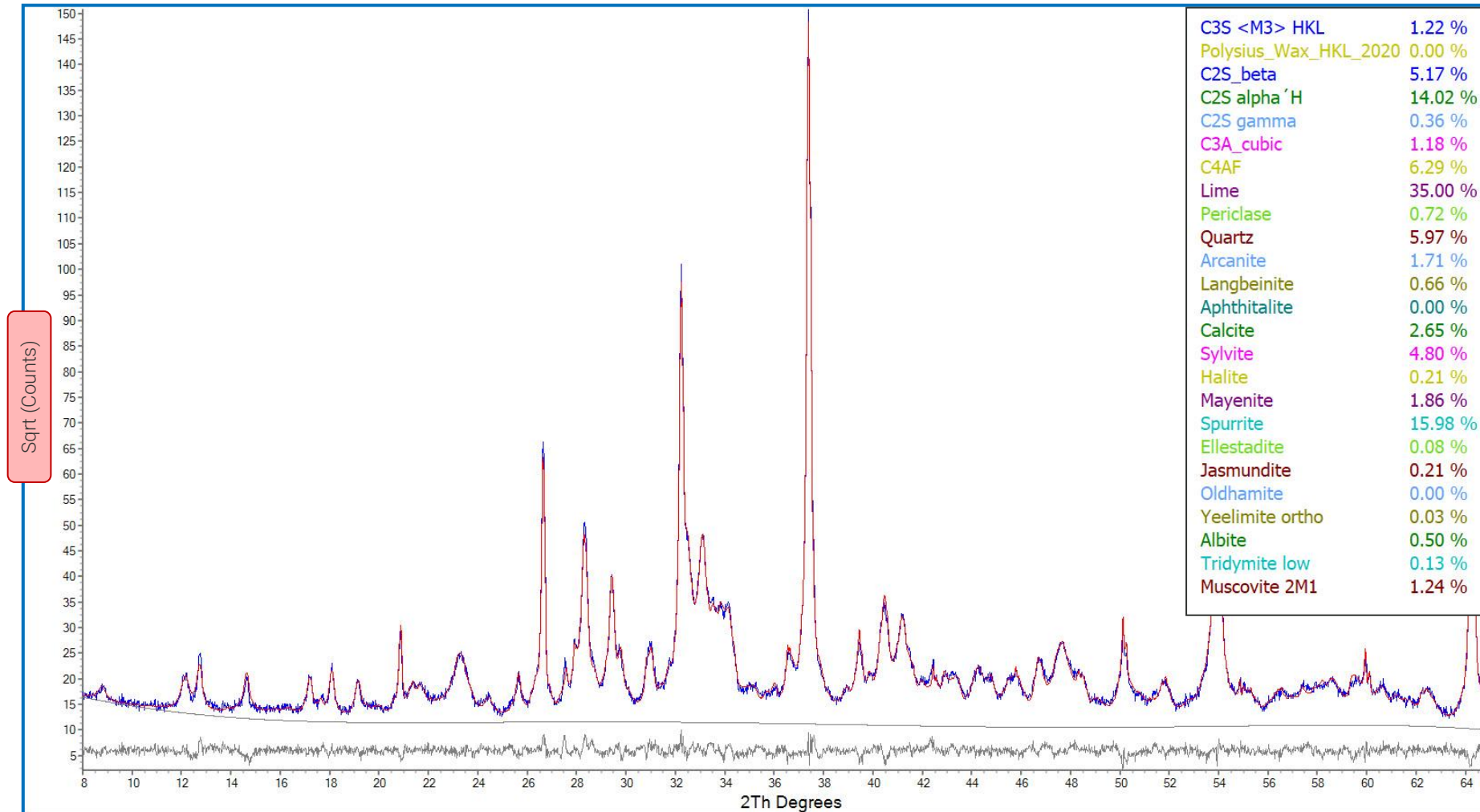


The Cement Production Process

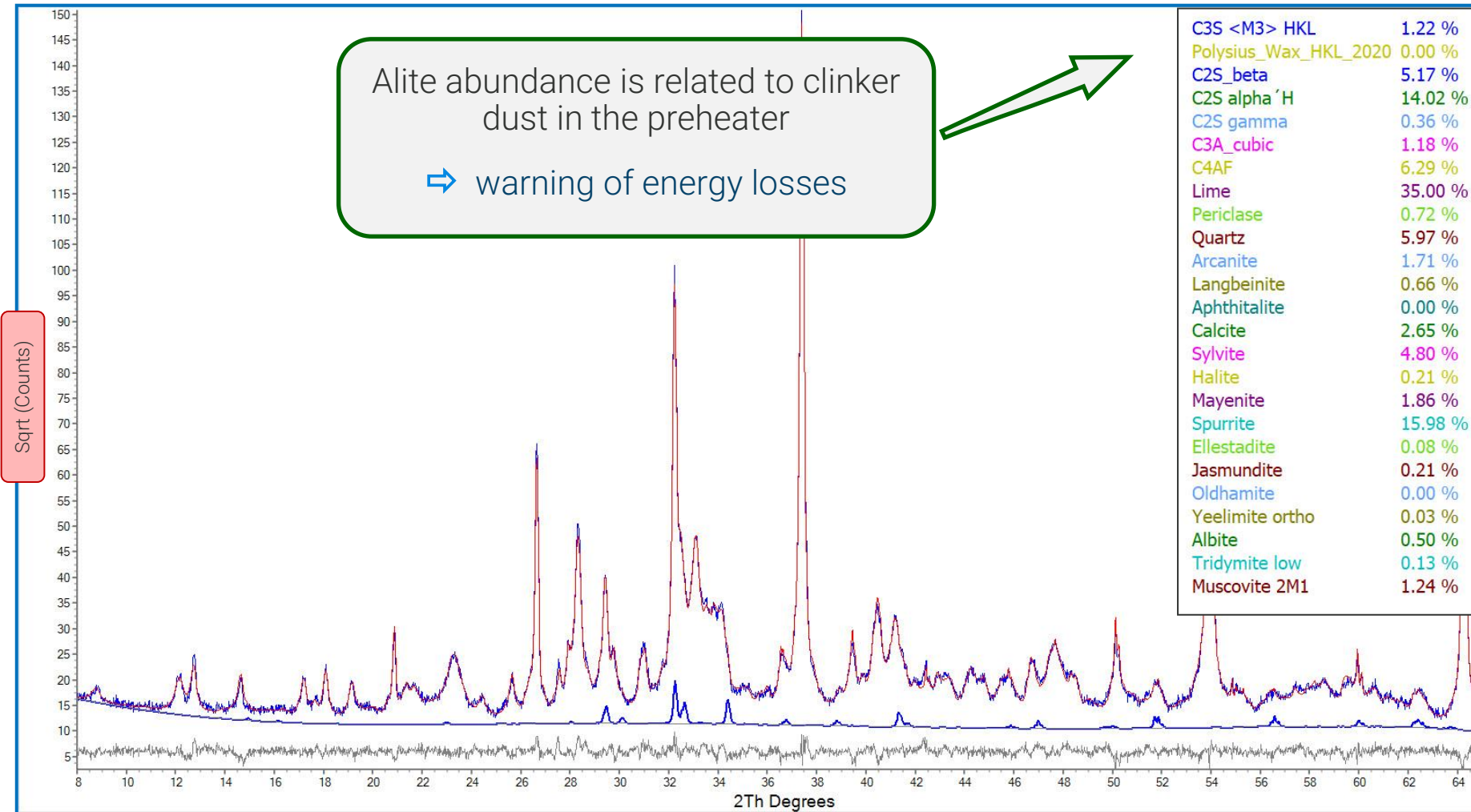




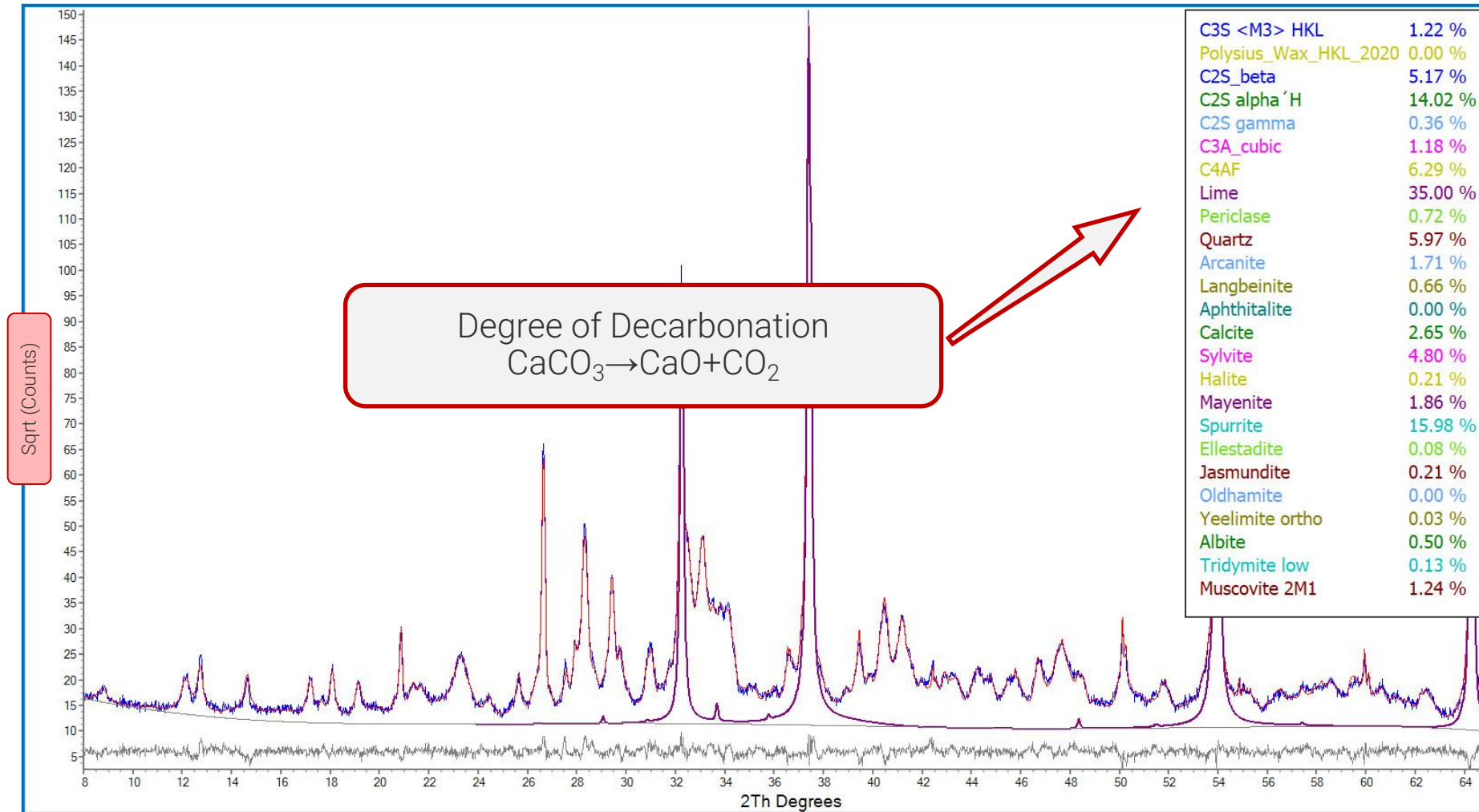
XRD Cyclones



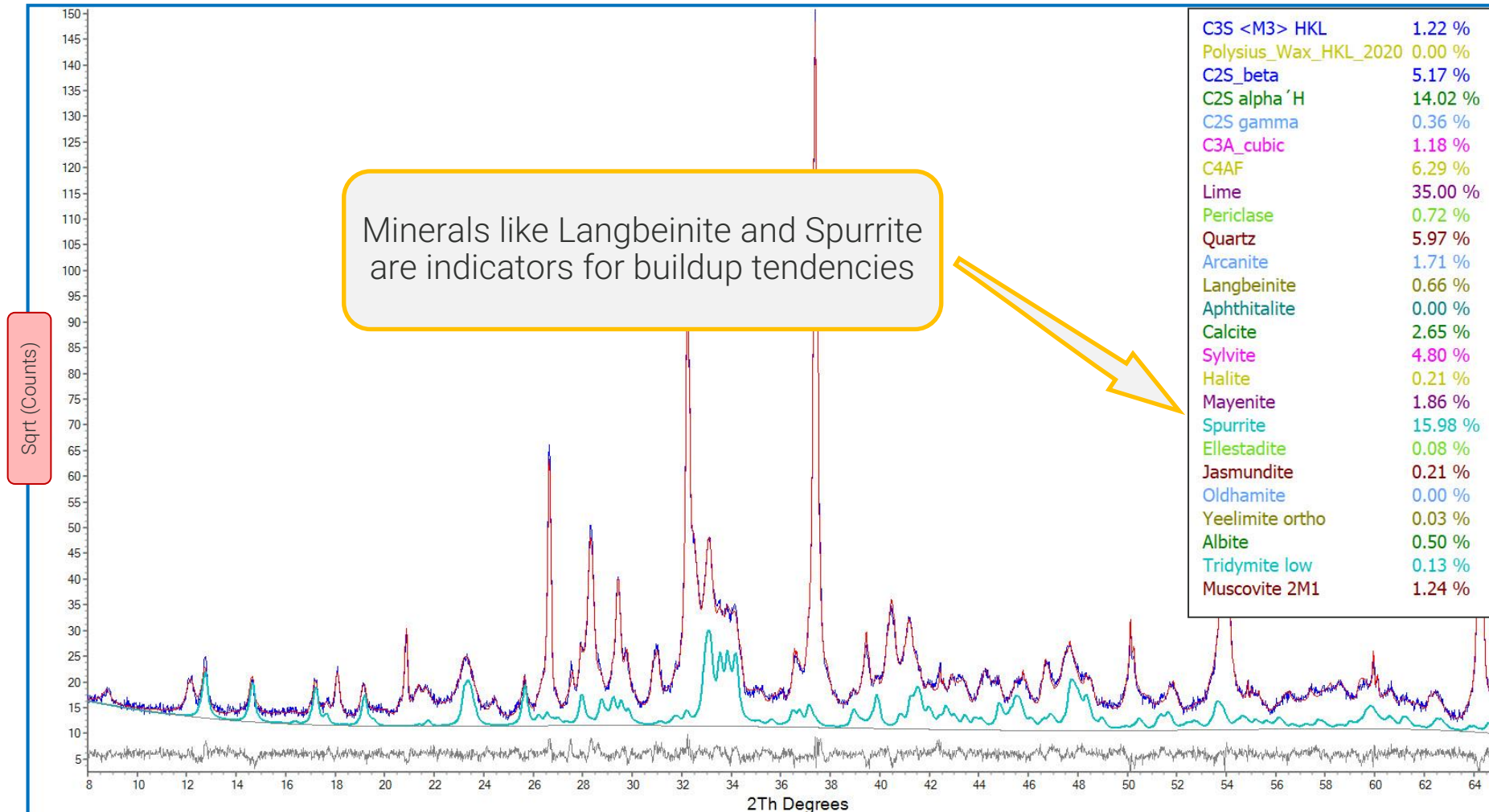
XRD Cyclones



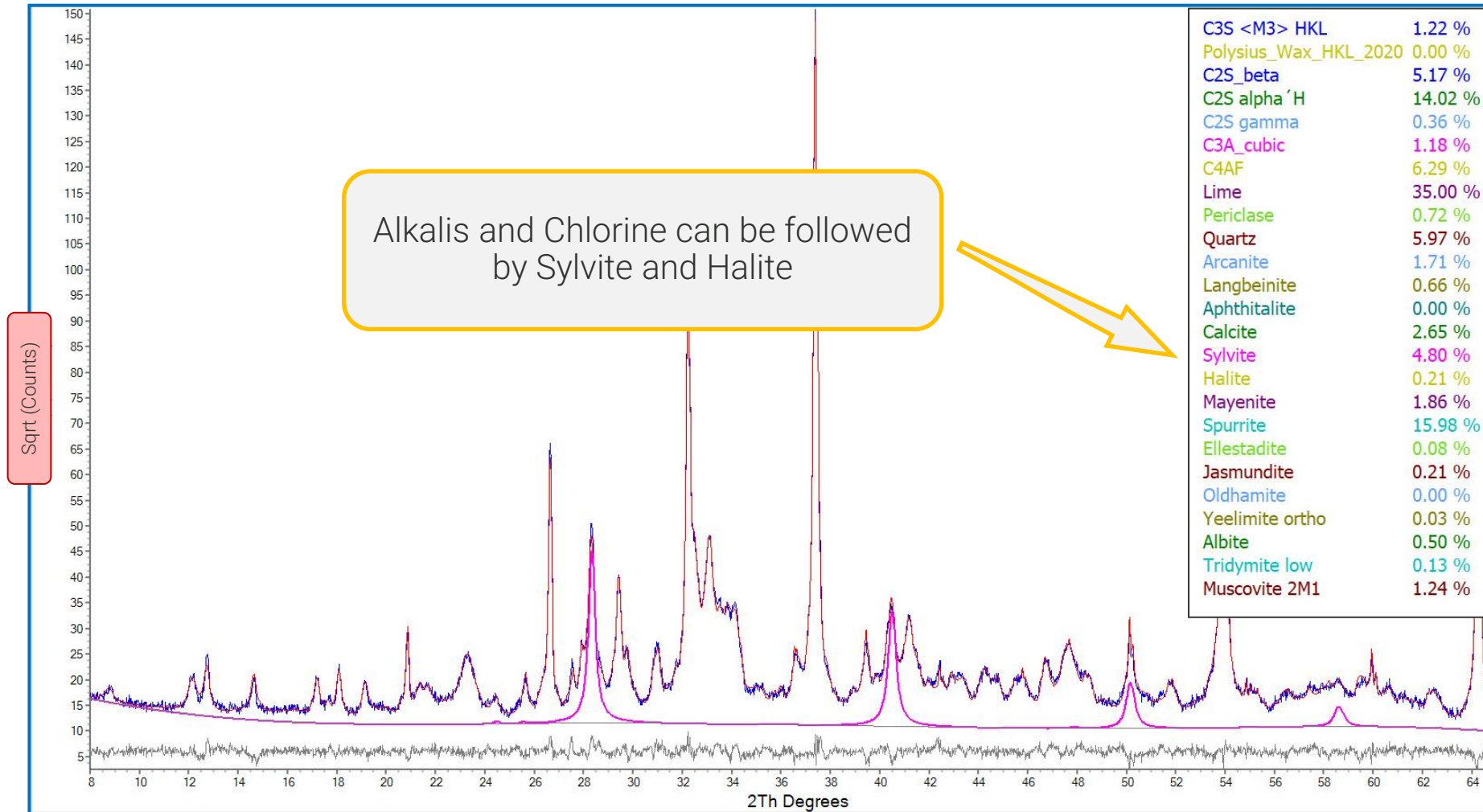
XRD Cyclones



XRD Cyclones



XRD Cyclones



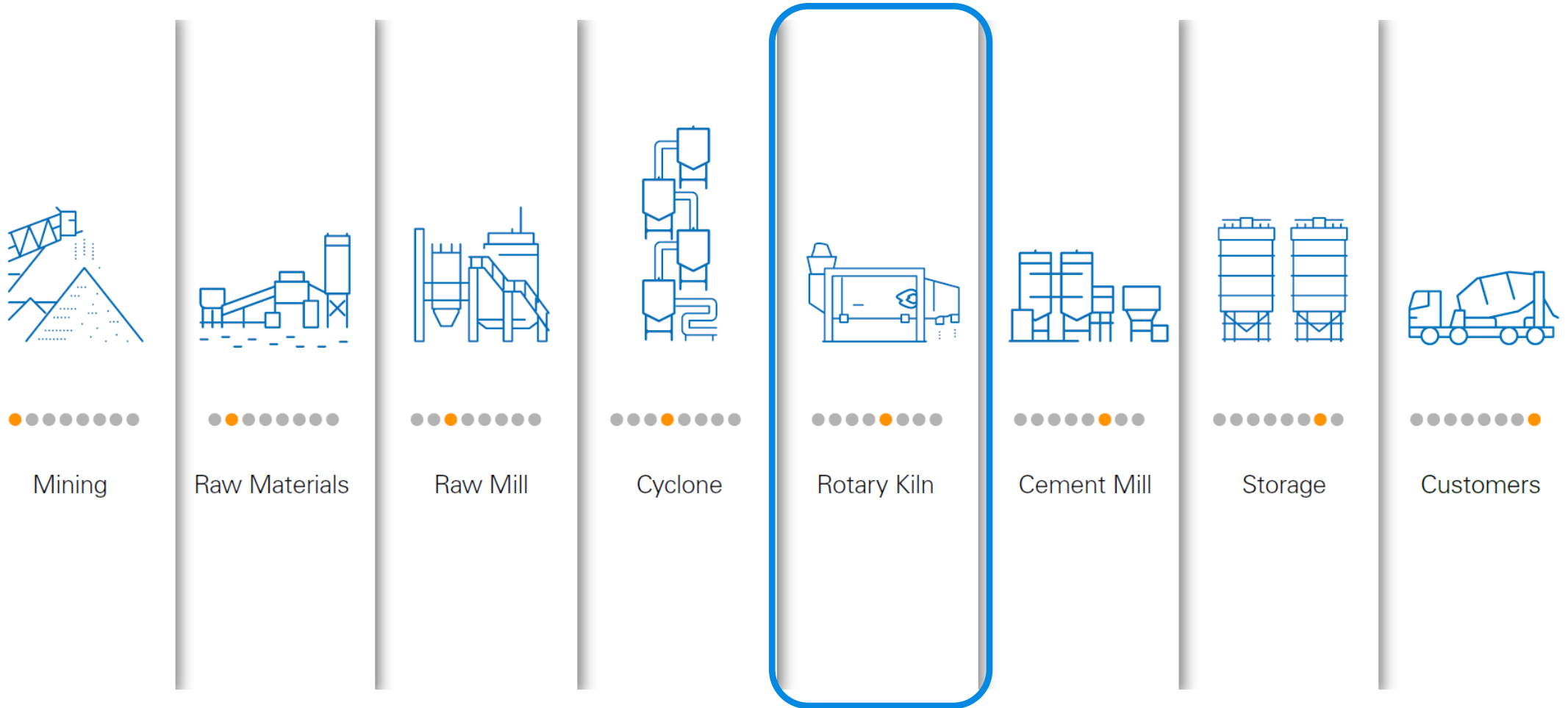


XRD Cyclones

Valuable information in just **5 minutes**

- Direct calculation of **Degree of Decarbonation**
- Alite is hint for **Kiln dust circulation** and **energy losses**
- Phases like Spurrite and Ca-Langbeinite are related to **blockages**
- Sylvite and Halite allow to monitor the **Alkali volatilization and condensation**

The Cement Production Process



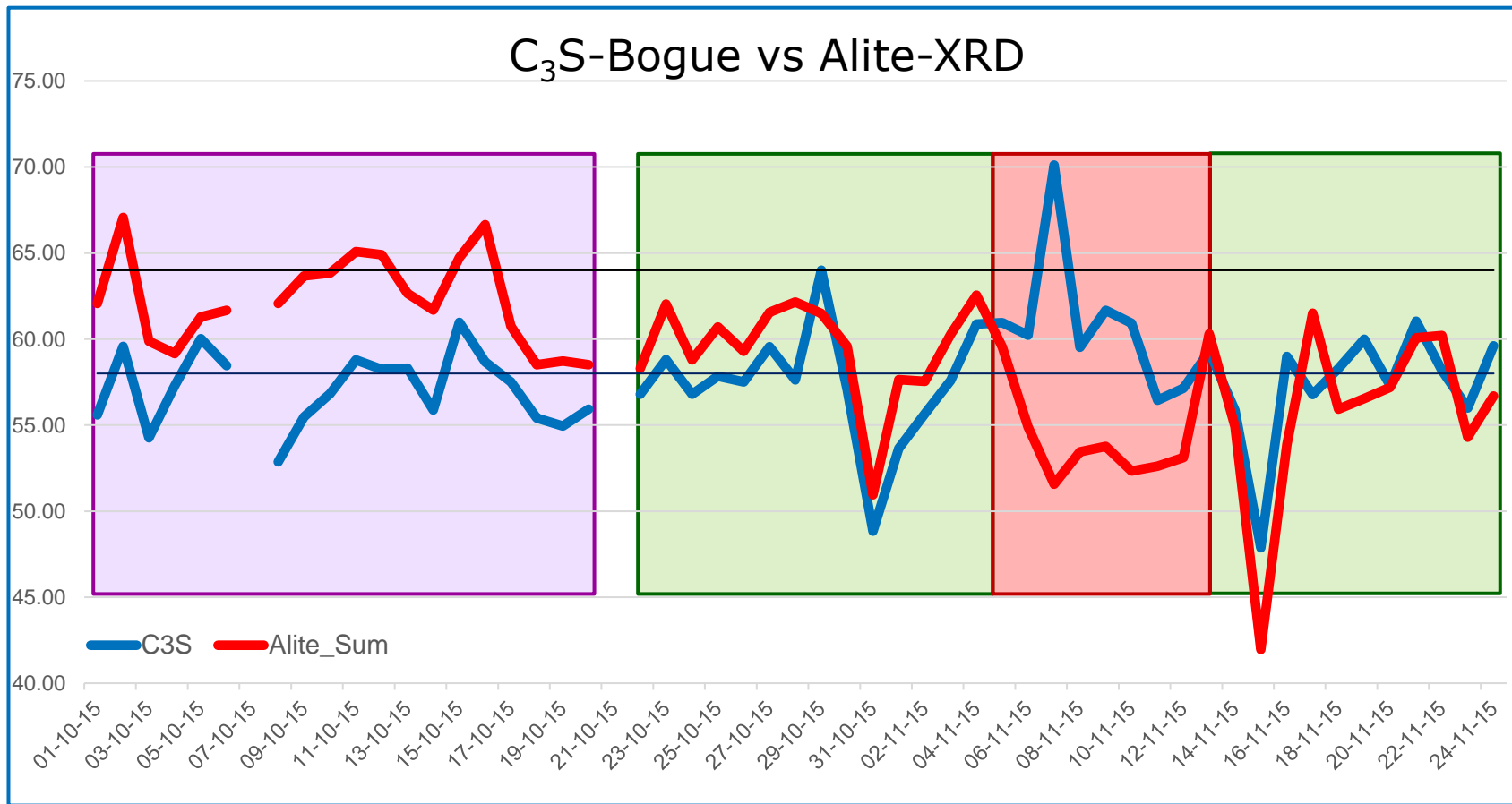
XRD Clinker

True phase composition

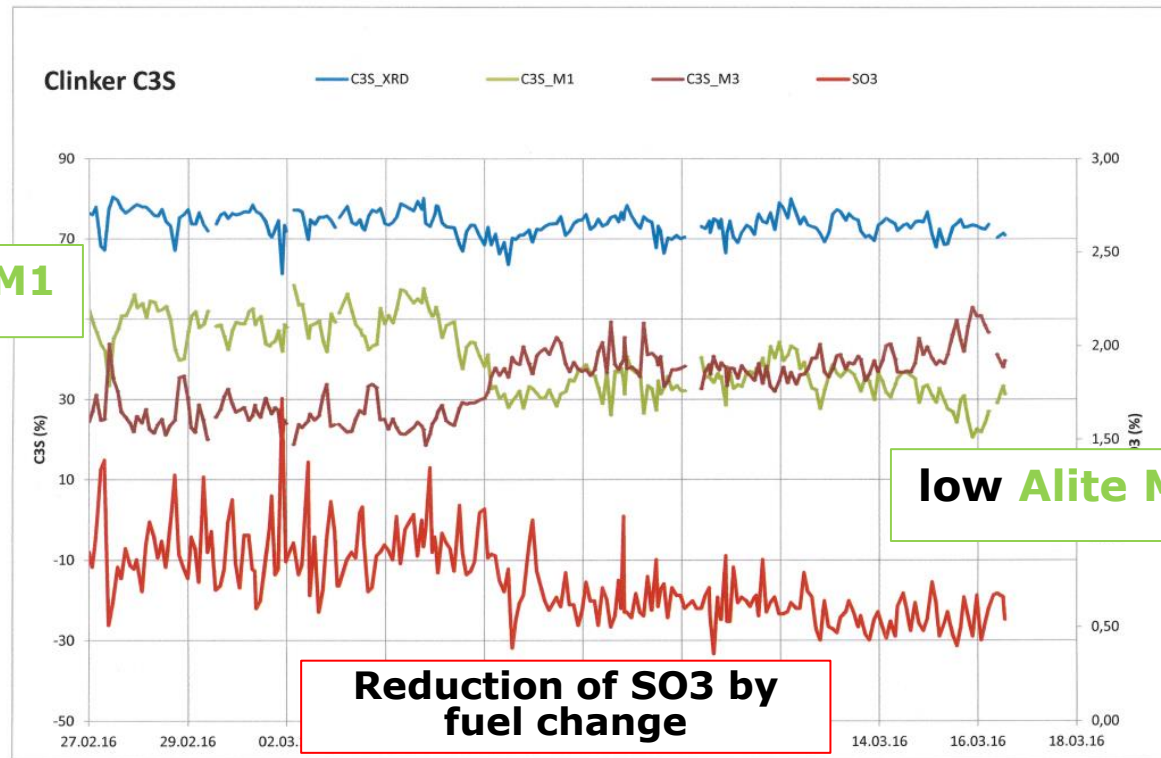
- Alite, Belite and Aluminate phases polymorphs
 - Alite M1& M3
 - Belite α' , β , γ
 - C3A cubic & orthorhombic
- Reliable and fast Freeline analysis



XRD Clinker



XRD Clinker



high Alite M1

low Alite M1

Reduction of SO3 by fuel change

Alite Sum

Alite M3

Alite M1

SO₃

The Cement Production Process



XRD Cements

True phase composition

- Differentiation of SO₃ carrier
 - Gypsum, Hemi-Hydrate and Anhydrite
 - Alkalisulphates
- Early Hydration detection
 - Syngenite

XRD Cements

Mill



Silo



Early Hydration



False/ Flash Setting



Lump Formation

XRD Cements

Mill



Silo



Syngenite



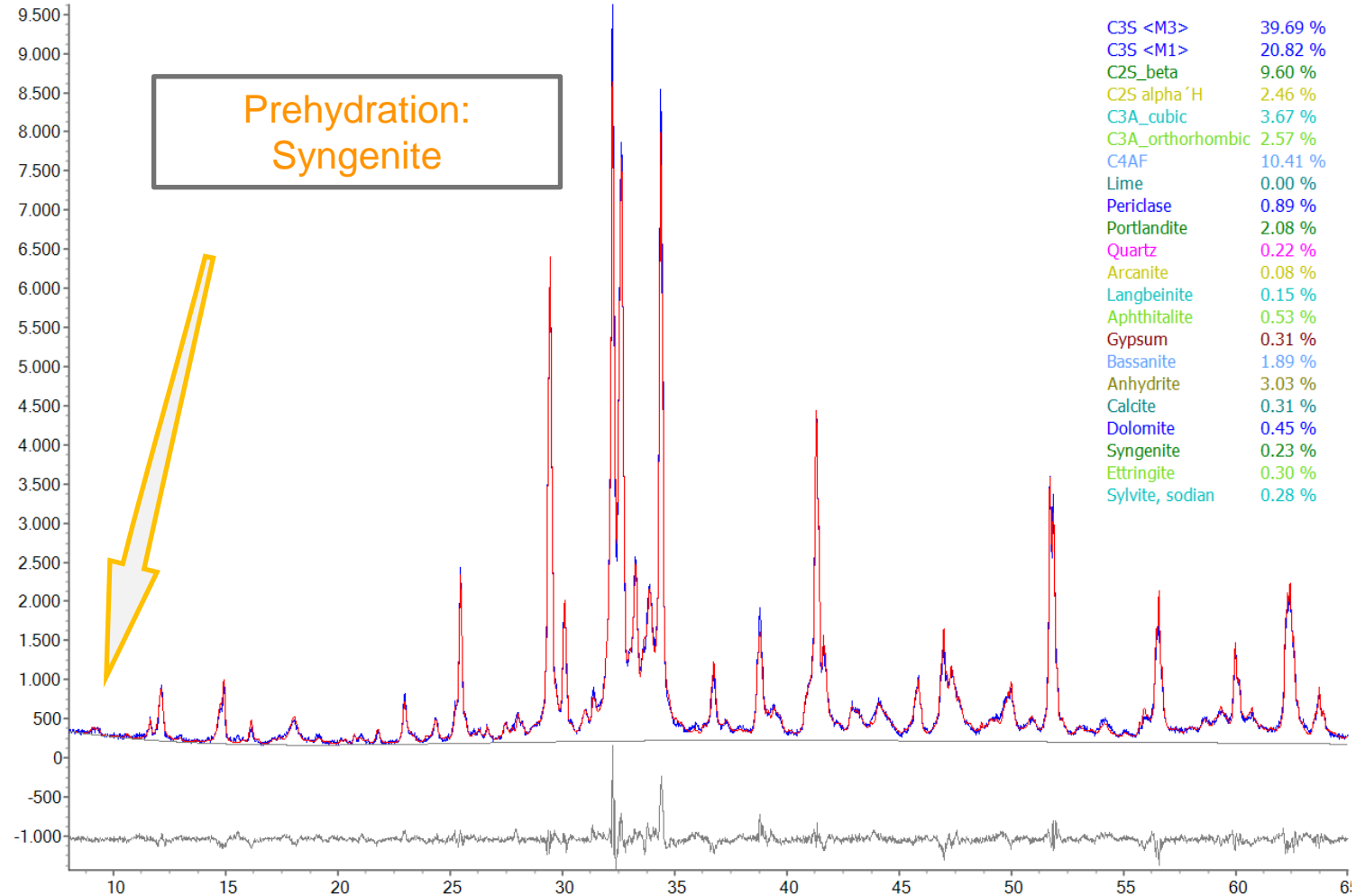
False/ Flash
Setting



Lump
Formation



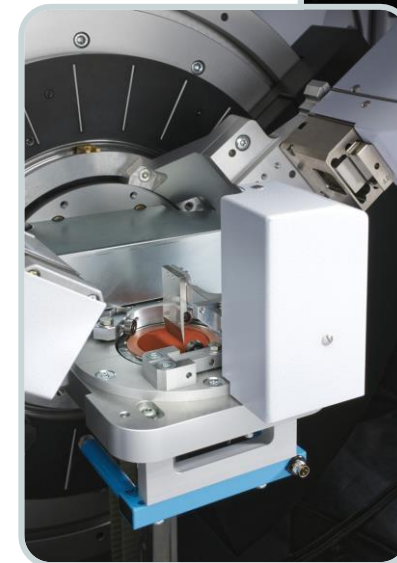
XRD Cements



XRD Cements

Low and linear background due to

- energy dispersive **LYNXEYE-XET** detector
 - suppresses K_{β} -lines, Fe-fluorescence & white radiation
- **Motorized Air-Scatter-Screen (MASS)**
 - provides flat background down to low angles



PRODUCTION OF HIGH-PERFORMANCE CEMENT AT LOWEST COSTS ENABLED BY LATEST ANALYTICAL TECHNOLOGY

Summary

Frank Portala

Summary: Bruker's Solutions for the Cement Industry

S8 TIGER Series 2

- Most advanced XRF solution
- Fast and Flexible
- Out-of-the box solutions



D8 ENDEAVOR

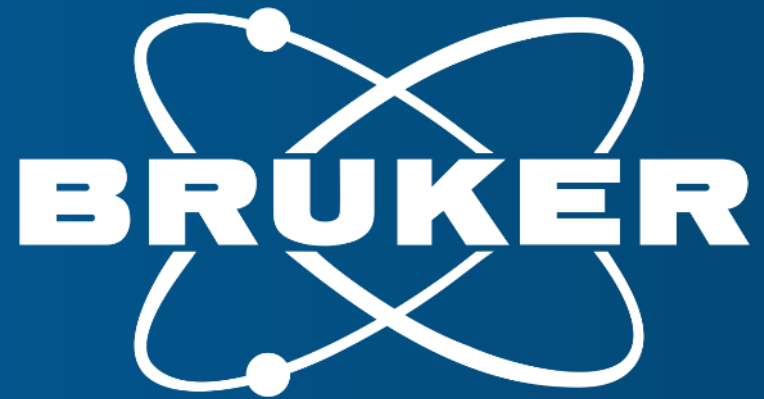
- Optimal solution for quantitative phase analysis



Benchtop XRF and XRD

- Ideal as back-up or for smaller plants and mines





Innovation with Integrity