Innovative Pathways for Decarbonization and Circularity of China Cement Industry

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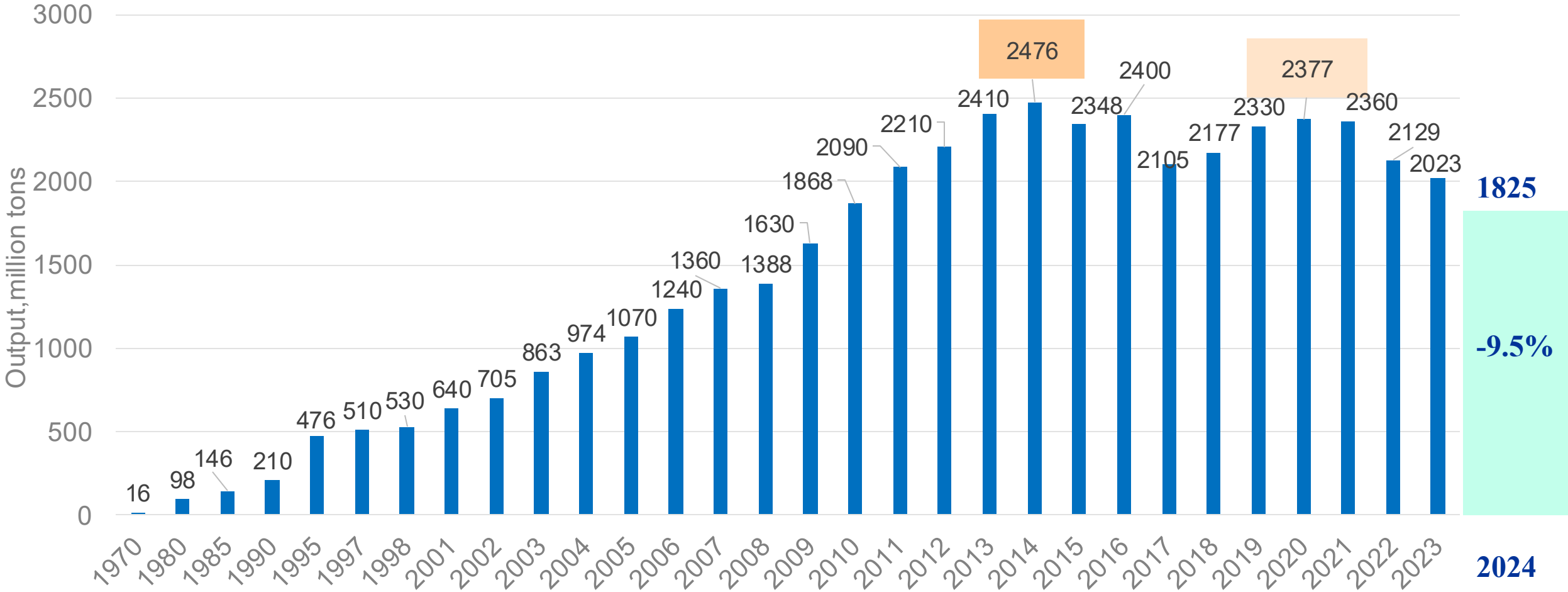
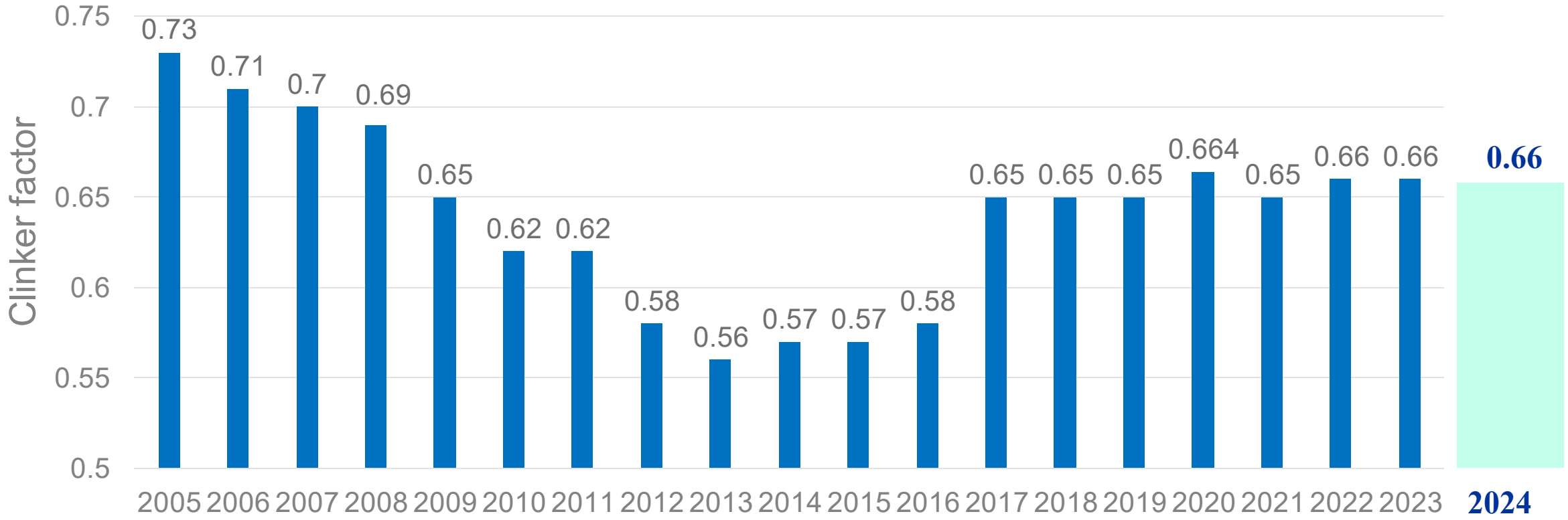
- Part 1: China Cement Industry – A Brief
- Part 2: Green, Low Carbon and Intelligence Solutions
- Part 3: Concluding Remarks & Future Perspective

Content

China Cement Industry
—— huge volume yet in a gradual decrease in prdn.



Clinker substitution
— Effective solution & immediate effect



- +1000 clinker lines equipped with WHR;
- Steady improvement in energy efficiency

The norm of energy consumption per unit product of cement（GB16780-2021）

Parameter	unit	limit of energy consumption level		
		Class 1	Class 2	Class 3
Comprehensive energy consumption per unit clinker	kgce/t	≤100	≤107	≤117
Comprehensive power consumption per unit clinker	kWh/t	≤48	≤57	≤61
Comprehensive coal consumption per unit clinker	kgce/t	≤94	≤100	≤109
Power consumption per unit cement for grinding	kWh/t	≤26	≤29	≤34

Target: by 2025, 30% clinker lines required to meet Class I energy consumption

Chinese Government Regulation〔2024〕No.5: Ultra-low Pollutants Emission for Cement Industry

Air Pollutant Emission: dust≤ 10mg/Nm³, SOx ≤ 35mg/Nm³, NOx ≤ 50mg/Nm³）

Target:
by 2025, 50% of clinker lines in the key regions, by 2028, 80% of whole clinker lines, to meet the requirement

Chinese Government Policy〔2025〕ETS implemented from 2025 for energy – intensive sectors, incl. Cement, Iron & steel, Aluminium smelting.

China Building Materials Federation (CBMF) on Dec. 29, 2021, proposed the concept of **"Six-Zero" factory**.

- **" Zero Purchased Electricity "** factory**:** green electricity, achieve zero or even negative annual net external electricity purchases
- **" Zero Fossil Fuels "** factory: renewable green energy, comprehensive disposal of waste with calorific value, waste heat, etc.
- **" Zero Carbon Emission** " factory: zero carbon dioxide emissions throughout the entire production process
- **" Zero Primary Resources "** factory: zero use of non-renewable natural resources
- **" Zero Waste Discharge "** factory: achieve near zero or zero emissions of solid, liquid, and gas wastes
- **" Zero Employee "** factory: enabled by digitalization & AI technology

- **BATs on Energy efficiency measures**
  - Further improve thermal efficiency and reduce power consumption;
  - ~100% large NSP kilns equiped with waste heat recovery;
  - the use of renewable energy, e.g., solar, wind power
- **BATs on AFRs**
  - Co-processing of municipal solid wastes (MSW), hazardous wastes (HW) & swedge sluge (SS);
  - AF 2-3%, more potential (best case TSR 60%+)
- **BATs on Low Carbon Cements**
  - Low carbon cements via clinker substitution (clinker fator 0.66)
  - Low carbon clinker cements: CSA-based, Belite-based (RBPC/HBC & BCSA) *
- **BETs: CCUS-Cement**
  - Post combustion
  - Oxyfuel combustion
  - Mineralization via carbon curing, ……

➢ **Emerging Digital & Intelligent Technologies**

- CSA=calcium sulfoaluminate,
- RBPC/HBC=Reactive Belite-rich Portland Cement/high belite cement,
- BCSA=Belite calcium sulfoaluminate)

Content

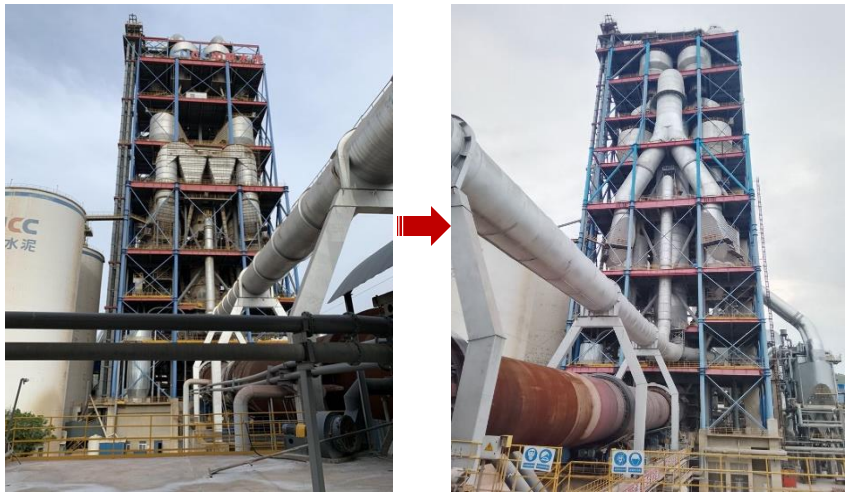
1 Energy efficiency improvement

Case: Xuzhou Union Cement 10000t/d production line pollutants and carbon reduction upgradation project

- **Project profile:** built in 2004, capacity 10000t/d, five-stage preheater, Φ6.0×90 m rotary kiln, CP grate cooler
- **Main measures:** retrofit of five-stage to six-stage preheater, upgrading of calciner for self denitration, replacement of grate cooler, replacement of tertiary duct, etc.
- **Commissioning time:** August 2022

Before modification

After modification



10000t/d line upgrading, Xuzhou, Jiangsu

Item	Before	After	Effect
Output（t/d）	10000	13000	↑3000
Coal Consumption（kgce/t.cl）	107	94	↓13
Power Consumption for Clinker（kW.h/t.cl）	56	53	↓3
Temperature at Preheater Outlet（℃）	345	260	↓85
Pressure at Preheater Outlet（Pa）	-5200	-5200	6sp
Clinker Temperature（℃）	190	90	↓100
NOx Emission of Self Denitration（mg/Nm³）	600	350	↓250
NOx Emission（mg/Nm³）	~60	50（25）	↓10
Ammonia Leakage（mg/Nm³）	5	3	↓2

2 Alternative raw materials & fuels and new energy

Case: 13 million t/y steel slag utilization + 1000t/d Co-processing of MSW, HW & SS (Wu'an, Hebei)

Site view of slag grinding systems in Wu'an, Hebei

➢ **Steel slag grinding & utilization**

Process: slag multiple crushing and magnetic separation systems, 8 sets of 230t/h steel slag vertical grinding mills.

Application: mineral addition for cement & concrete, pavers, ceramites, etc.

➢ **1000t/d Co-processing project**

—— A model combined with zero-waste city.

—— with co-processing only, coal saved for producing cement: 30 kt/y, ~80kt/y of CO2 avoided

2 Alternative raw materials & fuels and new energy

Case: Technology of Producing Sulfuric Acid and Cement with Phospho-Gypsum (PG)

project	scale
Consumption of Phosphorgypsum(dry basis)	1.4 million tons/year
Sulfuric acid products(98%)	650,000 tons/year
Cement clinker products(cement)	600,000 tons/year(About 800,000 tons)

- 1 t wet process phosphoric acid produces 4.5-5 t of phosphogypsum
- 80 million t of PG produced annually in China

Chemical reactions inside the kiln:

$$CaSO_4+2C \rightarrow CaS+2CO_2$$

$$3CaSO_4+CaS \rightarrow 4CaO+4SO_2$$

$$2CaO + SiO_2 \rightarrow 2CaO\cdot SiO_2\ (C_2S)$$

$$3CaO+Al_2O_3 \rightarrow 3CaO\cdot Al_2O_3\ (C_3A)$$

$$4CaO+Al_2O_3+Fe_2O_3 \rightarrow 4CaO\cdot Al_2O_3\cdot Fe_2O_3\ (C_4AF)$$

$$2CaO\cdot SiO_2 + CaO \rightarrow 3CaO\cdot SiO_2\ (C_3S)$$

- **No CO2 emission from Ca-bearing raw materials**
  CO2 emission intensity: 0.65

2 Alternative raw materials & fuels and new energy

Case: 36MWp Limak Cement Solar Project

Kurtalan1&2 Plant 19.9MWp

Sanliufa Plant 7.7MWp

Ergani Plant 3.9MWp

Derik Plant 4.4MWp

Estimated annual electricity production

62 mil. kWh

Estimated annual income from electricity price

25.4 mil. RMB

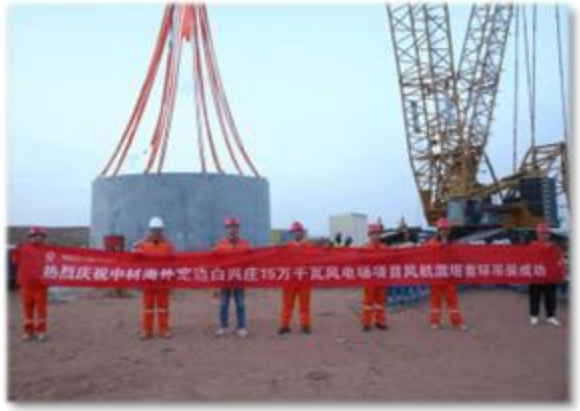
Estimated annual reduction of CO_2 emissions

51.6 kt

Estimated annual income from carbon emissions trading

23.9 mil. RMB

Case: Hybrid Towers EPC Projects, Yulin, Shaanxi



- Combination technology of hybrid tower and steel tower is adopted
- Advantages: cost effective, long span life, stable structure and strong seismic performance, and suitable for constructing high-power wind turbine (wind farm) in low wind speed area.

On April 3, 2024, the first ring of the hybrid tower was successfully lifted

3 Clinker substitution and new low carbon clinker cements

Limestone calcined clay cements - LC^3

The National Key Research and Development Program funded by MOST of China

Project Name:
Development of Key Technology and Equipment for New Low Carbon Cements & Int'l Demo-Application

Time: Sept. 2017-Sept. 2020 (June 2021)

Limestone Calcined Clay Cement LC3

Int'l Collaborative Project on New Low Carbon Cement

Int'l partners: led by Prof. Scrivener, EPFL, Prof. Martirena, UCLV; Prof. Bishnoi, IITD; & their teams

China project partners: led by Dr. Tongbo Sui, Sinoma, CNBM, in collaboration with Prof. Pengkun Hou, UJ, & Dr. Cheng Yu, Subote; & their teams

Low Carbon Cement

Suspension Calcining Technology (SCT), developed by Sinoma

- pilot production of calcined clay (600 t CC/d)
- MgO, CaO, Clay; capacity 300-1350tpd.

3 Clinker substitution and new low carbon clinker cements

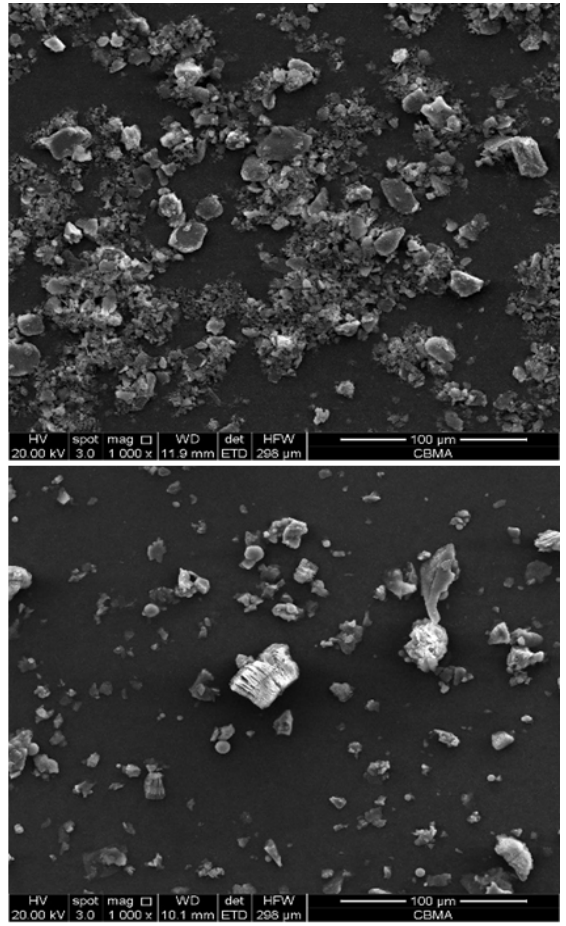
Comparison of CC via Rotary Kiln & Flash Calciner

Limestone calcined clay cements - LC^3

Item	CC-RK	CC-FC	PC
Kaolinite in raw clay*, %	64.6/50.3	51.2/39.7	-
Al_2O_3 in calcined clay, %	35.13	30.70	-
Flow rate, mm (PC:CC=7:3)	**171**	**194**	220
Dosage of superplasticizer, %	**0.1**	**0.05**	0
Reactivity Index, %	90-93	90+	100

* Note: Kaolinite in raw clay was quantified by TGA/Calculation+XRD, %

Challenge – Water demand & SP dosage



SEM of CC from rotary kiln (top) & flash calciner (down)

3 Clinker substitution and new low carbon clinker cements

Low carbon clinker cements – CSA, HBC, BCSA

Low Carbon Cement

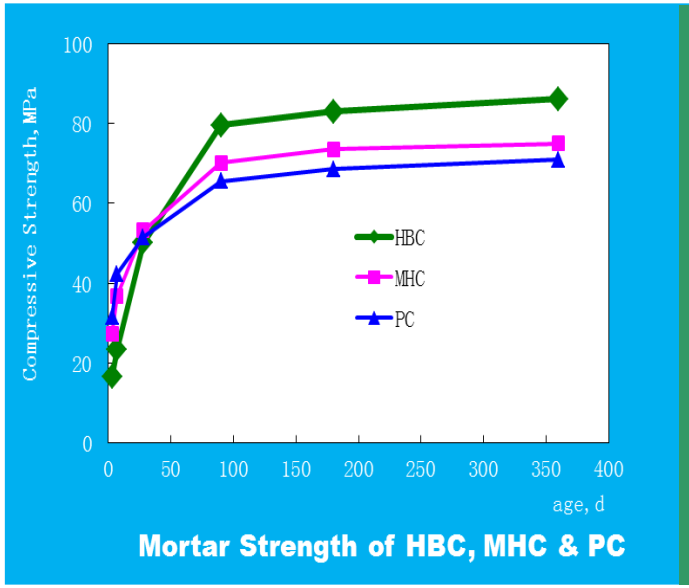
Energy saving & CO_2 emission reduction as compared with PC

Clinker system	Composition %	Burning temperature ℃	% of fuel energy saved*	% of CO_2 emission reduced*
CSA	C_4A_3S 40-70 C_2S 20-40	1300-1350	15-25	＞20
HBC	C_2S 40-65 C_3S 20-40	1350	10-15	＞10
BCSA	C_2S 40-65 C_4A_3S 20-40	1300	20-30	＞20

3 Clinker substitution and new low carbon clinker cements

Low carbon clinker cements – CSA, HBC, BCSA

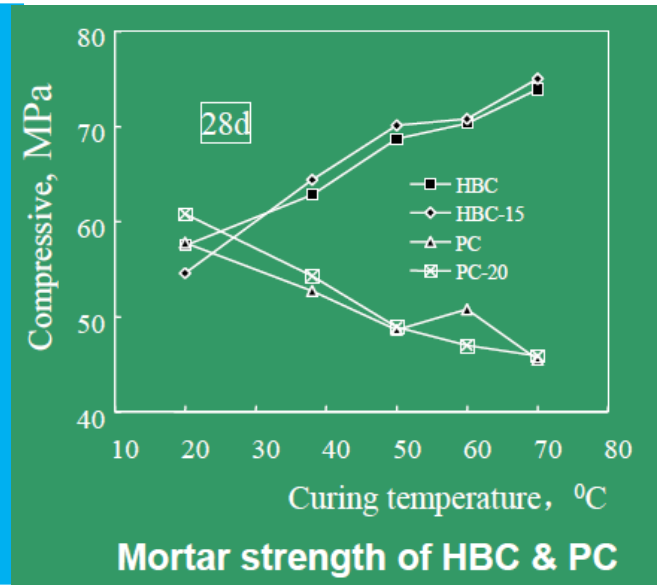
Strength comparison of HBC with PC & MHC



Mortar Strength of HBC, MHC & PC

under standard curing temp.

HBC: Lower heat, higher later age strength

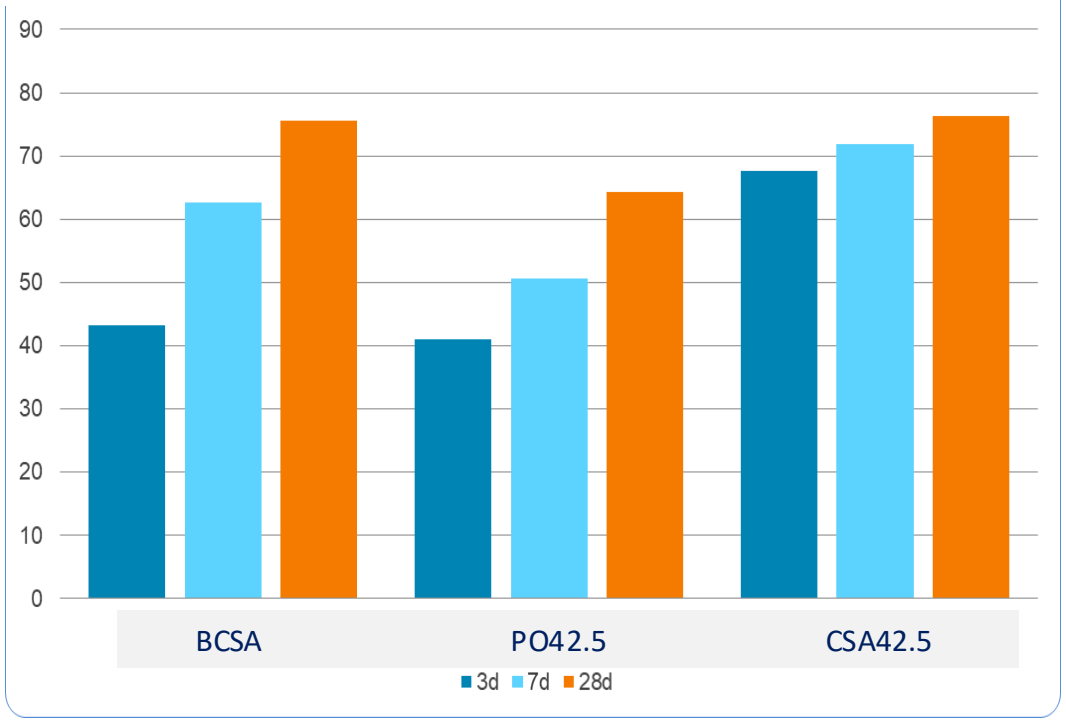


Mortar strength of HBC & PC

under elevated temp.

HBC: increase in 28d strength with curing temp., PC: just opposite

Concrete Strength comparison of CSA、BCSA & PC



***MHC: moderate heat PC**

C_3S=45-55%, C_2S=20-30%

Low carbon clinker cements – **CSA**, HBC, BCSA

3rd ring road, Beijing（1993）Fast construction

CSA Feature

Very high early strength

CSA

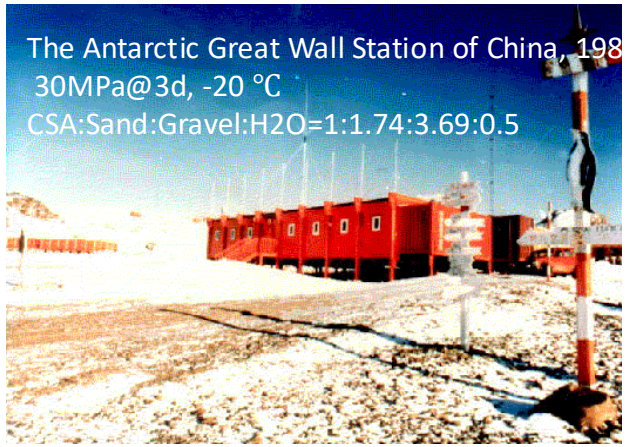
Field

Application

Precast pipe

C70/80 CSA concrete（1994）
103m building,
Winter Concreting

Precast panel



* Courtesy of Prof. SU Muzhen, CBMA

Part 2 Green, Low Carbon and Intelligence Solutions

Low carbon clinker cements – CSA, **HBC**, BCSA

HBC Feature

- ✓ Lower heat
- ✓ Higher late strength
- ✓ Better cracking resistance

HBC+SCMs can work better & FASTER than MHC+SCMs, without thermal crack

- World 2nd largest dam

Potential Application

Massive concrete

HPC, UHPC,

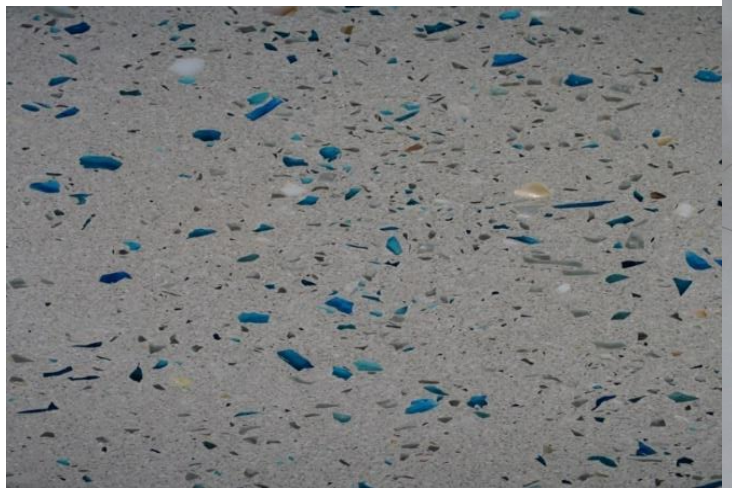
Pavement concrete,

Hot weather/summer concreting, …

- World 7th largest dam
The first use of HBC in arch dam

- World 1st largest dam
The first use of HBC

Low carbon clinker cements – CSA, HBC, **BCSA**

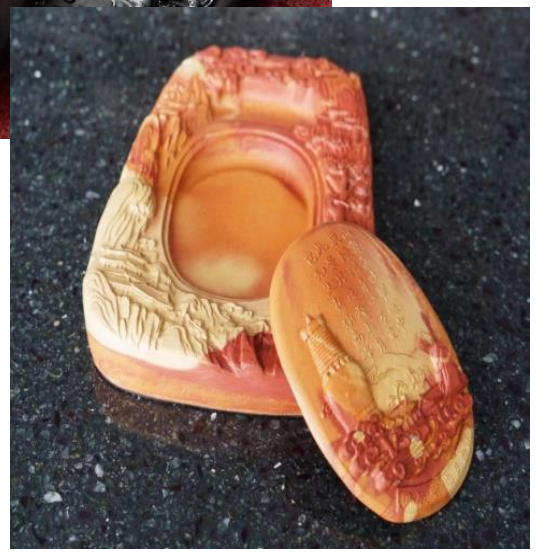


Feature:

Higher early strength, lower shrinkage

Application:

Grouting, Self-leveling, Artificial stone, etc.



Courtesy of Mr. Zhifeng Chen, Tangshan Polar Bear

4 Carbon Capture, Storage and Utilization

CCUS: the indispensable solution for cement sector to achieve Net-Zero

No	Cement Co.	Capacity	Commissioning time	Technology
1	CONCH	50,000 t/a	2018.10 (Completed)	MEA
2	CNBM	200,000 t/a	2024.01(Completed)	Oxyfuel
3	CRC	100,000 t/a	2023.12 (under test)	Oxyfuel
4	BBMG	100,000 t/a	2024(Completed)	MEA

4 Carbon Capture, Storage and Utilization

Carbon Capture

Case: Post combustion

Demo Project 2018:
Anhui Conch (chemical absorption)

- ✓ Kiln capacity: 4500t/d
- ✓ CCS capacity: 50kt/y of CO2;
- ✓ CO2 capture efficiency: 95%

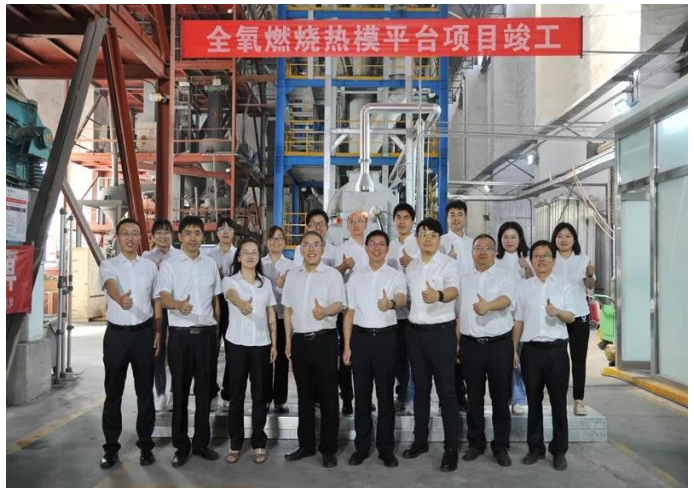
* Courtesy of Mr. JIN Feng, Anhui Conch

4 Carbon Capture, Storage and Utilization

Carbon Capture

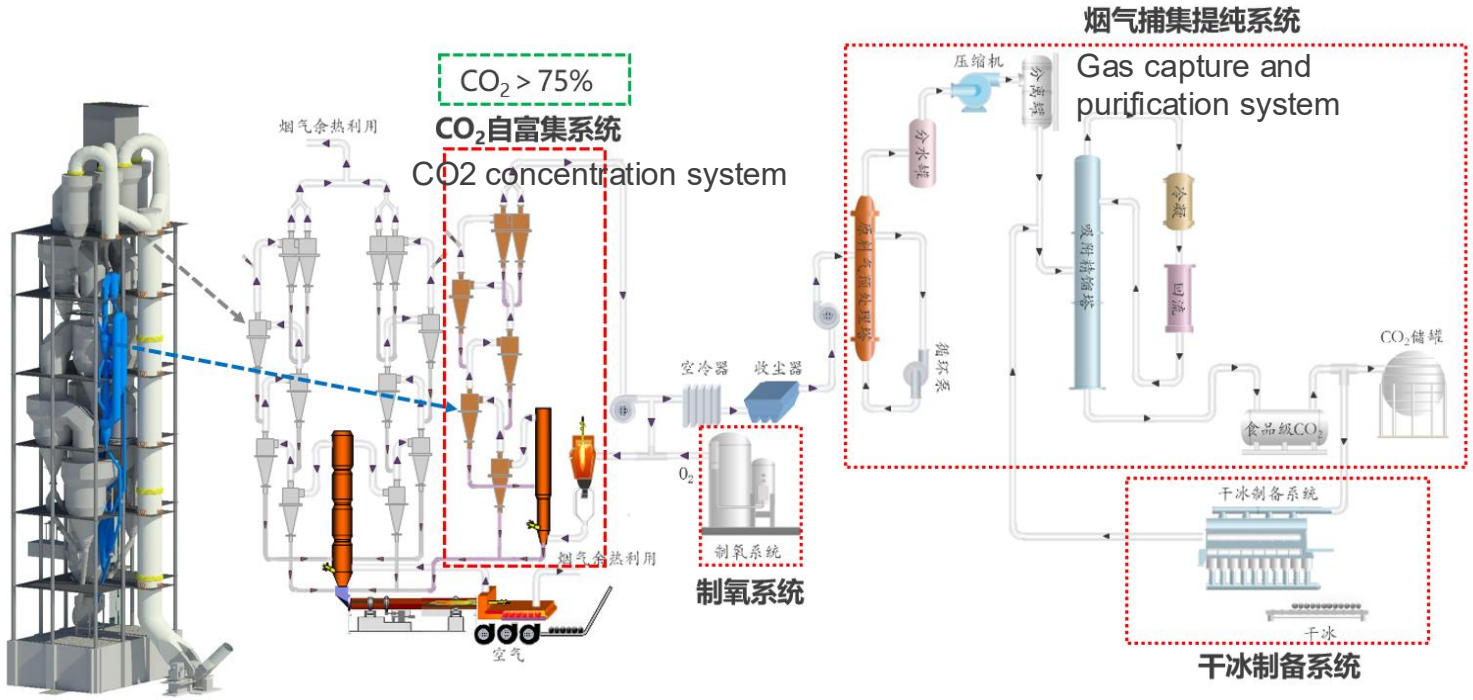
Case: Oxyfuel combustion coupling with carbon capture

——developed by SINOMA Int’ l, CNBM



Oxyfuel pilot plant completed and put into trial operation

- Enriched CO2 concentration: over 80%;
- Decomposition rate of raw meal ≥ 92%



Both CAPEX and OPEX of CO2 capture and purification facilities are expected to be reduced.

4 Carbon Capture, Storage and Utilization

Carbon Capture

Case: Oxyfuel Combustion coupling with carbon capture

——developed by SINOMA Int’ l, CNBM

Completed time: January 2024

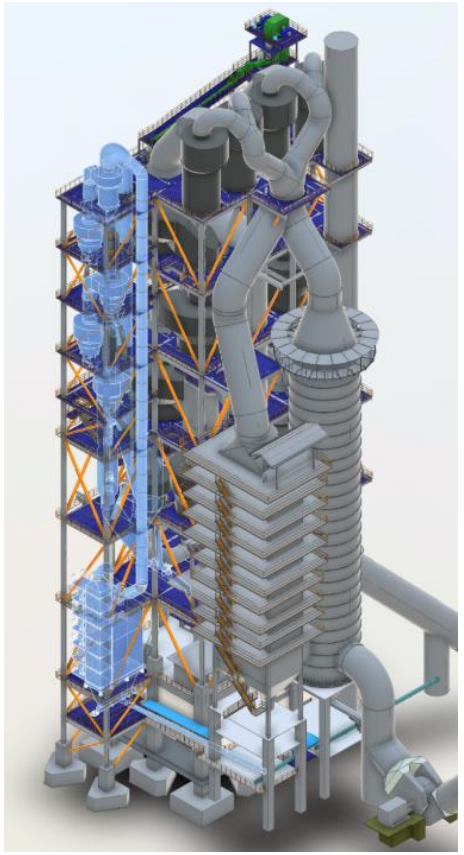
Demo Project site: Qingzhou, Shandong, China

Capture capacity: 200,000 ton CO_2 /year

Technical solutions:

oxyfuel combustion + variable pressure absorption enrichment + variable temperature & pressure absorption and purification + low temperature rectification

Energy consumption per ton of CO_2 : 1.60~1.70 GJ/t.CO_2



4 Carbon capture, Storage and Utilization – Sequestration via mineralization

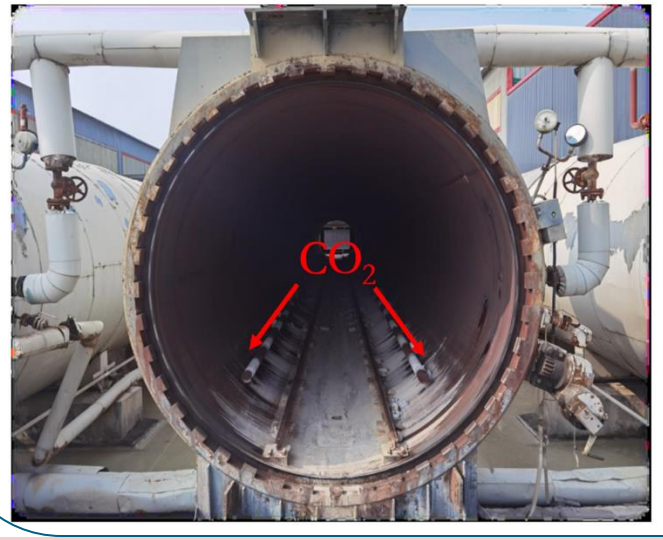
Carbon Capture

Demo Project 1: Sinoma, CNBM

Waste 1 (CO2 in exhaust gas of kiln) + **Waste 2** (carbide sludge Ca(OH)2) ⟶ **HVAD PCC (precipitated calcium carbonate)**

- ✓ PCC 50-100 kta industrial feasibility study
- ✓ PBC 50 kta industrial line built (Barium carbonate)

Demo project 2: technical support by Zhejiang University*
—— Pavers made via CO2 curing



72-hour trial
- Use steel slag, bottom ash etc., 1700 t;
- Concrete pavers1800 t, CO2 sequestered 50kg/t

*Prof. Tao Wang, Zhejiang University

Demo Project 3: Huaxin Cement + Hunan university)

CO2 Cured concrete brick line (100 mil. brick)
Strength: 15MPa+

中国建材

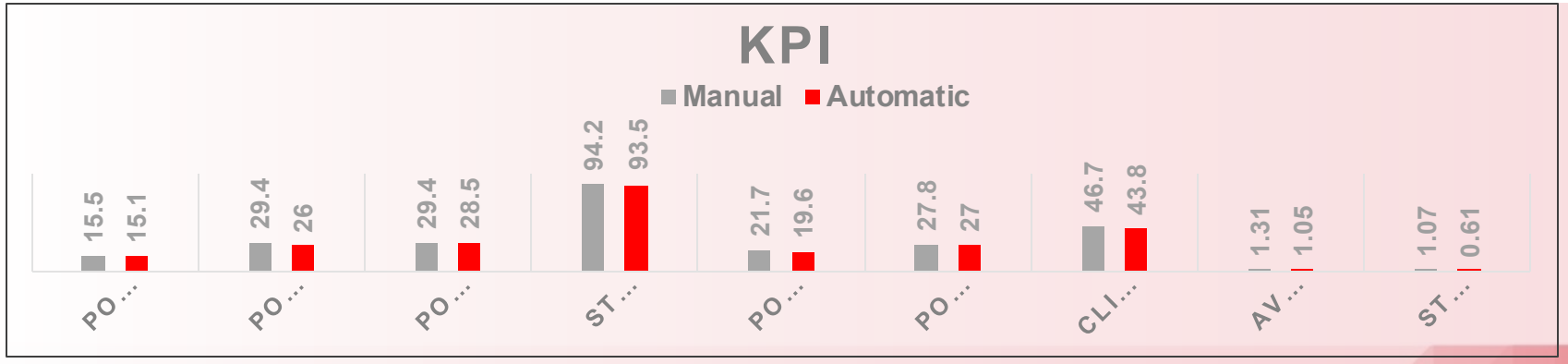
5 Digital & Intelligence Technologies

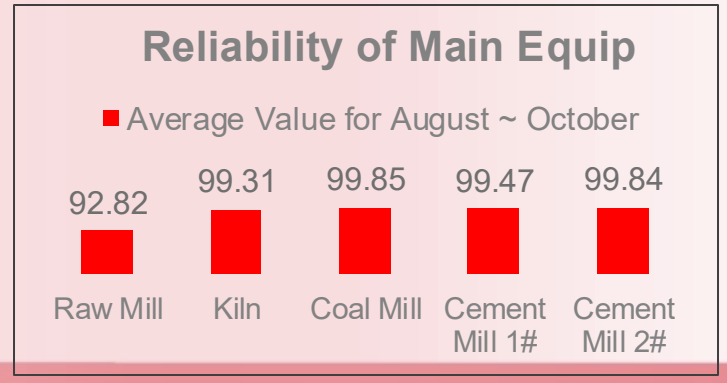
Intelligence Technologies

Cases:

- **HUAIKAN South Cement 7,500tpd Clinker Production Line**
- **JIDONG TONGCHUAN 10,000tpd Clinker Production Line** (National Demo Enterprise for Intelligent Manufacturing, National Green Factory)

The whole process digital control and the whole value chain penetration can be achieved from the raw materials incoming factory to the finished product delivery, through the integrated application of online monitoring, automatic control, artificial intelligence and other technologies





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Concluding Remarks & Future Perspective

All solutions contribute to cement sustainability & carbon neutrality

- process technology & equipment innovation
- increased use of AFRs, clinker substitution
- lower/zero carbon & higher performance cements & concretes

……

To achieve carbon neutrality, cement sector as a hard-to-abate one, has to work with

- value chain, cross-sector, cross-region/country;
- carbon-based circular economy model;

……

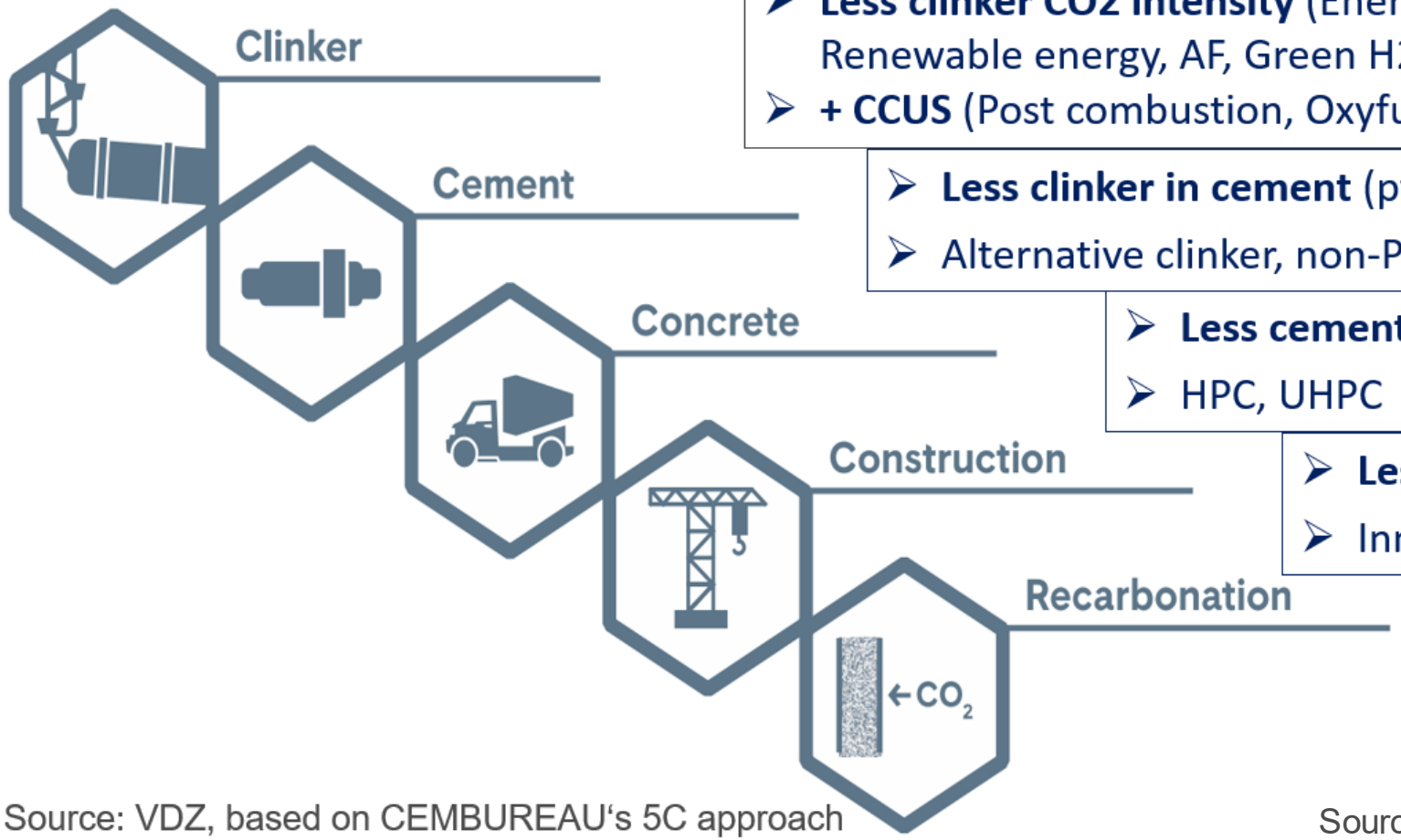
CCUS – one of the Key Solutions to carbon neutrality

- further R&D to reduce the cost;
- policy & regulation and standards enhancement;
- financing and business model;
- cross-sector model & international collaboration;

……

Concluding Remarks & Future Perspective

Decarbonization along the value chain



- **Less clinker CO2 intensity** (Energy efficiency, Reactivity optimization, WHR, Renewable energy, AF, Green H2; Non-carbonate Ca-RM, waste utilization, …
- **+ CCUS** (Post combustion, Oxyfuel combustion, Ca-looping, etc.)

- **Less clinker in cement** (pfa, ggbs, natural pozzola, calcined clay, ...)
- Alternative clinker, non-Portland binders, ...

- **Less cement in concrete**
- HPC, UHPC

- **Less concrete by lean design**
- Innovative tech., e.g. 3D printing, AI-enabling, ..

- **Less atmospheric CO2 increase**
- Natural occuring; Carbon curing

Source: VDZ, based on CEMBUREAU's 5C approach

Source: Tongbo Sui, 9th International VDZ Congress, Nov. 2024

Collaboration to Achieve More

Thank You !

Acknowledgement:

Projects collaborators in China:

- ✓ China Institute of Water Resources and Hydropower Research
- ✓ China Three Gorges Corporation
- ✓ Sichuan Jiahua Cement Group
- ✓ Research team both at CBMA & Sinoma Int'l.
- ✓ ……

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