Ash Improvement Technology Inc. (AIT)

ait CleanCem

In-boiler modification of fly ash

From an uncontrolled byproduct to an optimized SCM to enable maximum clinker substitution

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ANNA MARIA WORKSHOP XII, Concrete for the 21st century, Holmes Beach, FL , Nov 9-11 2011

Macro trend: Growing demand for Green cement and power

Global cement clinker production (tonnes)

2013 3.6bn

2010 3.3bn

2006 2.8bn

Coal ash produced: 1.2 billion tonnes/year

Coal Ash used: 300-350 million tonnes/year (30%)

Use of all coal ash would bring clinker production back to 2006 levels.

Cement as it is today:

- most widely used building material
- cement is blamed for 5% of global CO2 emissions (2.3bn tons/year)
- Annual portland cement production roughly 3.6 billion tonnes in 2010

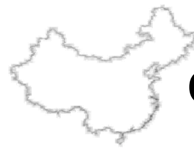
Energy generation as it is today:

- Coal dominates – and increasing
- Not enough natural gas, oil, nuclear by a long shot
- Emerging technologies slow and still expensive

Coal ash is the only SCM available in large enough quantity to potentially enable 50% and higher clinker replacement (along with slag, limestone, rice hull ash etc)

Market snapshot: India's fast growing coal power, China's mass and the US's established base

MARKET DATA

	 CHINA	 INDIA	 US
Cement Consumption	1,600 M ton/yr	265 M tons/yr	95 M tons/yr
Cement market price	US$45/ton	US$110	US$90/ton
Share of coal in power generation	80%	70%	48%
Amount of ash produced	425 M tons/yr	175 M tons/yr	85 M tons/yr
Current use of ash produced	30%	30%	43%
Ash content in coal	25%-45%	35%-45%	6%-15%
Average ash disposal cost	n/a	US$21/ton	US$ 15-20/ton
Ash production annual growth rate	15%	9%	1%
Government mandated re-use of ash	n/a	100% by 2014	n/a

Macro need - Coal ash: a three decade long debate …

Current Waste stream and disposal of coal ash

COAL FIRED PLANT

Unused ash (includes bottom ash)

60% (~720M tons)

LANDFILL / STORAGE POND

Potential Groundwater Contamination

Beneficially used ash

CEMENT PRODUCTION

CONCRETE CONSTRUCTION

OTHER APPLICATIONS

With no viable ash enhancement technology available, over **700 million tons** of coal ash are landfilled in the world every year.

Why is 60% of coal ash unused?
-Variability, poor early age performance, carbon, durability, color……
- Existing beneficiation technologies expensive

… leading to a global Environmental catastrophe

The US, India and China produce over 900 million tons of coal ash every year. All three have embarked on regulating disposal, requiring a substantial increase in coal ash utilization .

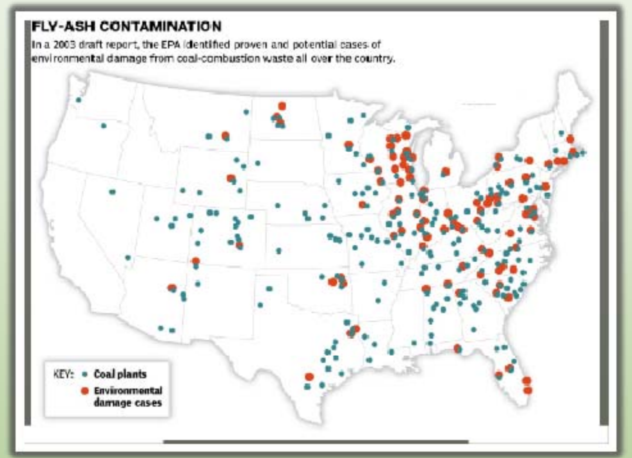
	Coal as % of Power Generation	**Ash Generated (tons/yr)**
US	48%	85 M tons/yr
India	70%	175 M tons/yr
China	80%	700 M tons/yr

December 2008 ash spillage in Kingston, TN - USA

“The size of the Kingston disaster is 48 times bigger than the 1989 Exxon Valdez Oil spill” (Greenpeace)

Ash slurry overflow from the NTPC's Simhadri plant in Devada village in Vishakhapatnam, India in June 2010

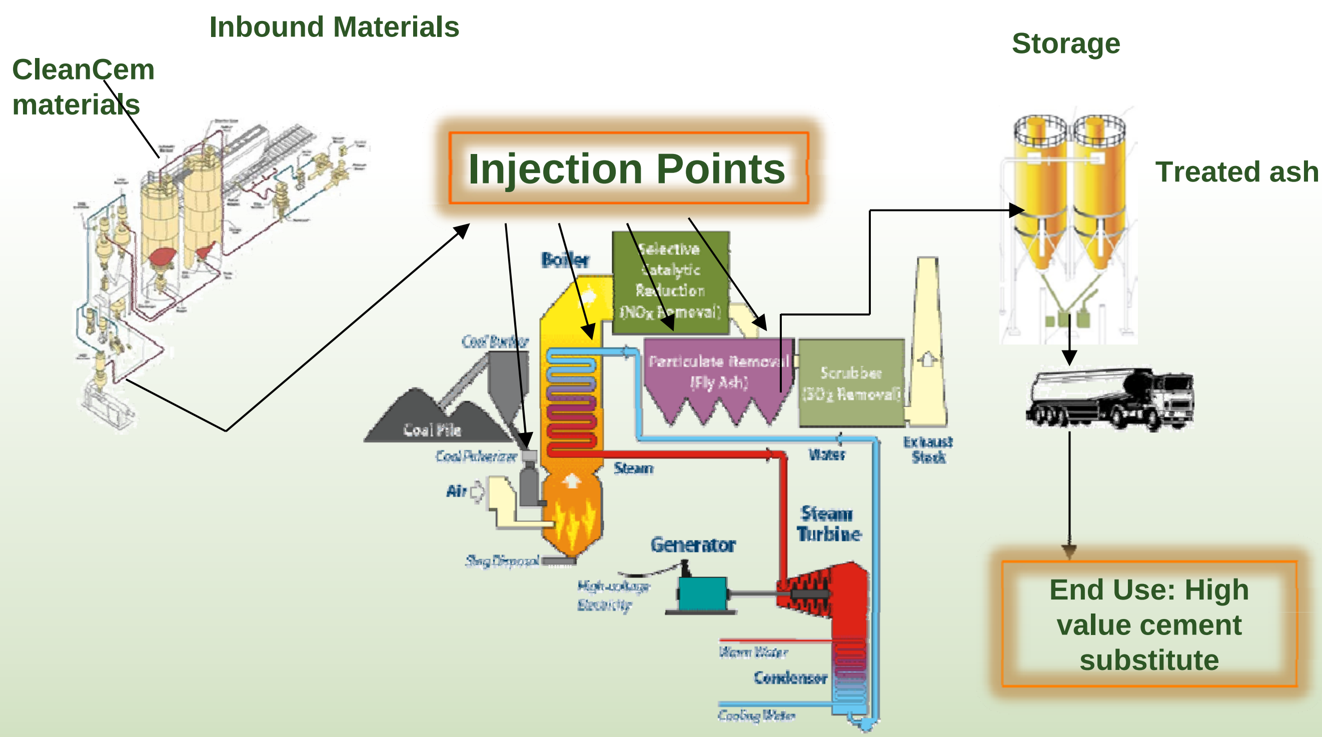
Shentou Number 2 Power Plan and ash pond and “ash storm”, Shuozhou, Shanxi province, China



Ash contamination sites and coal plants in the US

In-Boiler Manufactured SCM: a novel process that eliminates waste ash, creates low cost, high value cement substitute

The In-Boiler beneficiation process at the Coal Fired Power Plant



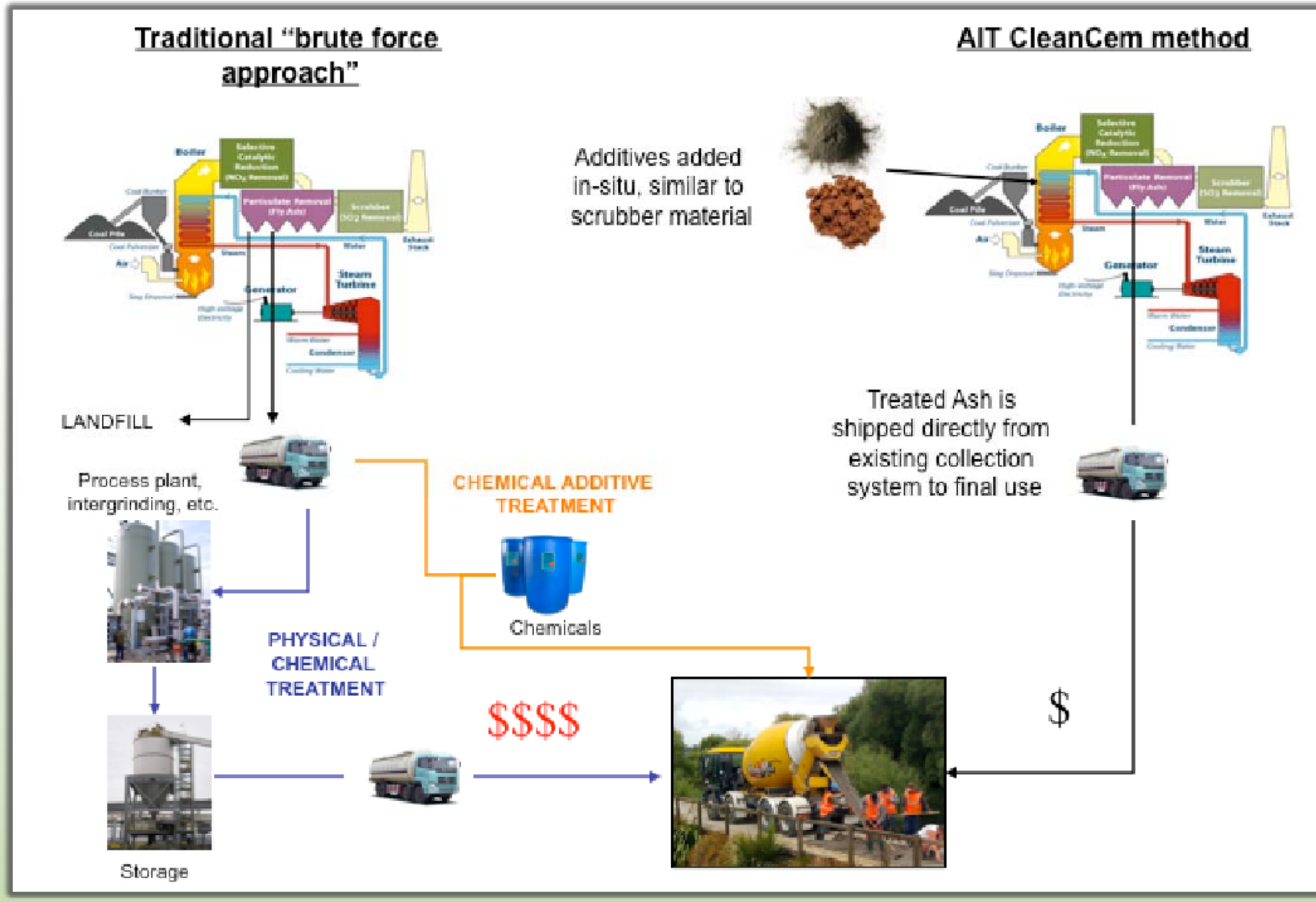
Our process converts a coal-fired plant into a manufacturing plant for a value added cement substitute

In-Boiler beneficiation: Flexible, "green" AND cost effective

How is In-Boiler beneficiation different from other clean technology solutions?

- **Better cost position**:
  - No separate treatment facility:
  - No inter-facility shipment cost
  - No large capital outlay
  - No costly chemical treatment
- **Better market acceptance**:
  - Can tailor additions so that treated product falls into existing standards
  - Does not require concrete producers to change the way they operate
  - Yields a consistent product manufactured under controlled production

In-Boiler beneficiation vs. other approaches



In-boiler beneficiation does not change the way concrete is produced today, and does not carry the burden of heavy capital investments or transportation costs.

How it works: Chemical & physical / thermal activation

Chemistry

Many industrial “waste” materials and natural deposits (limestone, clays etc) have the right chemistry at low cost

Physical

Smaller the better – surface area is critical for activation as well as nucleation of cement hydrates in concrete

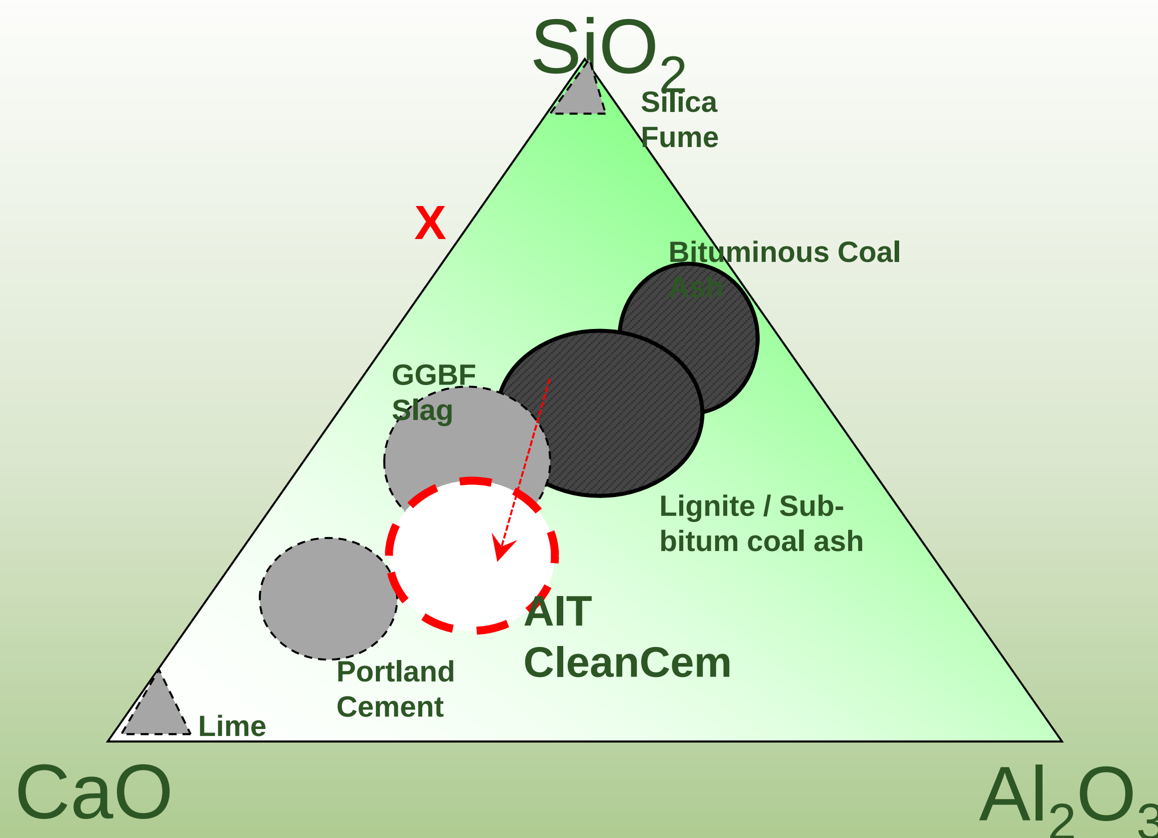
Thermal

Similar to kaoline – even an incomplete conversion yields improved performance

Process

Improved combustion – less carbon, smaller and more reactive fly ash particles. Surface activation

Example: Targeting faster strength development to allow higher clinker substitution without lower early strength



How it works: In-boiler additions changes the ash to a manufactured material with desired properties

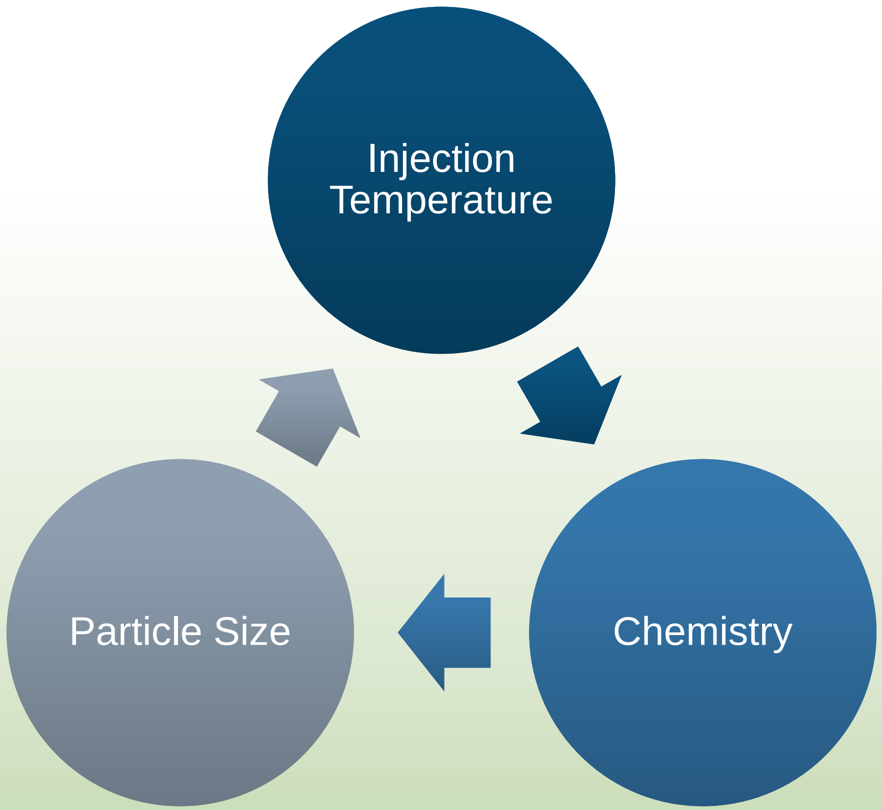
Inputs: Each Coal source / boiler combination will have different viable options for adjustments in:

- Raw material selection / dosages
- Injection points (temperature)
- Raw material particle sizes

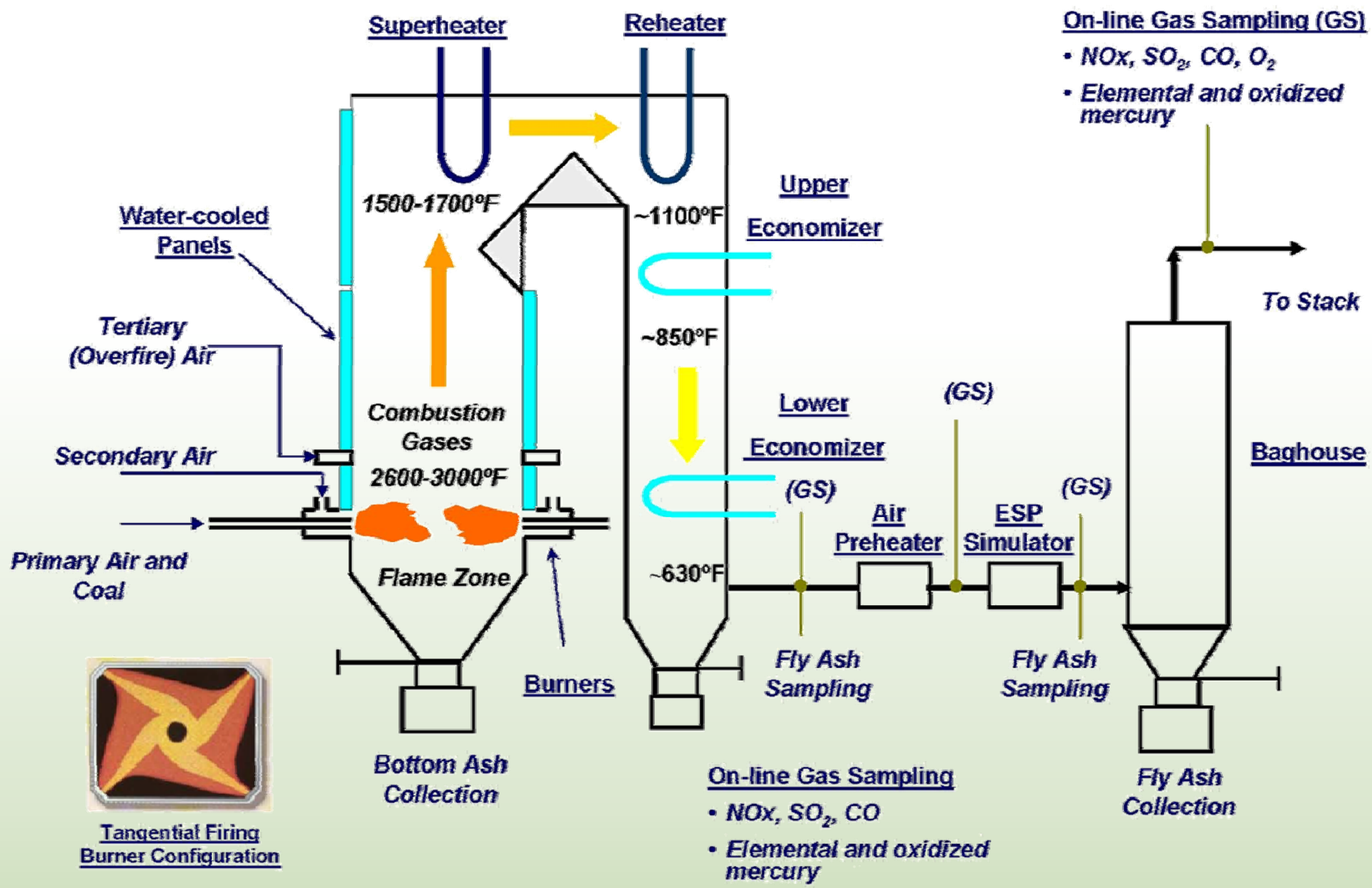
End Product: We control production of a high performance cement substitute, made to desired specifications:

- Target specific performance attributes (**strength, durability, LOI**)
- Control **consistency** of end material
- Manufactured product fits into **existing standards**

– Geopolymers (Ceratech, Zeobond, etc.) don't.



Experimental: Sub scale boiler test pilot plant in Wyoming



Details of materials added to the coal fired furnace

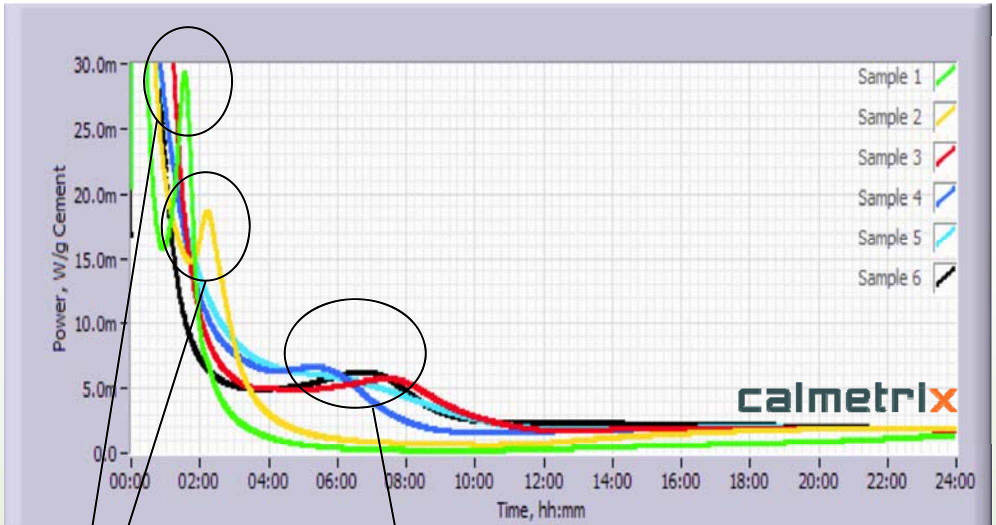
Raw material addition	Average particle size, µm	Elemental composition mass % by XRF						
		SO_3	Na_2O eqv	CaO	SIO_2	Al_2O_3	Fe_2O_3	MgO
Limestone	80	0	0	56	1.1	0	0	0
A	8	1.7	0.5	37	38	10	0	11
B	200	0.7	3.9	16	55	9.4	4.4	2.4
C	3	0	0.3	0	45	38	1.0	0
D	100	0.1	13.3	11	72	1.7	0	1.2
E	20	0.3	1.2	0	92	0.5	2.1	1.1

Details of Portland cement and un-modified fly ash

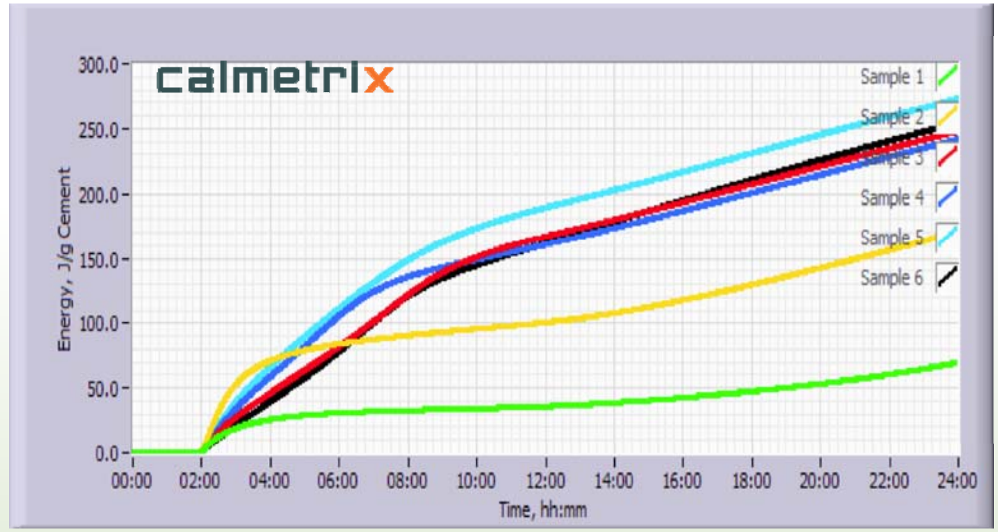
Material	Average particle size, µm	Elemental composition mass % by XRF						
		SO_3	Na_2Oeqv	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO
Portland Cement “A”	18	3.9	0.7	62	20	4.7	3.0	2.6
Portland Cement “B”	23	3.3	0.8	64	19	5.4	2.6	1.1
Portland Cement “C”	24	3.1	0.5	63	21	4.4	3.6	0.7
ASTM class C fly ash	12	4.7	2.6	30	27	18	6.3	6.7
ASTM class F fly ash	14	2.6	1.8	5	52	20	9.7	2.0

Calorimetry: In-boiler modifications improve early hydration of C ash

Effect of additions on reactivity of a 60% high calcium ash - 40% Portland cement blend at 23 C



Effect of additions on total energy (60% fly ash) as a proxy for potential strength development rate



Untreated ash: Uncontrolled aluminate reaction – Poor strength gain.

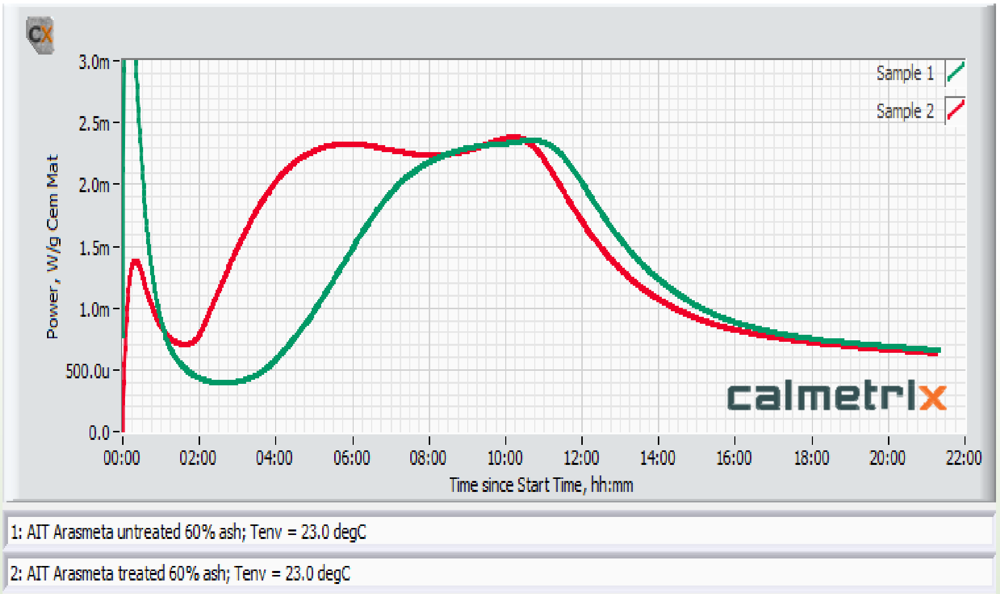
In-boiler modified ash: Normal hydration peaks, characteristic of controlled hydration and strength gain.

Plot #	Color	Description	1d psi	28d psi
N/A		Plain Portland	3046	5877
1	green	Plain (unscrubbed) ash	809	3953
2	yellow	Ash with scrubber	n/a	n/a
3	red	LSSL	n/a	n/a
4	blue	LSRC	n/a	n/a
5	light blue	LSRG	1506	7318
6	black	LSSLRCRGKSF	2041	10700

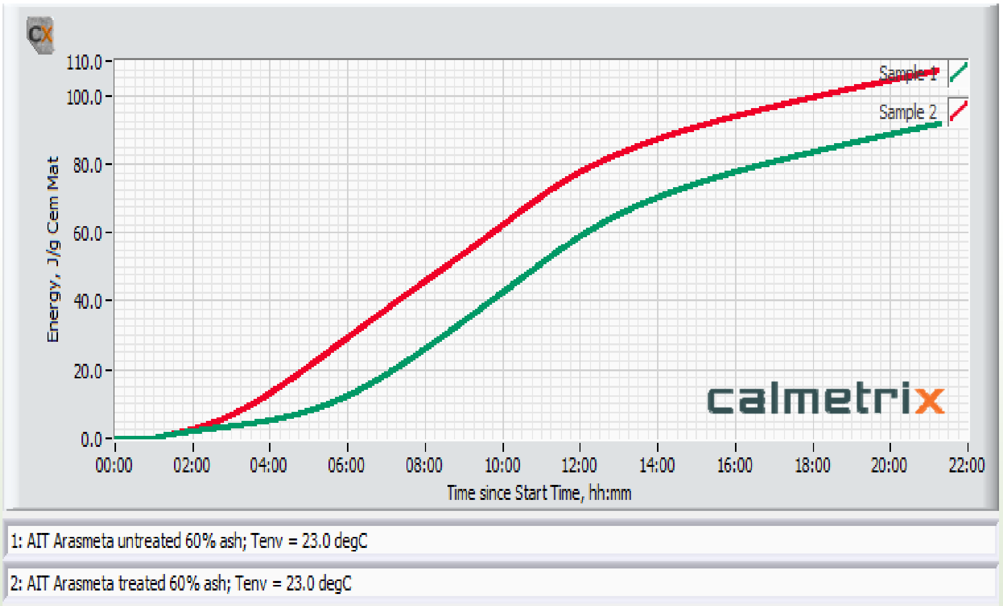
CleanCem material (red, blue, light blue and black curves) shows favorable early hydration pattern, with heat curves that are similar to Portland Cement.

Calorimetry: In-boiler modifications improve early hydration of F ash

Effect of additions on reactivity of a 60% low calcium ash - 40% Portland cement blend at 23 C



Effect of additions on total energy (60% fly ash) as a proxy for potential strength development rate



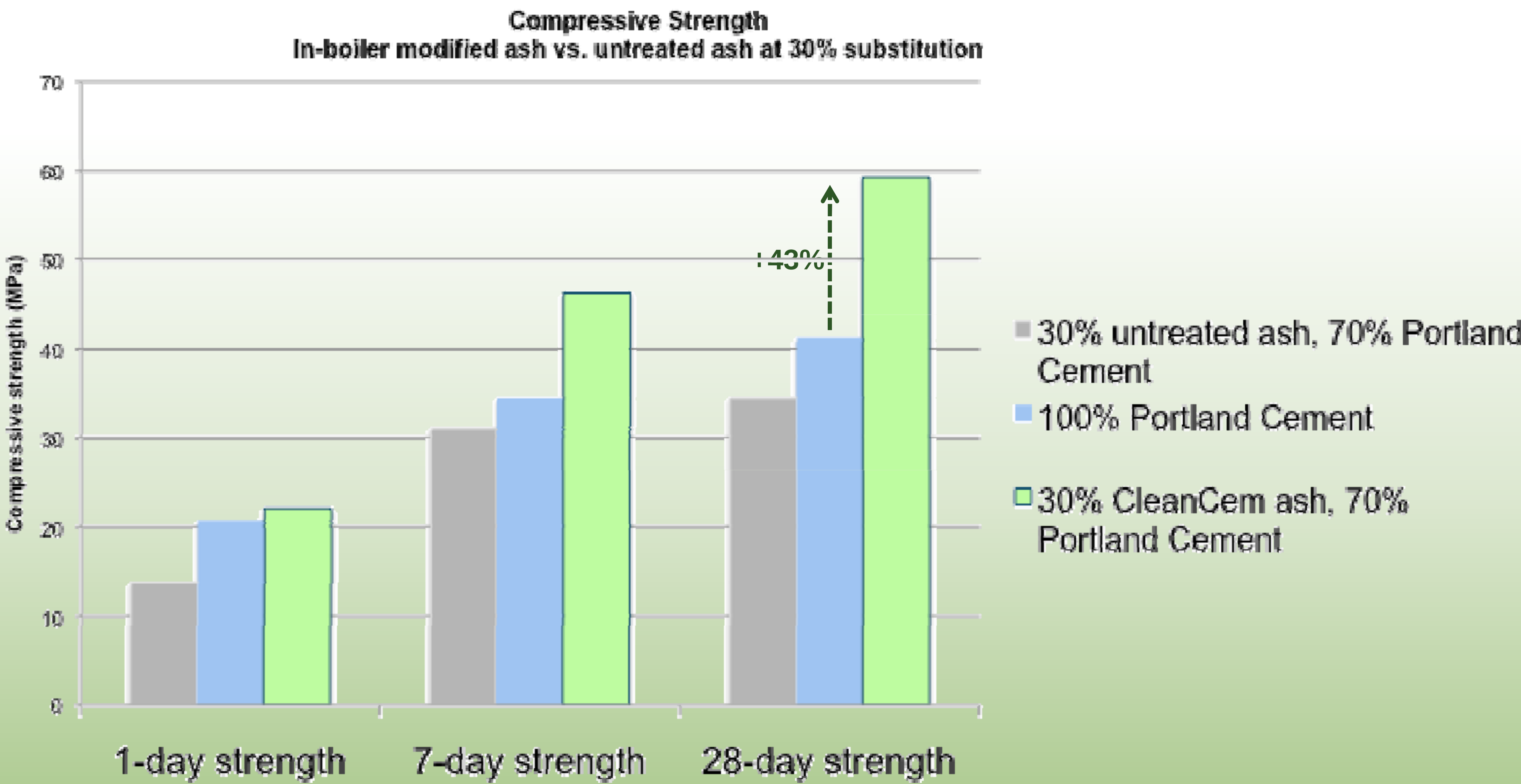
Results from recent full scale field trial in India

- The main target of the trial was to explore if in-boiler modification could reduce un-burned carbon and thereby improve on color
- Approx 2 hrs set acceleration and strength enhancement as well as improved compatibility with PCE seen as secondary improvements.
- Key result was a 50% reduction in un-burned carbon, a lighter colored ash, and a 5% improvement in boiler efficiency

Caution: Many local coal sources in India has very high ash content and are thereby difficult to use to generate good quality ash. We do not expect such drastic performance enhancement for the average US or EU class F-ash

Performance: Sub-bituminous coal: superior compressive strength at 30% replacement …

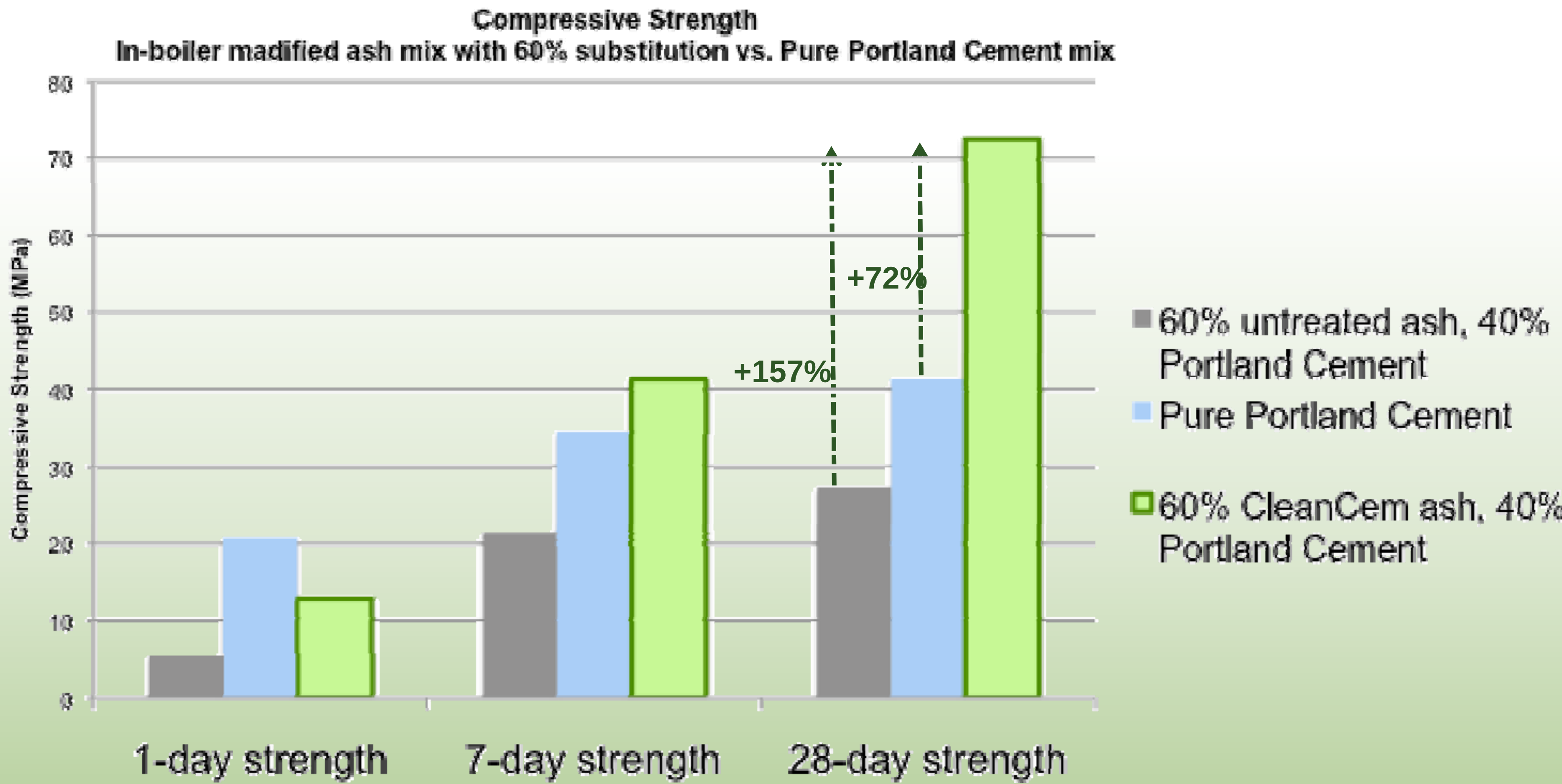
Strength development of mortar with **30%** In-boiler modified ash vs. untreated ash and pure Cement



Performance Testing made at Clarkson University (NY) and University of Texas, Austin

… and at 60% cement replacement

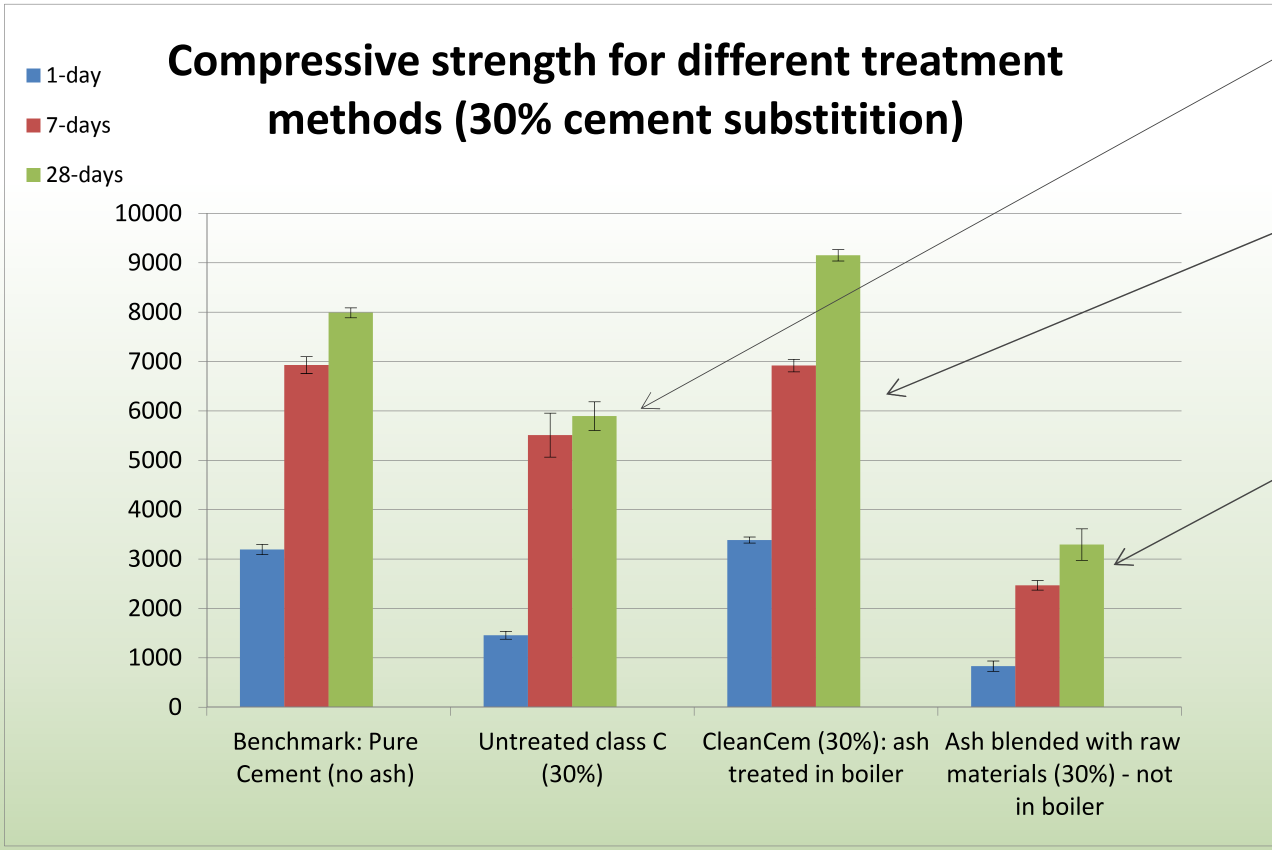
Strength development of mortar with **60%** In-boiler modified ash vs Portland Cement mix and untreated ash



Performance Testing made at Clarkson University (NY) and University of Texas, Austin

The CleanCem process: is heat necessary?

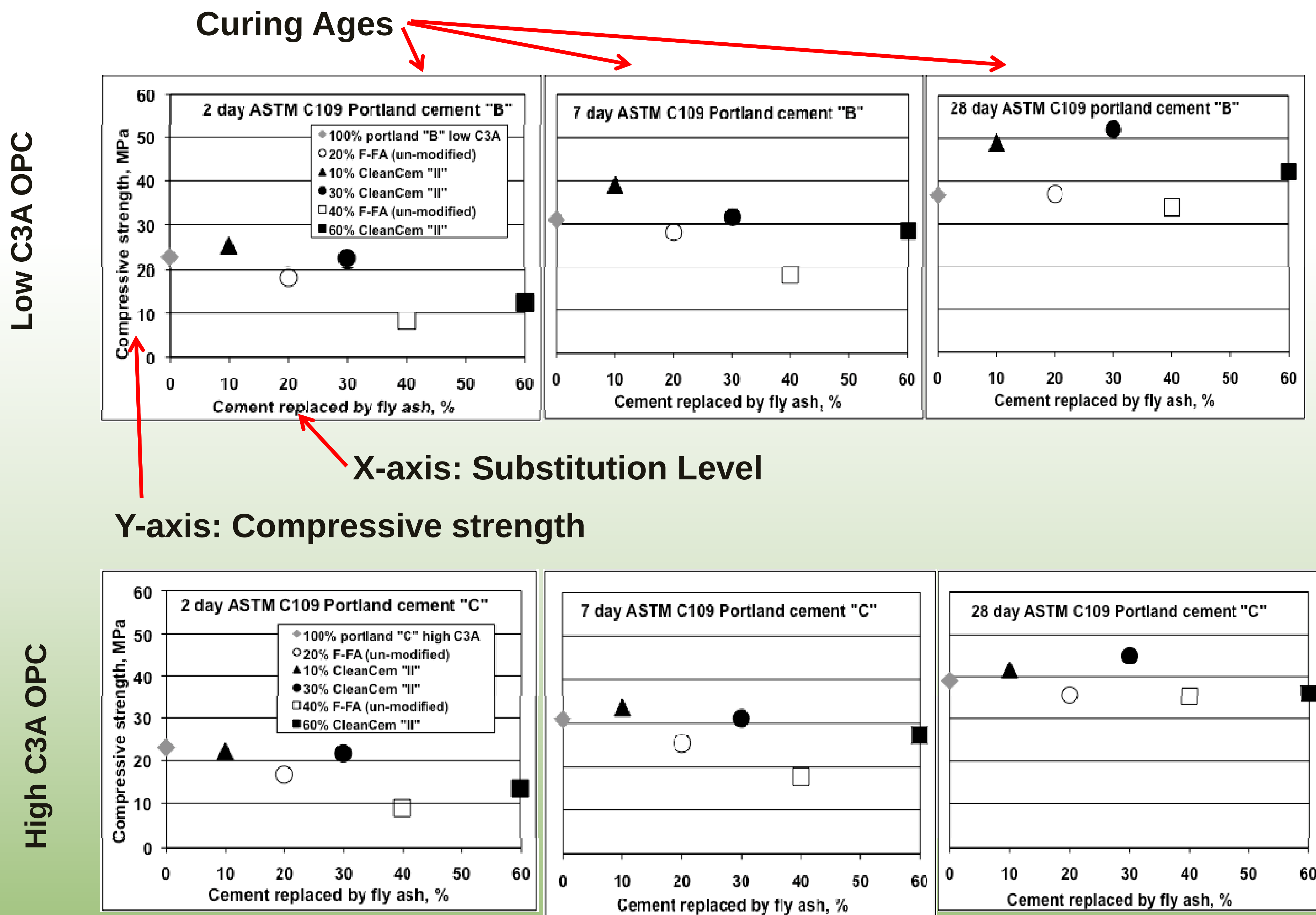
Could the Raw Materials used be applied without heat treatment, as a cold blend with ash?



- Untreated ash has insufficient early strength gain (barely sets at 1-day)
- CleanCem treated ash (in boiler) has the best performance, even better than pure Portland Cement
- Ash that is cold-blended with raw materials used in the CleanCem process has a very poor performance across the board

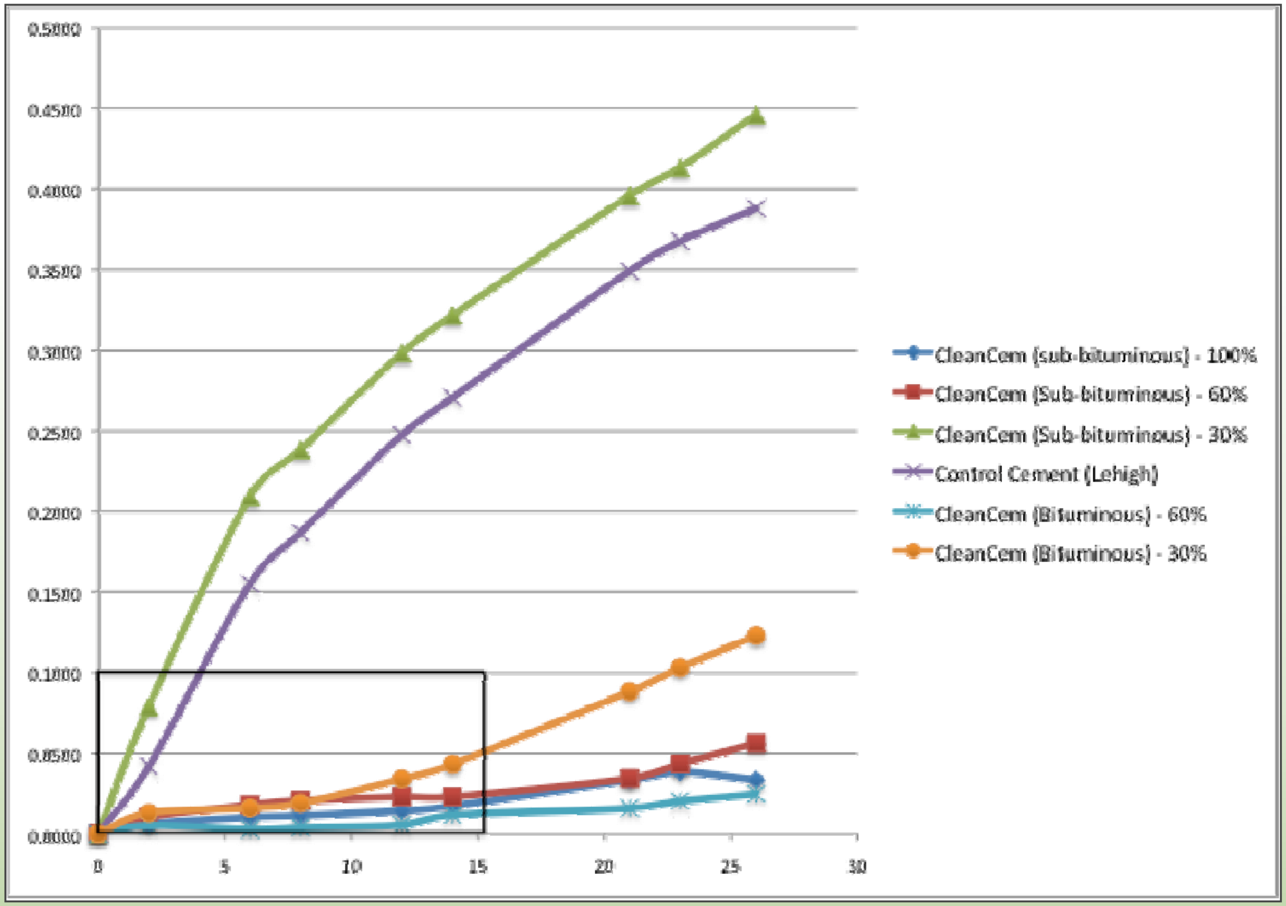
Conclusion: High temperature treatment is essential for the process to work. A raw material- ash blend alone is ineffective, and even detrimental to compressive strength.

Robustness: In-boiler modification yields superior strength across cements: low C3A to high C3A



Better Durability: ASR testing

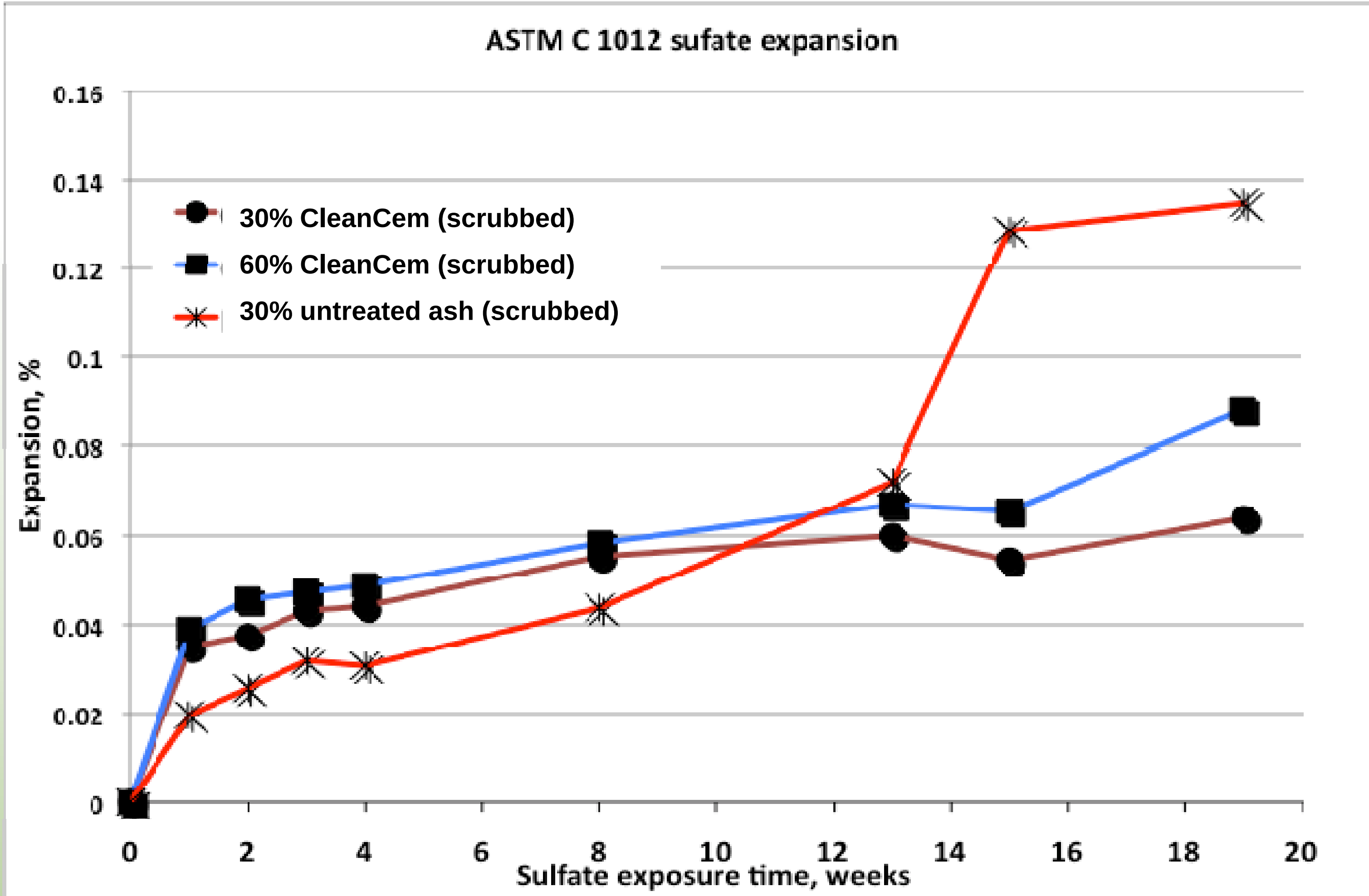
ASR Expansion (ASTM C1260)



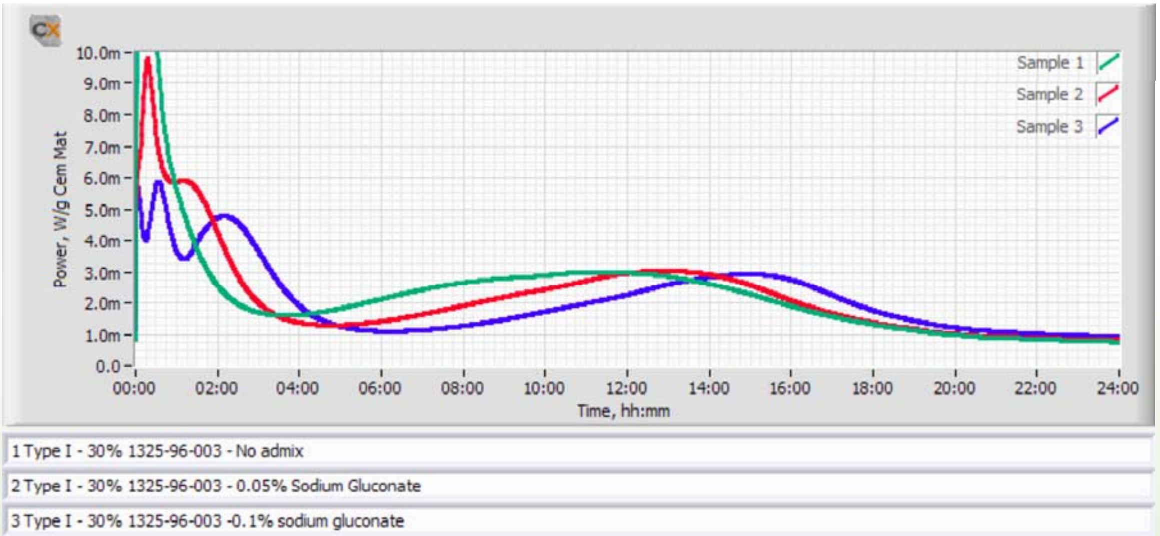
- Durability of in-boiler modified ash from Sub-bituminous coal (30% substitution) acts similar to OPC
- All in-boiler modified ashes exceed OPC performance at higher substitution rates (40%+)
- Potential to use in-boiler modified ash at higher substitution rate creates advantage over traditional ashes (especially C-ashes)

Drastically improved strength development at 60% substitution allows for much higher replacement levels than today. This in turn results in drastically improved ASR control relative to most untreated C ashes

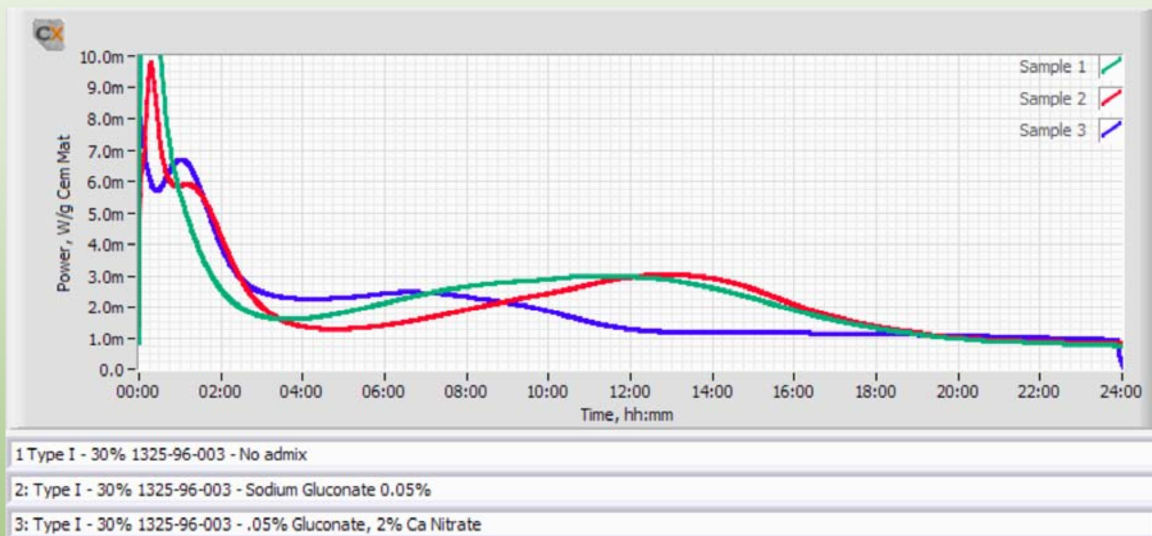
Durability: Sulfate resistance



Calorimetry tests: Admixture compatibility



Effect of sodium gluconate at 72 F



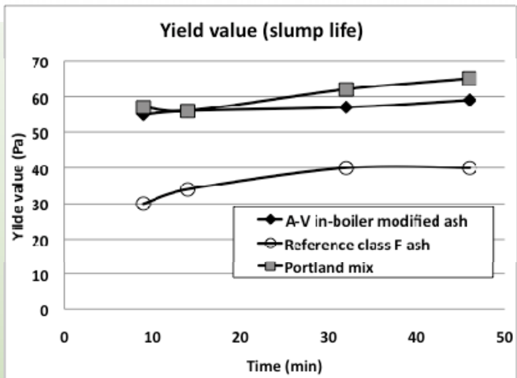
Effect of sodium gluconate + Calcium nitrate At 72 F

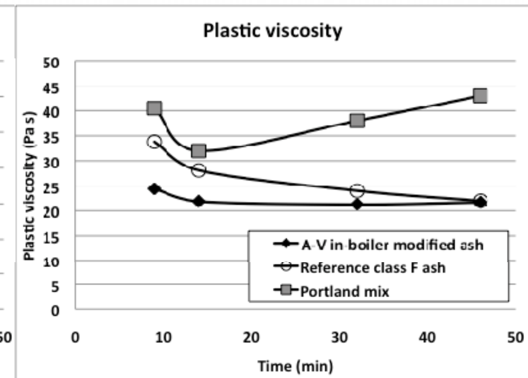
Ecocrete: Flowable concrete with less binder

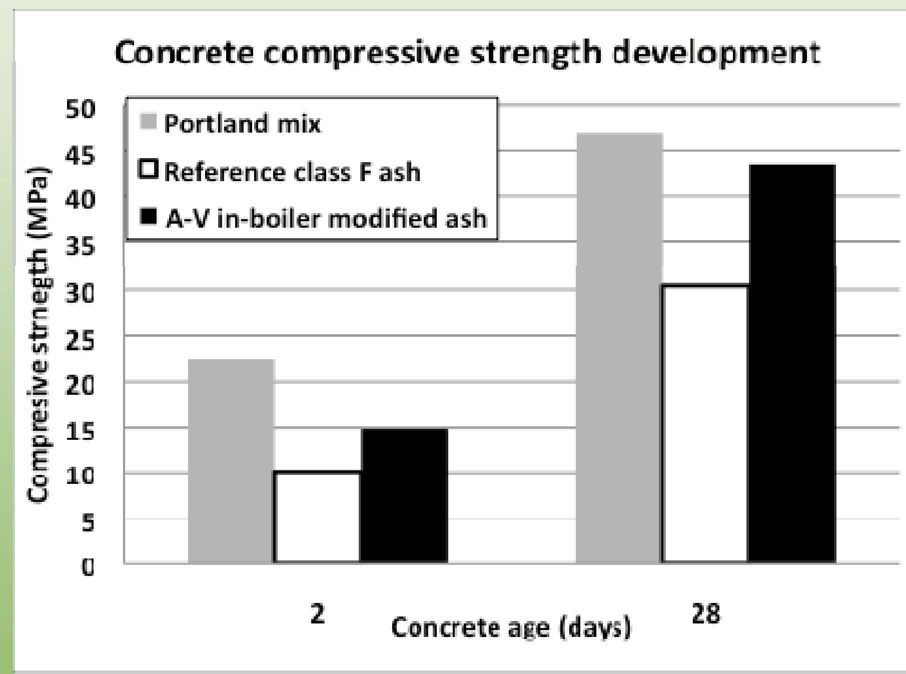
Ecocrete is a low-binder flowable concrete concept developed by Wallevik on Iceland

Details of EcoCrete concrete mixture designs tested

Materials, kg/m^3	Portland mix	Reference ash mix	A-V (modified ash)
Portland cement "D"	315	215	215
Reference class F ash	0	100	0
A-V in-boiler modified ash	0	0	100
Water	185	185	185
Sum binder	315	315	315
w/c-ratio	0.59	0.59	0.59
Fine aggregate 0-8 mm	1320	1301	1301
Coarse granite aggregate 8-16 mm	513	506	506







Conclusion: AIT process enables higher substitution rates, cost-effectively

Conclusion – AIT CleanCem is a comprehensive process to:

- Improve reactivity – enables higher cement substitution rates (60% or more)
- Improve durability
- Reduce LOI

… AND ALL THIS IN A COST-EFFECTIVE, LOW CAPITAL WAY

- No separate treatment facility, no added transportation costs
- Sorbents derived from other waste streams
- No new QC requirements – use as you would use ash or cement today

http://www.aitcleancem.com

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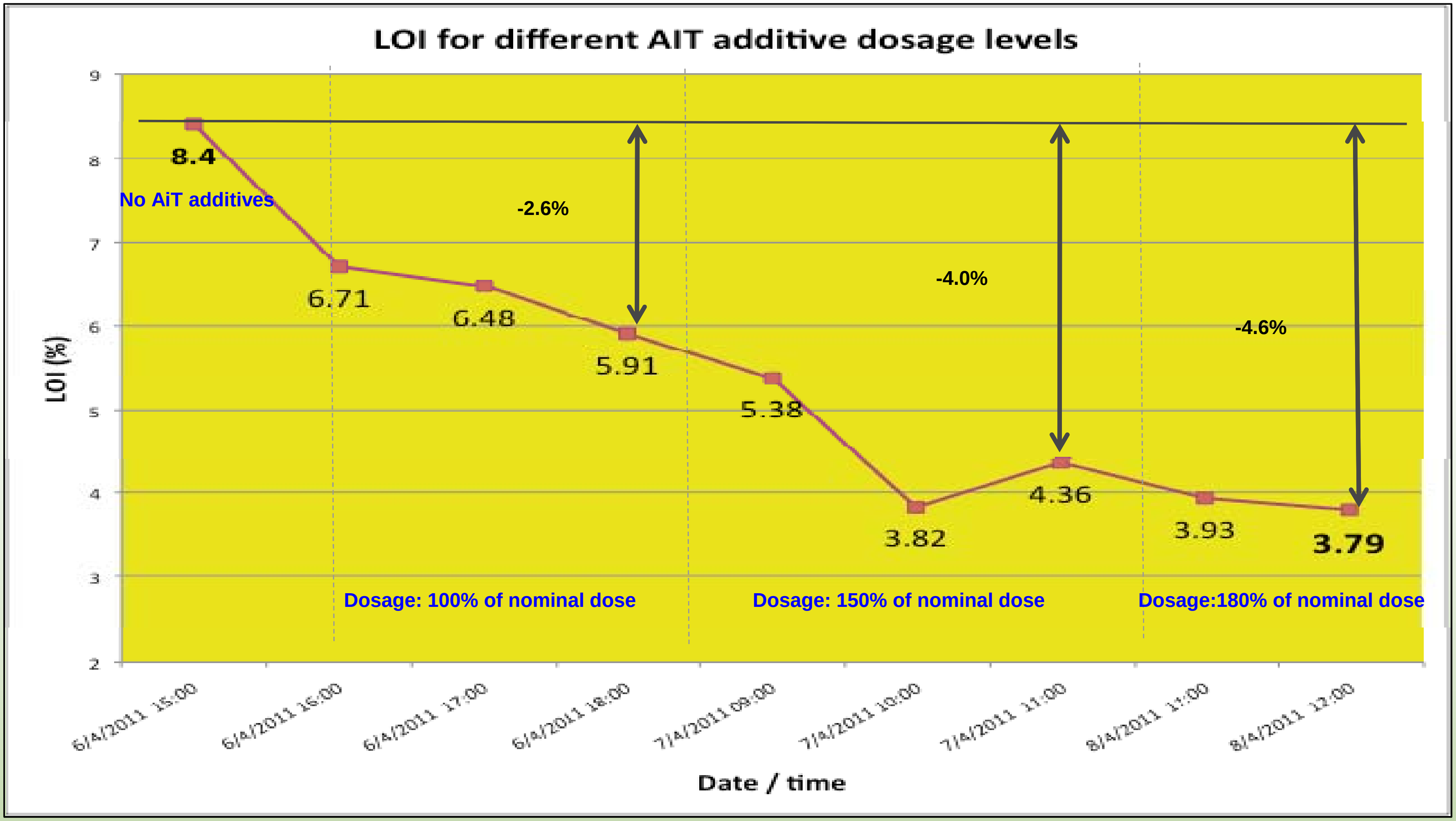
Appendix

Indian industrial trial: Impact of in-boiler modification process on LOI



Conclusion:

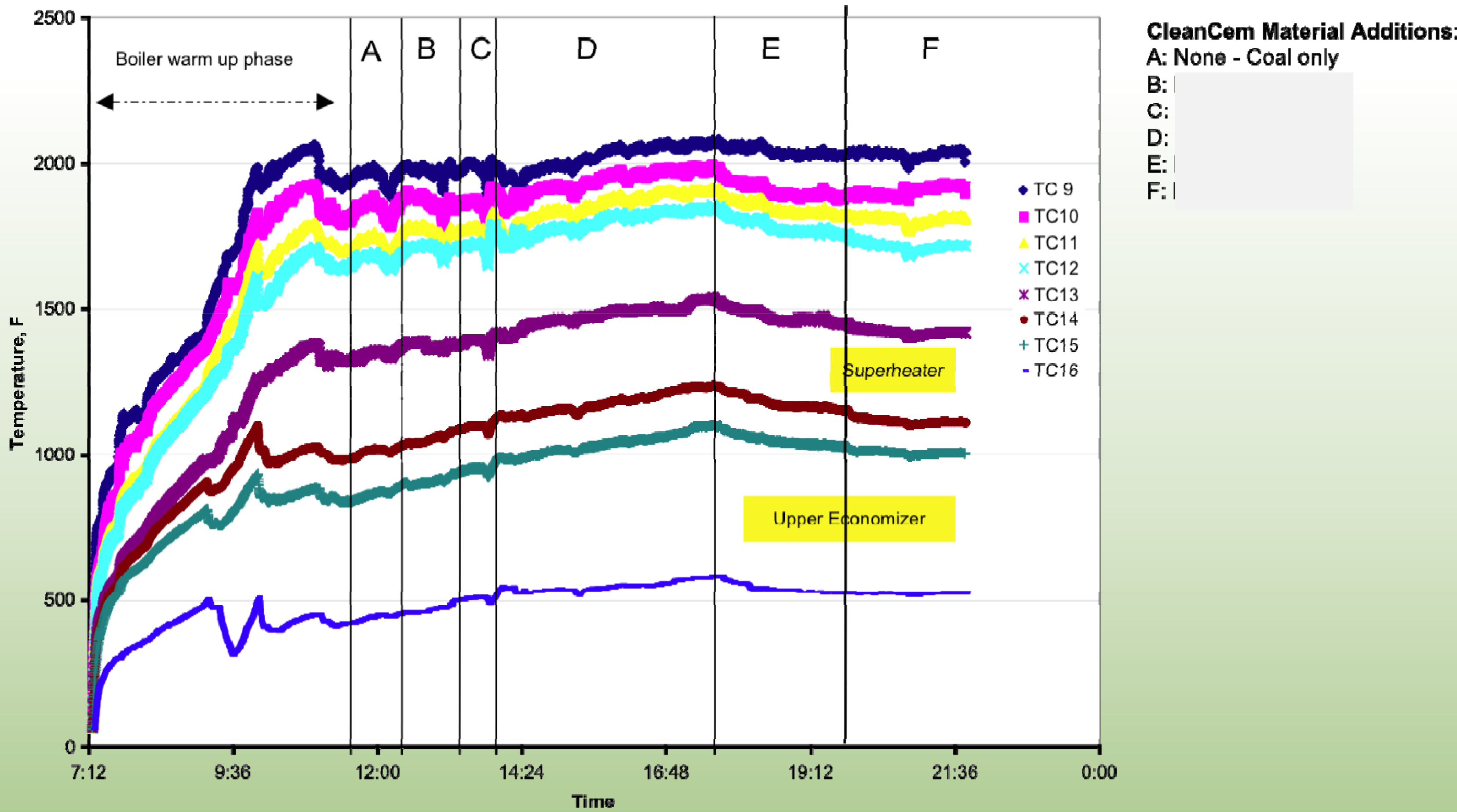
There is a direct relationship between LOI reduction and AIT material dosage.

The AIT process brought LOI down from 8.4% to 3.79% as dosage of AIT additives gradually increases.

Boiler efficiency is not affected

In solid fuel incineration processes, boiler efficiency is not affected: boiler temperatures stay constant at equal coal input as materials are added to the boiler

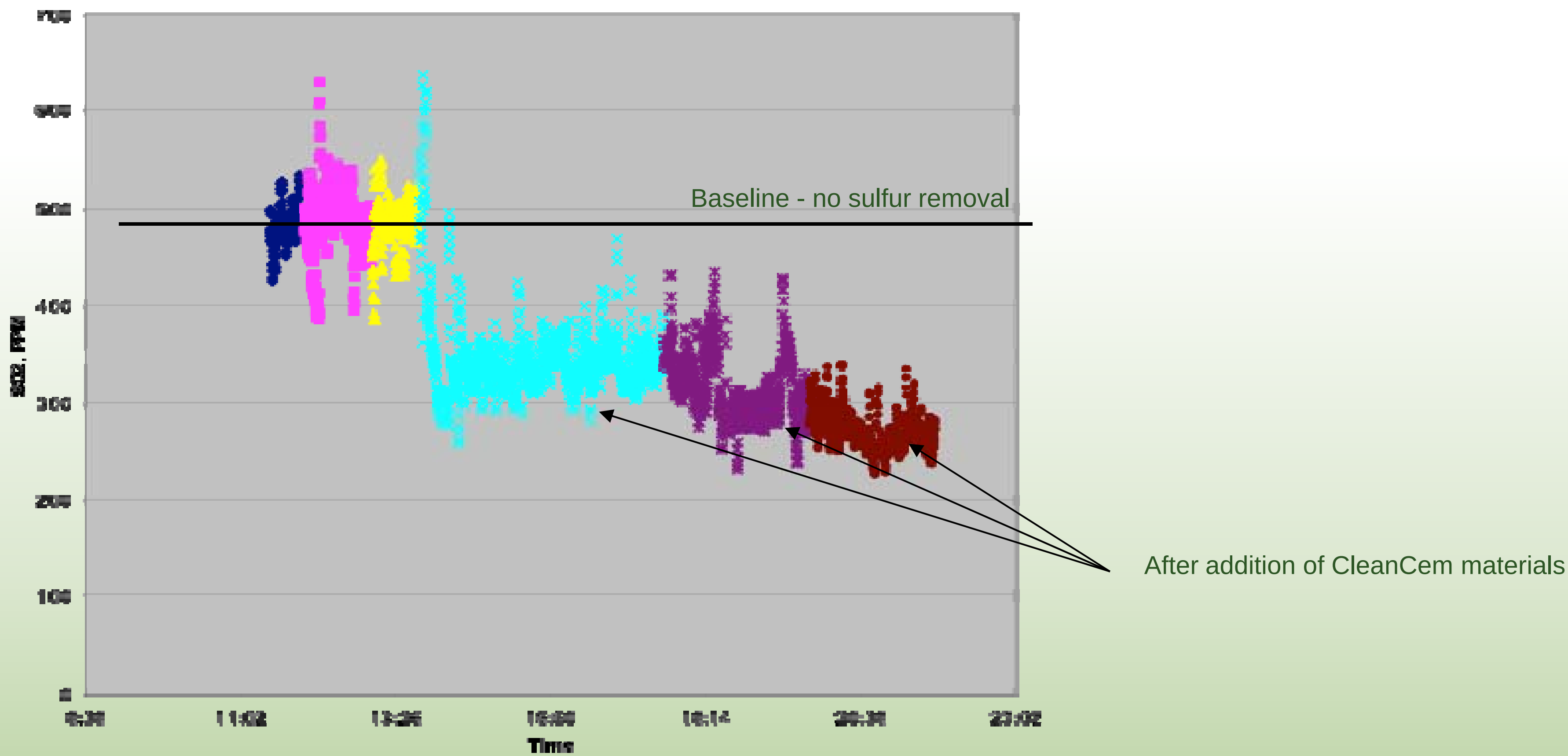
Boiler temperatures measured at different stages during material addition



SOx control is improved

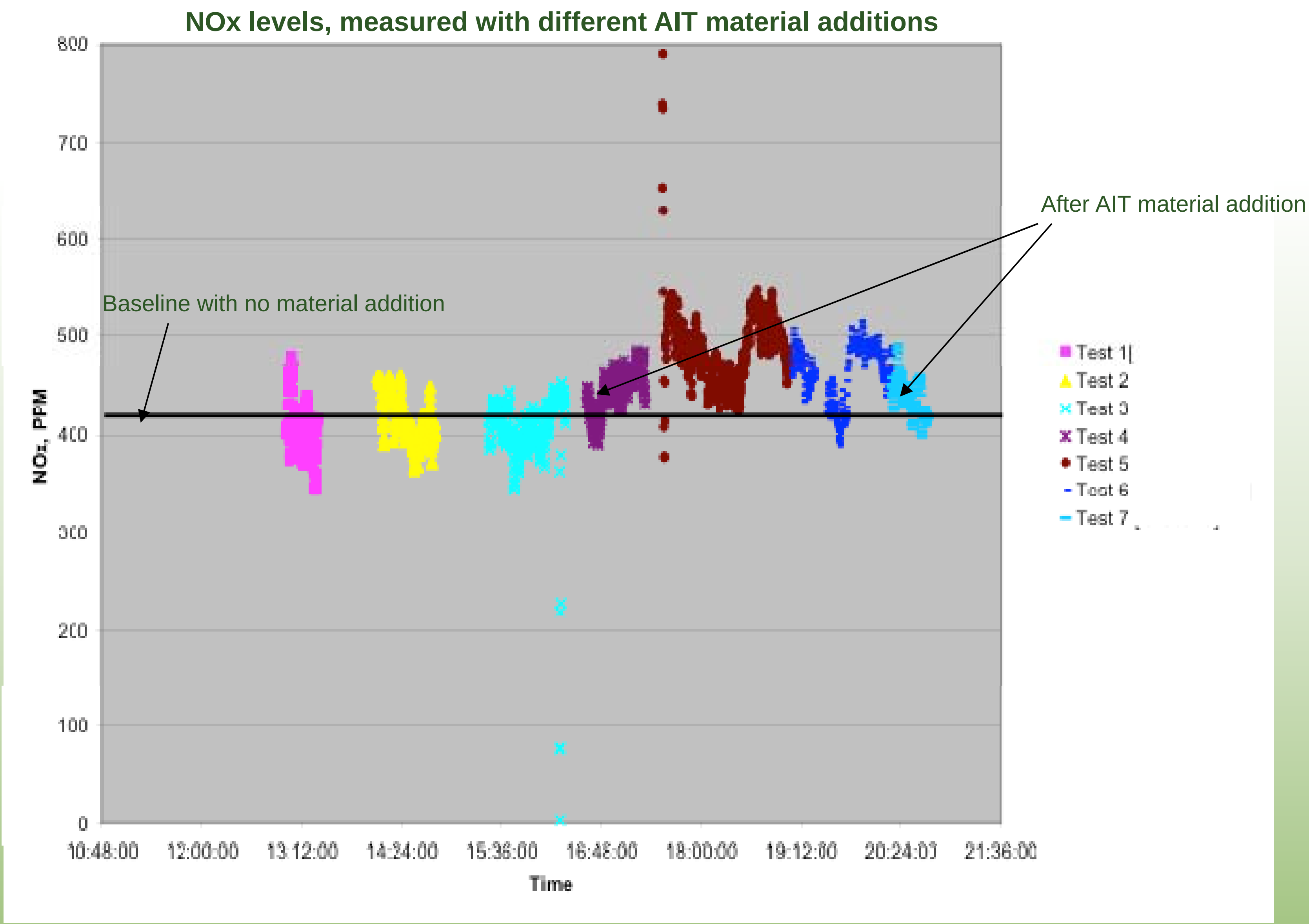
Materials added in the process have a favorable effect on SOx reduction (40% SOx reduction)

SO2 levels, measured with different AIT material additions



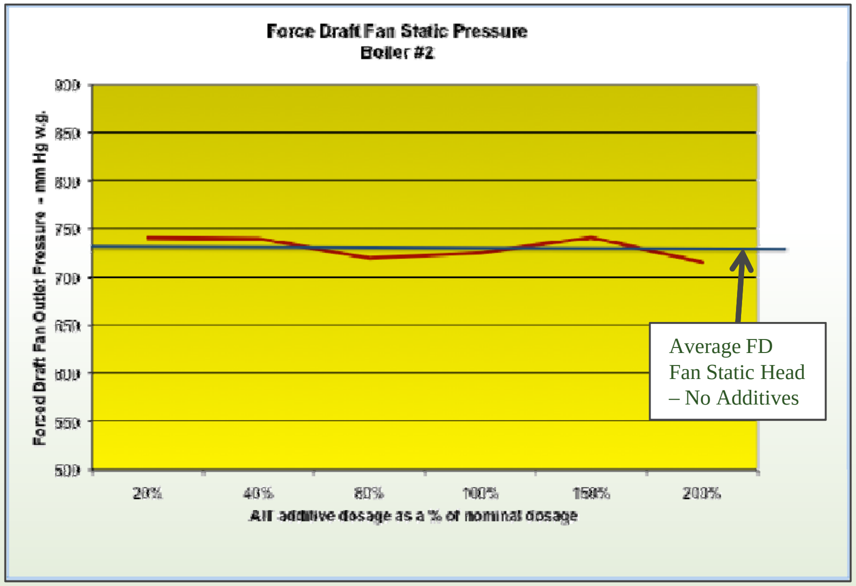
No negative impact on NOx Control

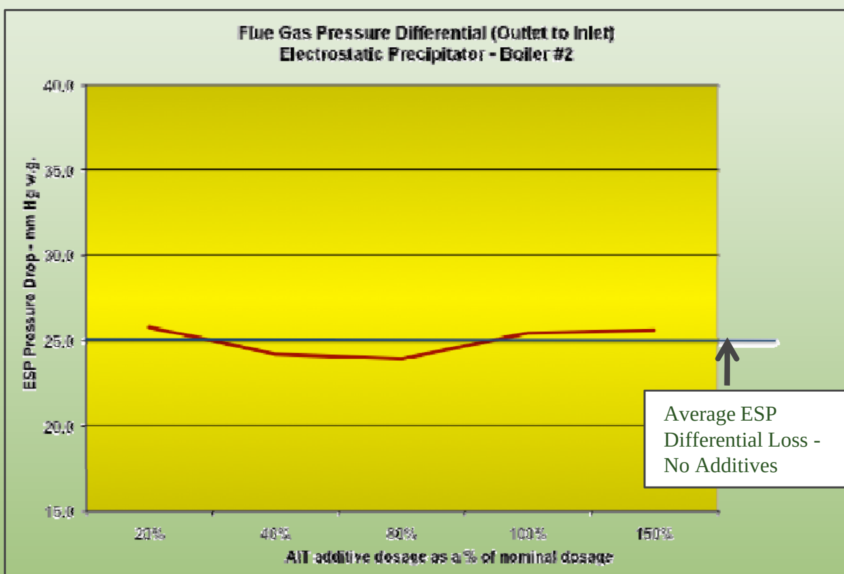
Materials added in the process have a neutral effect on NOx control



The impact of in-boiler modification on boiler operations

Operational data was monitored throughout the duration of a full scale industrial trial in India





Main observations:

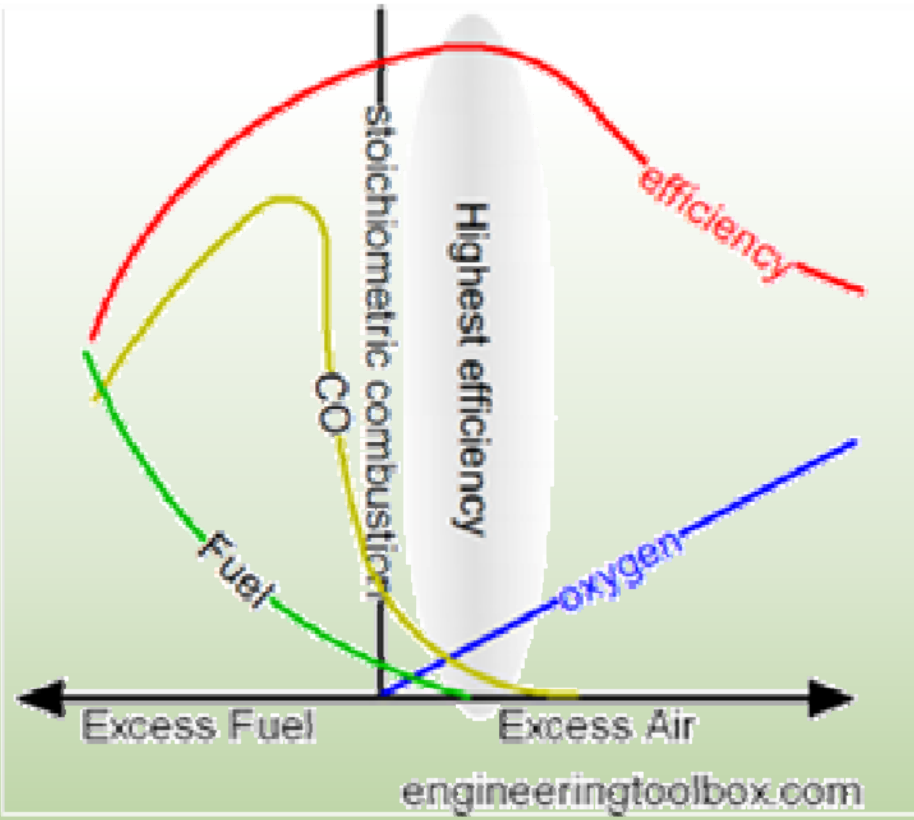
- There was no statistically significant impact on the boiler draft system as a result of injection of additives
- Air flow to the boiler bed was not a problem
- Flue gas pressure drop across the electrostatic precipitator only increased a 0.5 mm Hg at high injection rates
- Induced Draft fan horsepower increased by a maximum of 4 amps (less than normal variations observed in the absence of AIT additive)

Conclusion: Additions to the boiler did not induce any negative impact on normal boiler operation

I.D. Fan – Boiler #2

A more detailed method to measure the impact on LOI

In order to measure the impact of the AIT process, we have to isolate other variables that influence combustion and LOI



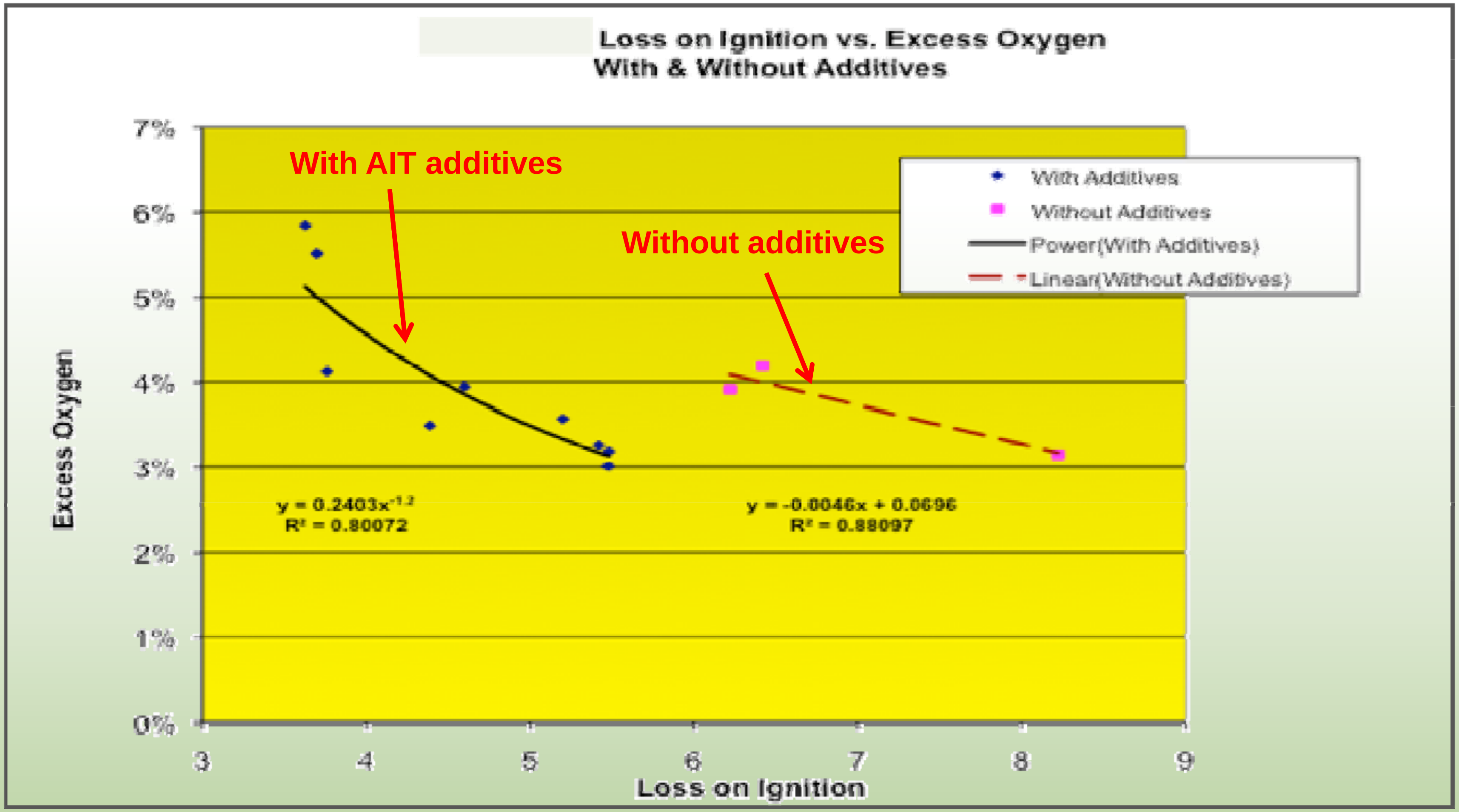
The lowest LOI is achieved at higher efficiencies. AIT's process has an impact on LOI and boiler efficiency.

As shown in the graph on the left, boiler efficiency also depends on carbon monoxide (CO) and oxygen (O_2) levels.

Hence, the precise impact of AIT material injection has to be measured at constant CO levels and constant O_2 levels.

LOI – apples to apples: Impact on LOI at constant oxygen

Impact of In-boiler modification on average LOI isolating Oxygen levels as an independent variable

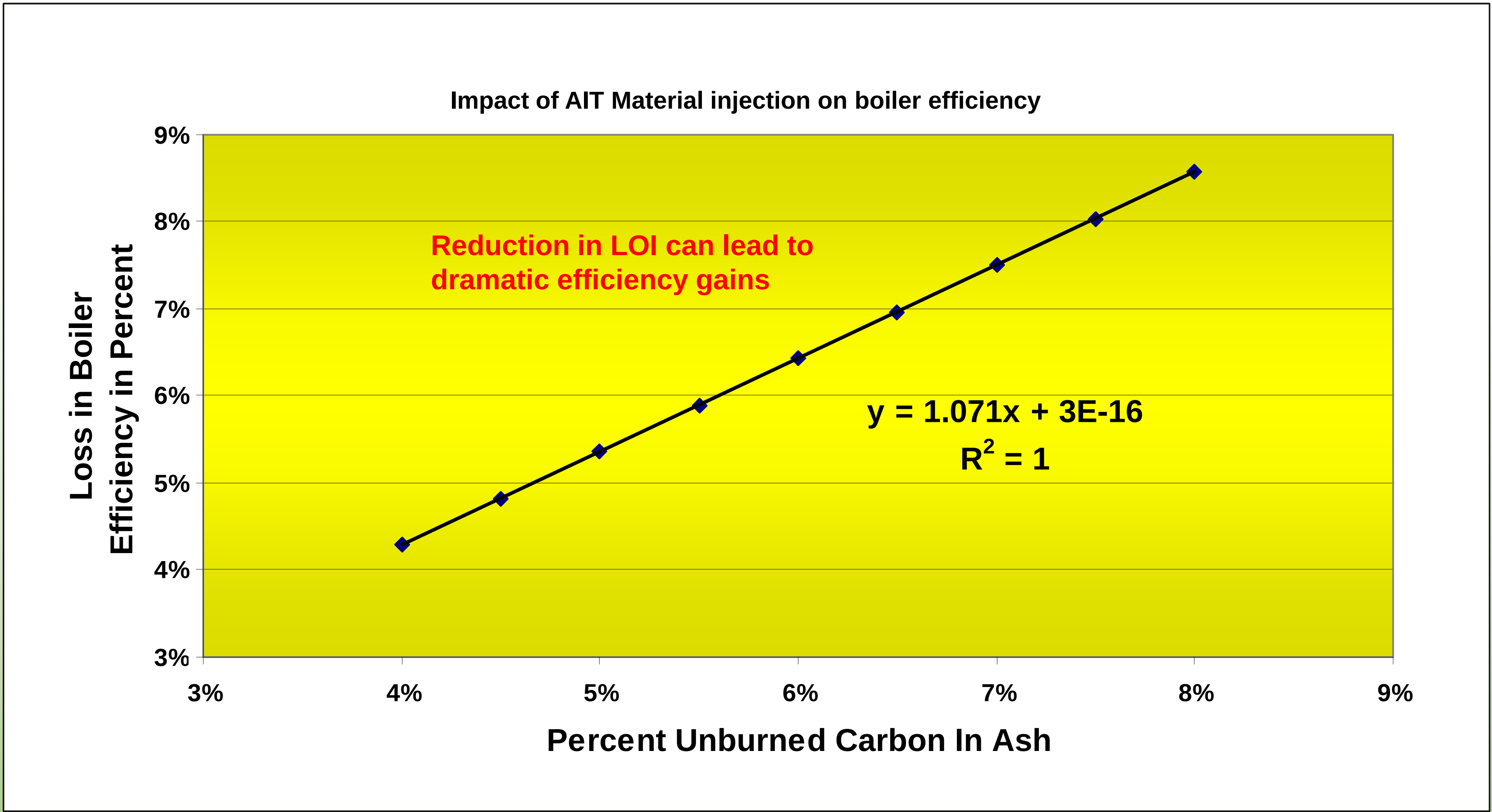


Conclusion:

At constant O_2 levels in the boiler flue gases, the injection of AIT materials at target levels (80% to 150% of nominal dosage) consistently lowers LOI by ~3 percentage points

Boiler Performance: In-boiler modification improves efficiency

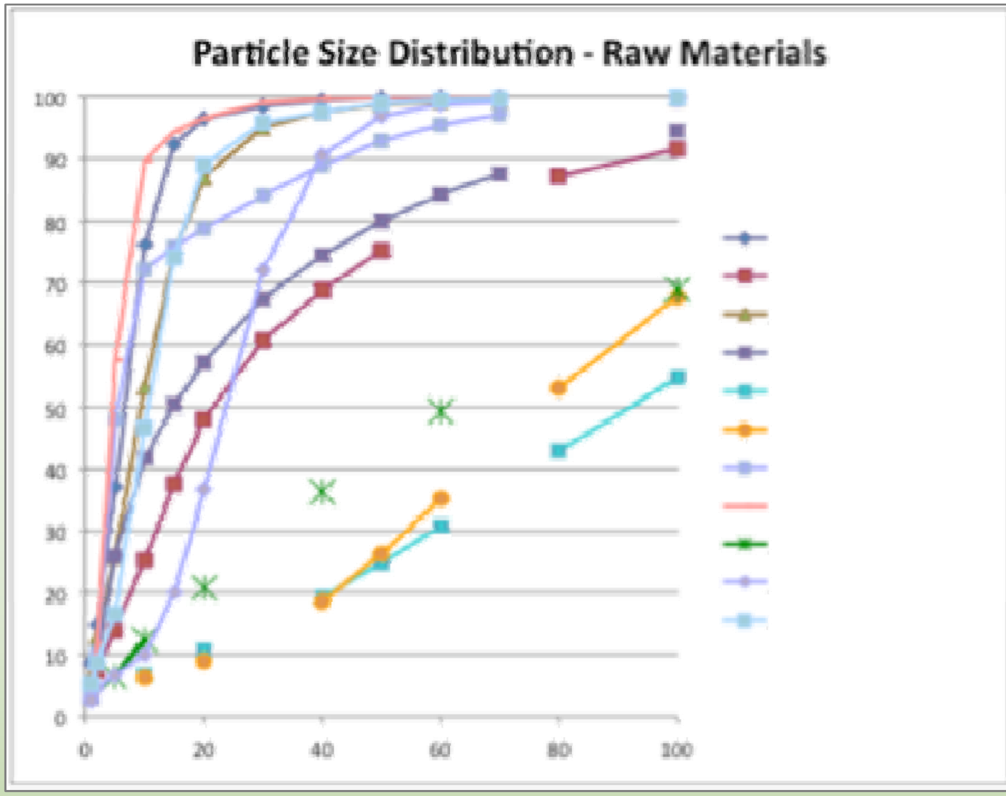
In-boiler treatment to reduce LOI leads to efficiency gains. Post boiler treatment doesn't



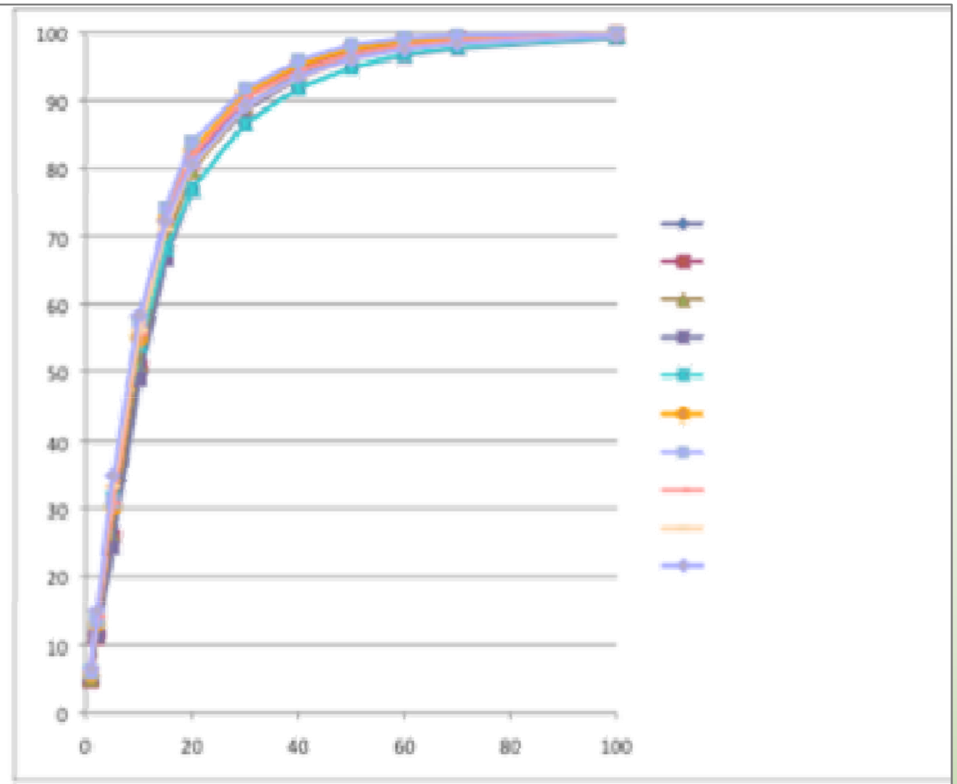
Due to the high ash content of Indian coal (46%) unburned carbon in ash has a dramatic impact on boiler efficiency

How it works: Particle size – Grinding effect

Particle sizes: Raw Materials



Particle sizes: Finished Product



Careful choice of raw material PSD and injection point yields a consistent, finely ground finished product

ASTM C151 soundness results for two in-boiler modified ashes

In boiler modified ashes passes demanding soundness test

From bituminous coal → 1325-96-003

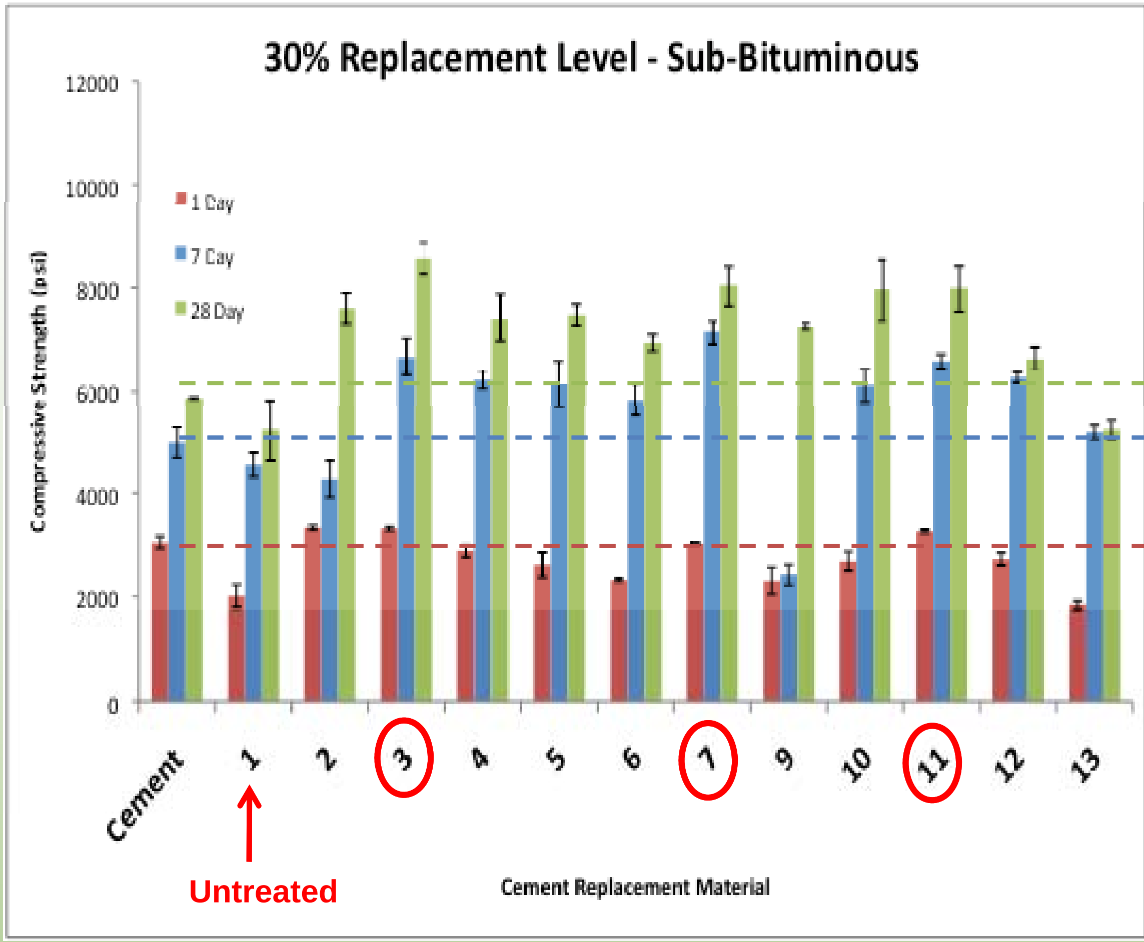
From sub-bituminous coal → 1325-79-006

Sample ID:	Soundness, ASTM C151 Autoclave Expansion (%):
1325-96-003	0.00
1325-79-006	-0.03
ASTM C 618-08 Specifications	
Class F	Max 0.8
Class C	Max 0.8

Robustness: Effect of material dosages / injection points

CleanCem efficiency with different material dosages / injection points (30% replacement level)

Test #	Sorbents / Materials added						
	KA	ST	BE	GL	LE	SI	TI
1	UNTREATED ASH (SCRUBBED)						
2	✔						
3	✔	✔					
4		✔					
5	✔		✔				
6			✔				
7	✔			✔			
9	✔	✔	✔				
10		✔	✔		✔		
11	✔	✔	✔		✔		✔
12	✔	✔	✔			✔	
13	✔	✔	✔			✔	✔



100% Portland Cement – 28-day strength

100% Portland Cement – 7-day strength

100% Portland Cement – 1-day strength