

## Considerations on Valorization of Biomass Origin Materials in Co-combustion with Coal in Fluidized Beds

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**Objectives**

**Experimental facility**

**Fuel characterisation**

**Operational conditions**

**Results**

**Temperature profiles**

**Pollutant emissions**

**Ash production**

**Ash leachability**

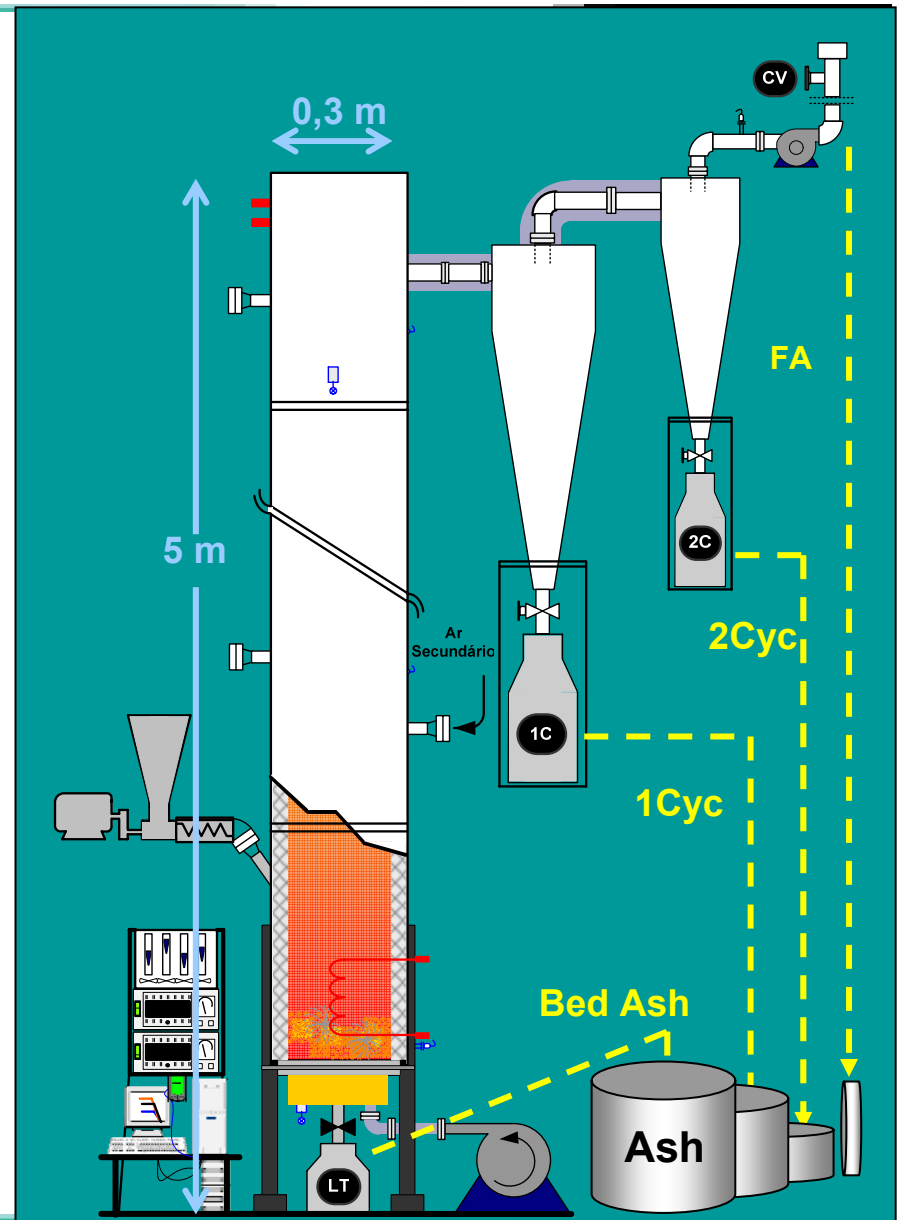
**Conclusions**

## Objectives:

1. The identification of techno-economic barriers to the utilisation of biomass and other wastes as energy source from either plantation or waste lands to its final use
2. The analysis of adequate fuel preparation system to achieve the synergy in fuel mixes to be prepared for energy processes
3. The characterisation of the wastes available to determine their potential for synergy in fuel mixes to be prepared with a particular attention given to its reactivity, ash composition and ash fusion point
4. The understanding of the combustion of fuel mixes in fluidised beds with the aim of determining the limits of optimized synergy for efficiency.
5. The understanding of ash behaviour during the combustion to determine synergy required in the fuel mix preparation to minimize the tendency to slagging and fouling
6. The determination of the levels of the pollutants resulting from the co-firing system and definition of conditions for synergy of different components in the fuel to minimise the emissions of potential pollutants to the atmosphere
7. The analysis of ashes produced during co-firing with the aim of their re-utilisation
8. Based on the results, the evaluation of co-firing for energy production in an economically acceptable manner by closely analysing the costs involved and the potentials to reduce costs

## INETI - Fluidized Bed Pilot

- ✓ Refractory Steel
- ✓ 5 m high
- ✓ Square cross section 0.3 x 0.3 m
- ✓ External insulation
- ✓ Water coil refrigeration
- ✓ Bed material-Sand
- ✓ Air Staging between bed and freeboard
- ✓ 2 Cyclones for fly ash separation
- ✓ Sampling Probes along the Reactor for gas measurements
- ✓ Sampling Probes in the stack for particles, metals, HCl and PCDD/F
- ✓ Computerized Control (T, P, air and Fuel flow)





## Fuels Characterization

Proximate Analysis (ar, %wt)	Coal		Biomass		
	Cerejon Coal	Polish Coal	MBM	Olive Cake	Straw (pellets)
Moisture	9.3	4.7	3.2	7.9	9.1
Ash	11.4	10.5	37.3	4.9	6.3
Volatile Matter	33.6	31.5	54.1	70.6	68.5
Fixed Carbon	45.7	53.3	5.4	16.6	16.2
Low Heating value (ar, MJ/kg)	28.0	29.3	14.5	19.1	16.5

Different compositions:

**Ash** – wastes and biomass may present different levels of mineral matter, but composition is determining factor for slagging and fouling (under study).

**VM** – higher in biomass – different combustion patterns – influence pollutant formation and burn-out efficiency.

**Heating Value** – lower in biomass and residues because of higher ash or oxygen.

## Fuels Characterization

Elemental Analysis (db, %wt)	Coal		Biomass		
	Cerejon Coal	Polish Coal	MBM	Olive Cake	Straw (pellets)
C	66.4	69.5	32.2	46.6	41.7
H	4.7	4.8	5.0	6.4	6.2
N	1.4	1.2	8.2	1.0	0.7
S	1.0	0.5	0.4	0.10	0.13
Cl	0.07	0.25	0.28	0.31	0.24
Ca	0.23	0.45	13.4	0.29	0.30
Na	0.08	0.08	0.63	0.03	0.03
K	0.25	0.12	0.26	1.62	1.09
P	0.004	0.002	5.0	0.23	0.09

Different compositions:

**C – lower in biomass and wastes. – LHV is lower. N – higher in wastes.**

**S – lower in biomass. Cl – high levels in wastes and biomass and also in coal.**

**Minerals (Ca, Na, K, P) – high in wastes and biomass – influence pollutant formation and slagging and fouling behaviour.**

## Fuels Characterization

Heavy Metals (db, %wt)	Coal		Biomass		
	Cerejon Coal	Polish Coal	MBM	Olive Cake	Straw (pellets)
As	<10	<10	<10	<10	<10
Cd	<0.5	<0.5	<5	<0.5	<0.5
Cr	13.8	29.8	<10	<1.0	5.2
Cu	7.9	11.2	4.1	1.1	2.9
Hg	0.048	0.110	0.025	0.004	0.018
Mn	47.1	108	<10	0.8	19.3
Ni	8.5	30.9	<10	<1.0	4.5
Pb	<1.0	12.0	<10	<1.0	<1.0
Zn	6.5	27.2	97.5	0.9	6.5

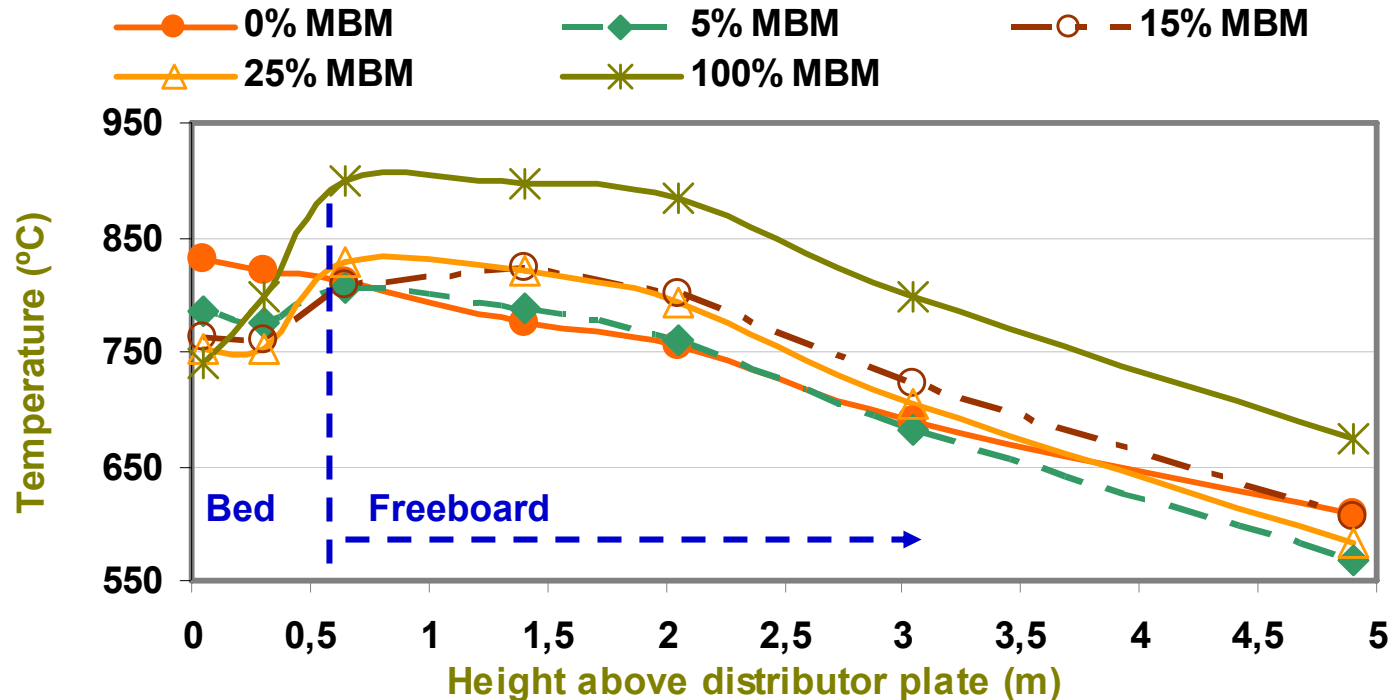
Different compositions:

**Heavy metals content is generally higher in coals.**

## Operational Conditions

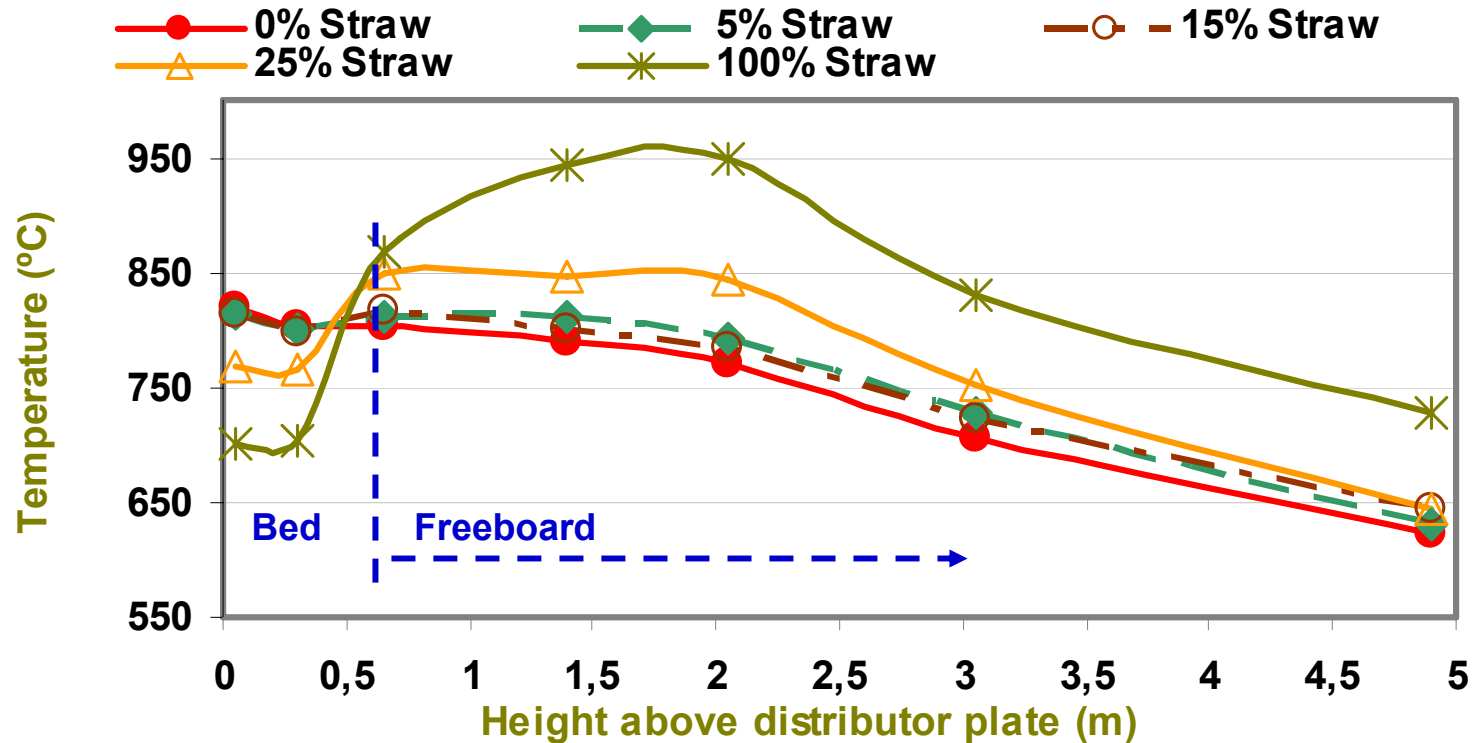
Fuel Blend:	PCoal+Straw / CCoal+MBM / CCoal+OliveCake				
Coal Fraction:	100%	95%	85%	75%	0%
Excess air (%)	35/40/40	31/40/40	36/40/35	31/39/35	52/83/45
Secondary air (%)	18/20/20	20/20/25	21/21/25	23/26/25	35/46/35
Bed veloc. (m/s)	1.0/1.0/1.0	1.0/1.0/0.8	1.0/1.0/0.8	0.9/1.0/0.9	0.7/0.7/1.0
Freeb. veloc. (m/s)	1.3/1.3/1.3	1.2/1.2/1.0	1.3/1.2/1.0	1.2/1.3/1.1	1.1/1.2/1.4
Bed temperature (°C)	818/830/830	813/785/846	813/763/841	769/752/831	701/739/767

## Temperatures profiles – Cerejon Coal / MBM



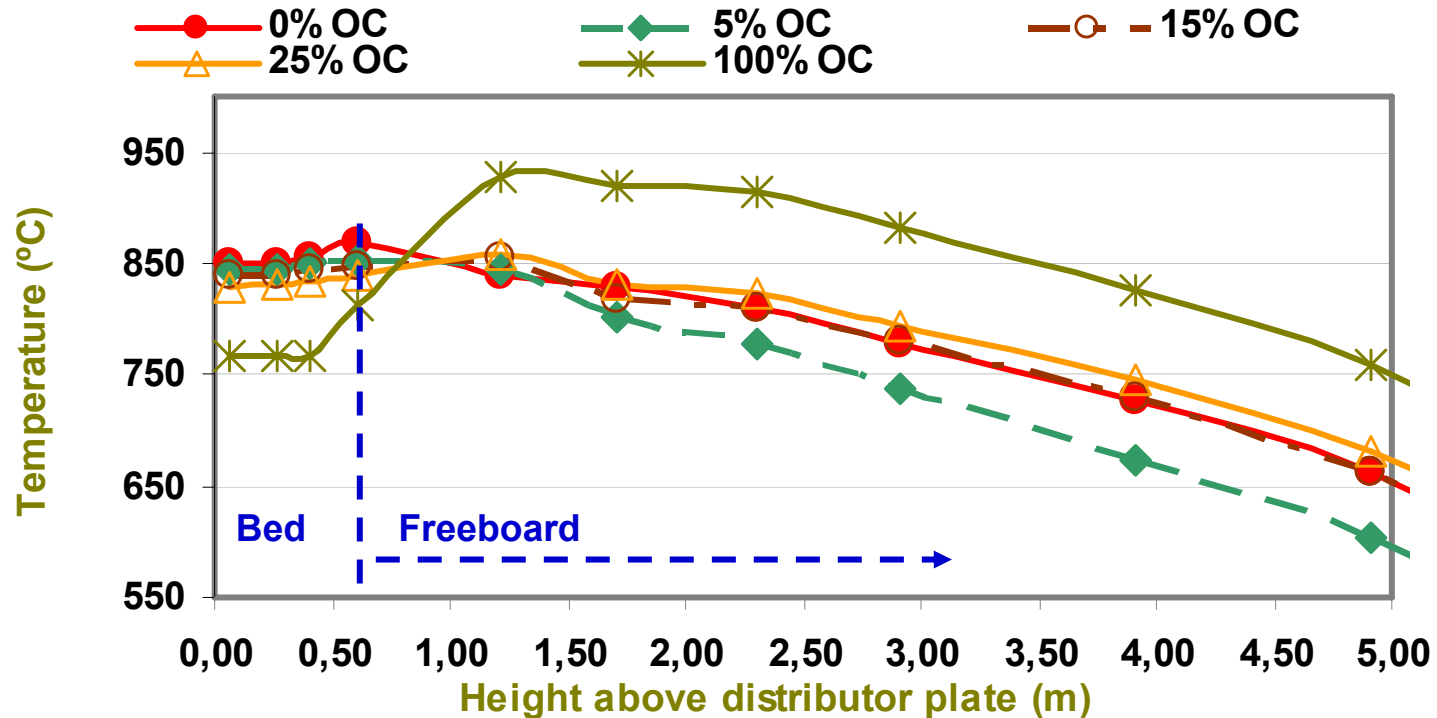
- The bed temperature had to be limited below 750°C to prevent bed agglomeration
- MBM increase the freeboard temperature due to greater extent of VM combustion in the freeboard

## Temperatures profiles – Polish Coal / Straw Pellets



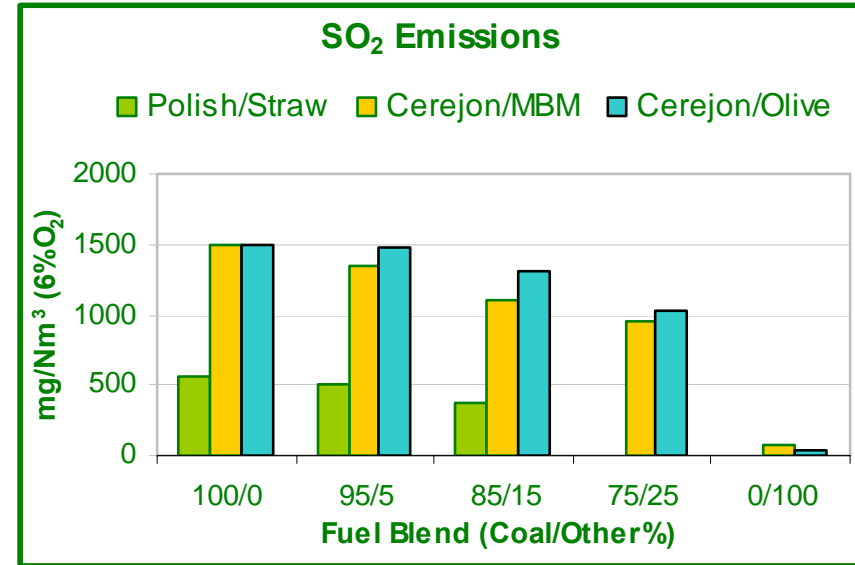
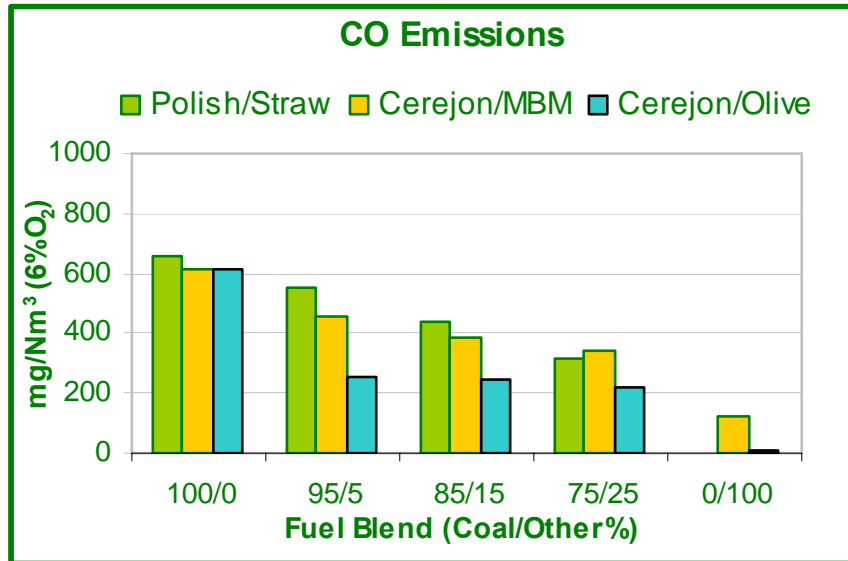
Straw increases the freeboard temperature for the same reason as MBM

## Temperatures profiles – Cerejon Coal / Olive Cake



Olive cake increases the freeboard temperature for the same reasons as MBM

## Pollutant Emissions in a pilot fluidized bed – CO and SO<sub>2</sub>



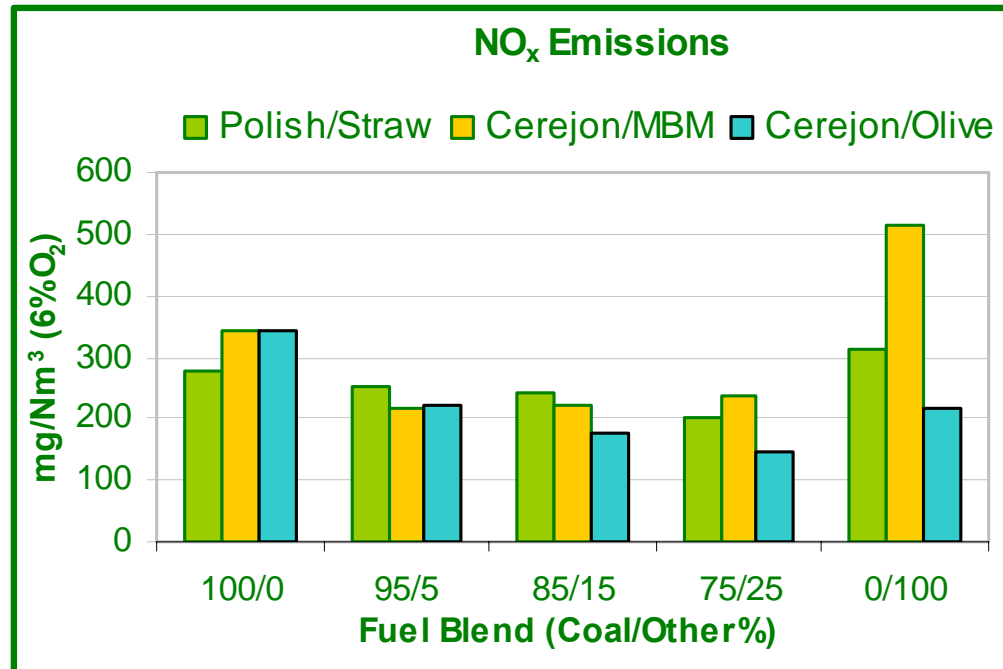
CO decreases with greater amounts of straw, MBM or olive cake addition due to :

- use of secondary air and better mixing;
- higher VM release from secondary fuels;
- extensive VM combustion in the freeboard
- hence greater freeboard temperatures

SO<sub>2</sub> decreases with higher additions of straw, MBM or olive cake due to:

- lower S in straw, MBM and olive cake;
- presence of Ca compounds in MBM;
- lower Ca in the olive cake.

## Pollutant Emissions in a pilot fluidized bed – NO<sub>x</sub>



### Polish/Straw:

NO<sub>x</sub> decreased with greater additions of straw due to lower N in straw;  
 - 100% straw: > excess air;  
 less char inventory in bed  
 and lower gas volume.

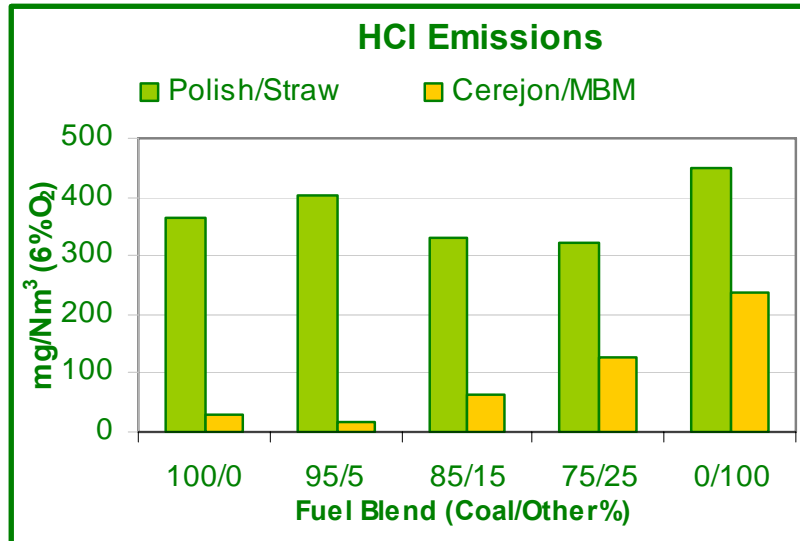
### Cerejon/MBM:

- NO<sub>x</sub> decreased with addition of MBM, although N in MBM is 6 times higher than in coal: fuel-N in MBM may be released as NH<sub>3</sub>, promoting NO reduction in the freeboard where excess O<sub>2</sub> is relatively high and the temperature is above 900°C  
 - 100% MBM: >N-fuel; less char inventory in bed > excess air and lower gas volume.

### Cerejon/Olive cake:

- NO<sub>x</sub> decreased with greater additions of olive cake due to lower N in olive cake ;  
 - 100% olive cake : > excess air; less char inventory in bed.

## Pollutant Emissions in a pilot fluidized bed – HCl and Particulate Matter



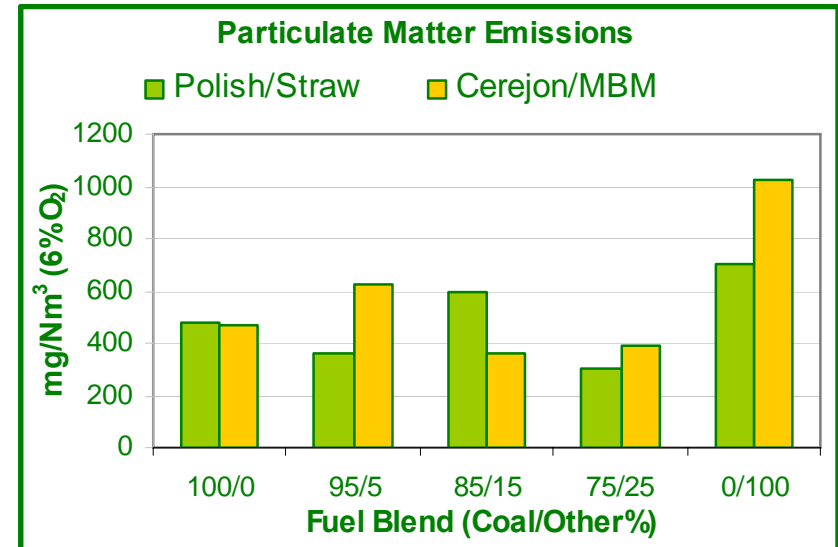
### Polish/Straw:

- small HCl variation
- similar Cl in both straw and coal

### Cerejon/MBM:

MBM addition increased HCl emitted

- higher Cl content in MBM compared with Cerejon
- Ca compounds retained part of Cl.



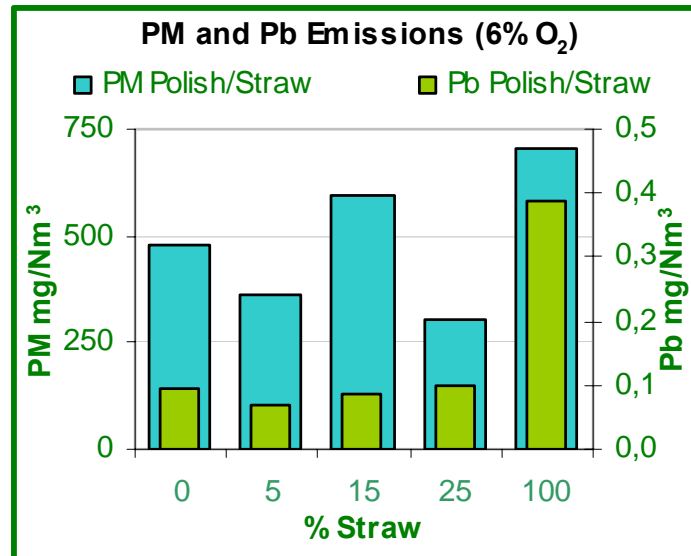
-Particulate emissions: 300 to 600 mg/Nm<sup>3</sup> with the use of only cyclones.

-Variations do not correlate with blend mixture.

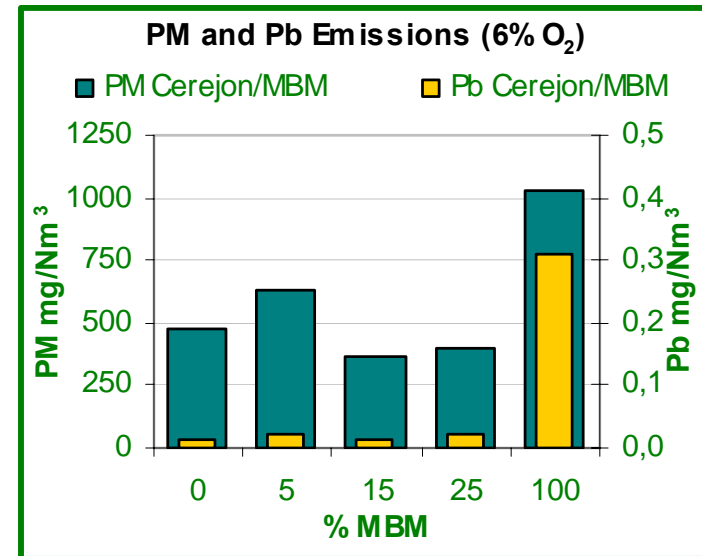
- Higher particulate emission for mono-combustion of secondary fuels: > ash content of MBM, fine fly ash particles and lower gas volumes.

## Pollutant Emissions in a pilot fluidized bed – Heavy Metals (Pb)

### Polish/Straw



### Cerejon/MBM

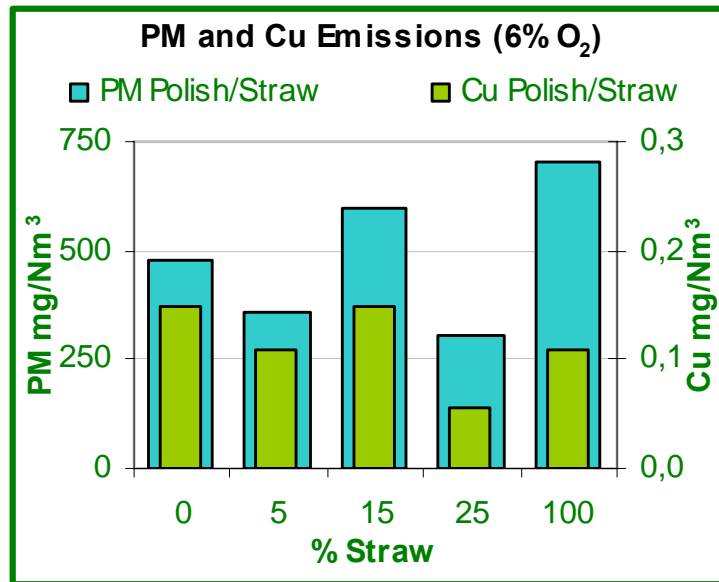


Trace metal emissions are influenced more strongly by fluctuations in particulate emissions, compared with the metal content in fuel blends supplied.

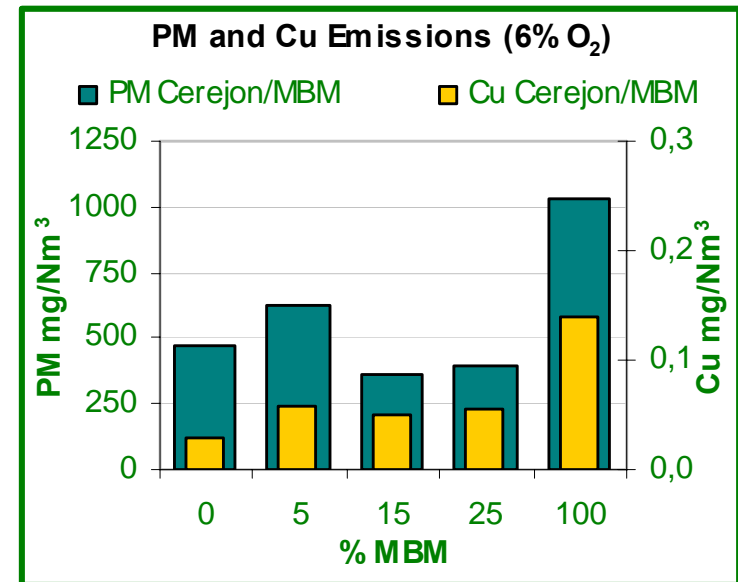
Fly ash emitted are enriched in heavy metals, especially for blends with Polish coal that contained higher trace metal content.

## Pollutant Emissions in a pilot fluidized bed – Heavy Metals (Cu)

### Polish/Straw

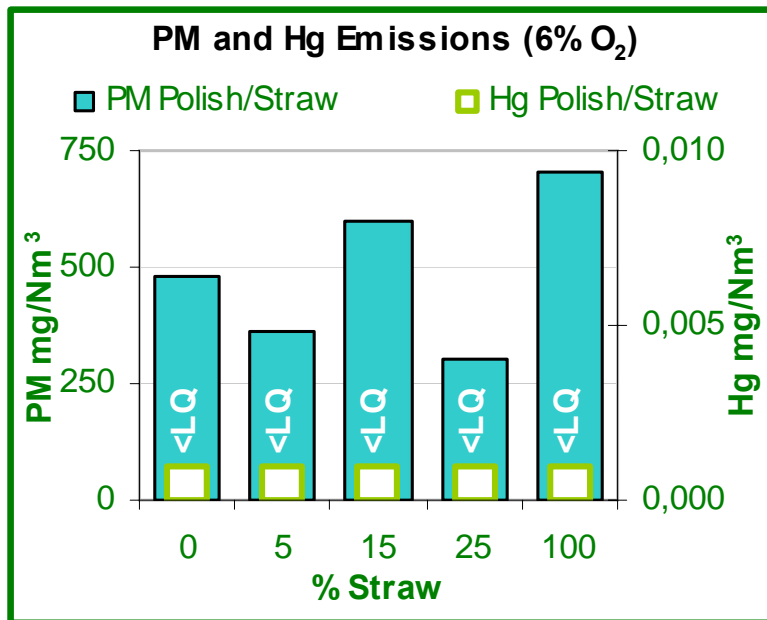


### Cerejon/MBM



## Pollutant Emissions in a pilot fluidized bed – Heavy Metals (Hg)

### Polish/Straw

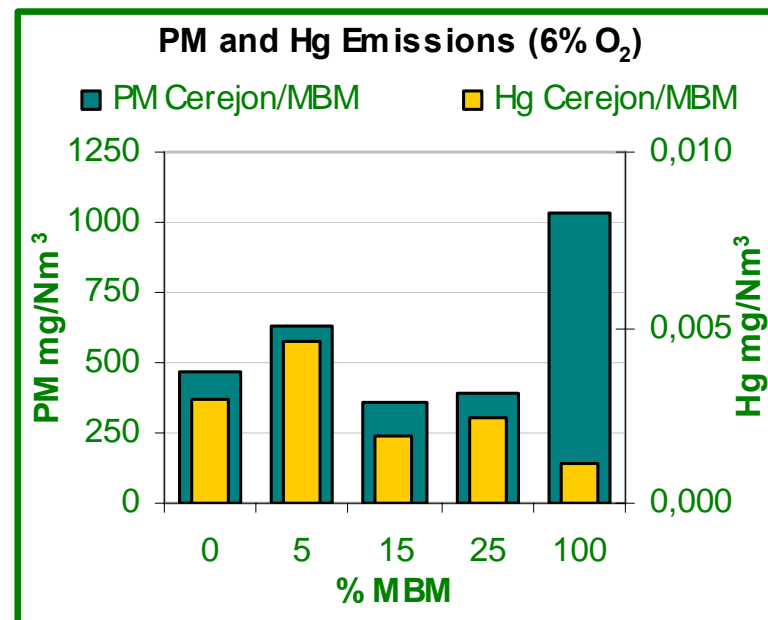


#### Polish/Straw:

Hg emissions not detected

- Hg trapped in ashes, helped by Cl and S

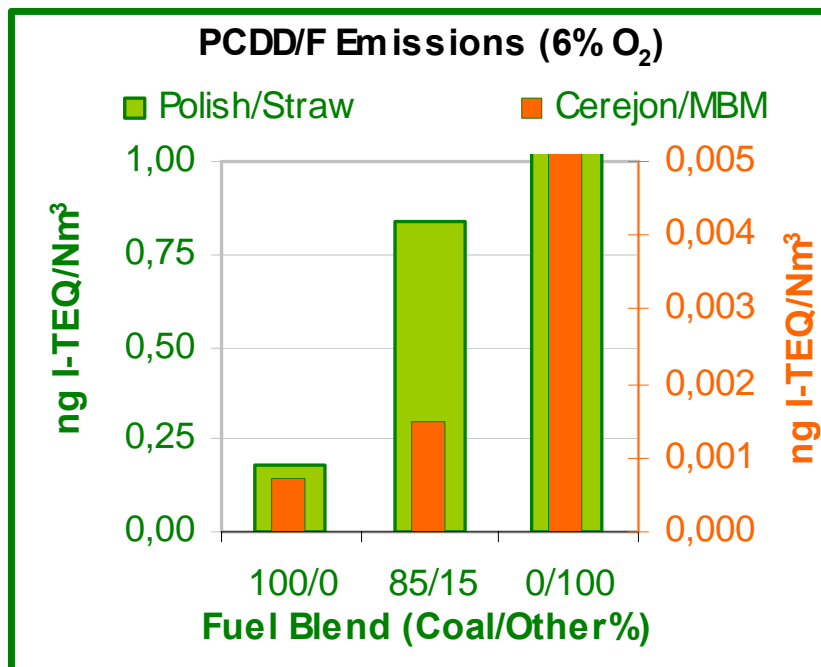
### Cerejon/MBM



#### Cerejon/MBM:

Hg emissions decreased with MBM due to the lower Hg and higher Cl

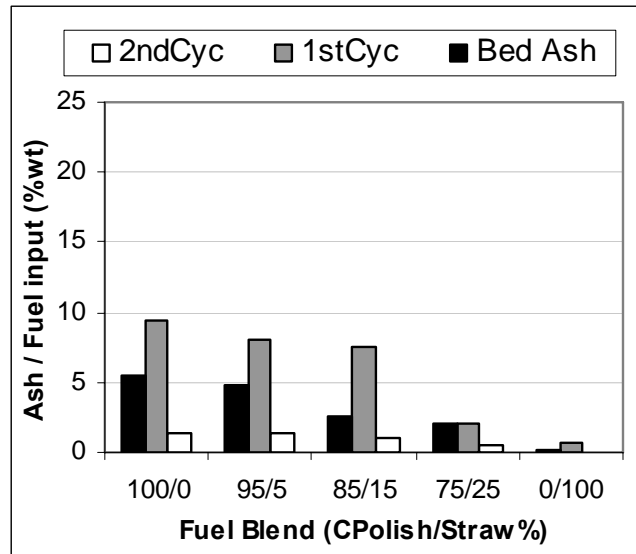
## Pollutant Emissions in a pilot fluidized bed – PCDD/F



**Higher PCDD/F emission for Polish/Straw than for Cerejon/MBM tests:**

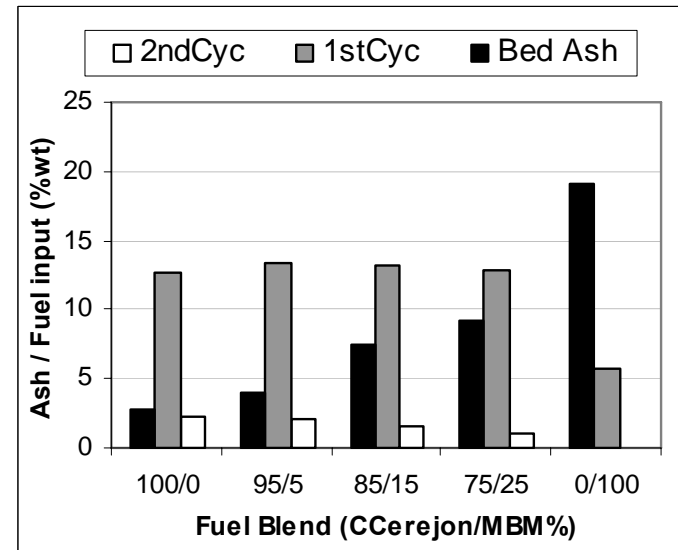
- higher Cl and metals (particularly Cu),
- low S
- nature of straw (organic structure)

## Ash Production



### Polish/Straw

- Total Ash ( 16 to 1%) diminished with the addition of straw - lower ash content of straw..
- Higher quantities were collected in first cyclone for all fuel combinations.



### Cerejon/MBM

- Higher production of total Ash (18 to 25%)
- Increases with MBM (higher ash content)
- Most of MBM ash is retained in the bed (bone fragments).
- MBM produce lower quantities of cyclone ash than coal.

## Ash Leachability

## Polish/Straw

	pH	Conductivity mS/cm	Cd	Cr	Cu	Zn	Pb	Ni	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>
	<b>Quantification Limit (mg/kg)</b>		0.2	0.5	0.3	0.2	0.5	0.3	10	10
<b>Bed Material</b>	<b>0%SP</b>	11.3	0.84	<QL	<QL	<QL	<QL	<QL	58	2275
	<b>5%SP</b>	11.0	0.68	<QL	<QL	<QL	<QL	<QL	90	2534
	<b>15%SP</b>	11.6	0.91	<QL	<QL	<QL	<QL	<QL	50	3345
	<b>25%SP</b>	10.6	0.57	<QL	1.4	<QL	<QL	<QL	99	2290
	<b>100% SP</b>	11.0	2.48	<QL	6.0	<QL	<QL	<QL	3058	4061
<b>1<sup>st</sup> Cyclone</b>	<b>0%SP</b>	12.0	3.74	<QL	<QL	<QL	<QL	<QL	1560	12675
	<b>5%SP</b>	10.7	2.88	<QL	<QL	<QL	<QL	<QL	2326	16367
	<b>15%SP</b>	11.5	3.12	<QL	<QL	<QL	<QL	<QL	1859	14264
	<b>25%SP</b>	10.6	7.60	<QL	17	<QL	<QL	<QL	14527	23559
	<b>100% SP</b>	10.5	17.9	<QL	68	<QL	<QL	<QL	40670	28475
<b>2<sup>nd</sup> Cyclone</b>	<b>0%SP</b>	10.0	2.38	<QL	<QL	<QL	<QL	<QL	2335	12005
	<b>5%SP</b>	10.0	2.45	<QL	<QL	<QL	<QL	<QL	2096	12907
	<b>15%SP</b>	10.1	3.41	<QL	<QL	<QL	<QL	<QL	2478	18430
	<b>25%SP</b>	10.3	15.01	<QL	20	<QL	<QL	<QL	30335	40400
	<b>100% SP</b>	10.6	24.4	<QL	31	<QL	<QL	<QL	50310	61335

Landfill Directive: Inert Level, Non-hazardous Level, Hazardous Level

## Ash Leachability

## Cerejon/MBM

		pH	Conductivity mS/cm	Cd	Cr	Cu	Zn	Pb	Ni	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>
	<b>Quantification Limit (mg/kg)</b>			0.2	0.5	0.3	0.2	0.5	0.3	10	10
<b>Bed Material</b>	<b>0%MBM</b>	11.0	0.43	<QL	<QL	<QL	<QL	<QL	<QL	<QL	1201
	<b>5%MBM</b>	10.2	0.32	<QL	<QL	<QL	0.5	<QL	<QL	9	1221
	<b>15%MBM</b>	10.5	0.47	<QL	<QL	<QL	<QL	<QL	<QL	10	2313
	<b>25%MBM</b>	10.5	0.47	<QL	<QL	<QL	<QL	<QL	<QL	37	2116
	<b>100%MBM</b>	11.2	1.60	<QL	3.2	<QL	<QL	<QL	<QL	856	6093
<b>1<sup>st</sup> Cyclone</b>	<b>0%MBM</b>	9.9	1.98	<QL	<QL	<QL	<QL	<QL	<QL	76	13758
	<b>5%MBM</b>	9.5	2.59	<QL	<QL	<QL	<QL	<QL	<QL	110	17658
	<b>15%MBM</b>	9.8	2.64	<QL	<QL	<QL	<QL	<QL	<QL	407	14500
	<b>25%MBM</b>	9.8	3.33	<QL	6.6	<QL	<QL	<QL	<QL	569	56338
	<b>100%MBM</b>	10.8	3.08	<QL	18	<QL	<QL	<QL	<QL	2221	73956
<b>2<sup>nd</sup> Cyclone</b>	<b>0%MBM</b>	7.9	1.73	<QL	<QL	<QL	<QL	<QL	<QL	167	12319
	<b>5%MBM</b>	8.0	1.99	<QL	<QL	<QL	<QL	<QL	<QL	311	14513
	<b>15%MBM</b>	8.6	2.50	<QL	<QL	<QL	<QL	<QL	<QL	362	16098
	<b>25%MBM</b>	9.2	3.88	<QL	0.6	<QL	<QL	<QL	<QL	684	57303
	<b>100%MBM</b>	8.8	8.68	<QL	19	<QL	0.2	<QL	<QL	3583	70170

Landfill Directive: Inert Level, Non-hazardous Level, Hazardous Level

## CONCLUSIONS

- ✓ **Successful demonstration of co-combustion of coal with up to 25% MBM, Straw or Olive cake addition.**
- ✓ **Positive synergies in the co-combustion of biomass with coal as for the pollutant emissions reduction:**
  - **SO<sub>2</sub>, CO and NO<sub>x</sub> reduction when compared with the monocombustion of coals, due to the addition of secondary fuels with higher volatile matter contents;**
  - **reduction of HCl emissions in the co-combustion of MBM when compared with 100% coal;**
  - **minimization of PCDD/F emissions in the co-combustion of coal and biomass as secondary fuels, in the presence of high levels of both Cl and S.**

## CONCLUSIONS

- ✓ For temperatures above 800 °C, bed agglomeration was observed for all biomass species studied, when they were burned alone.
- ✓ Ash production and partitioning depends on the ash content of fuels, nature of mineral matter and burnout of ashes.
- ✓ Leachates are alkaline - metals do not leach in general, but  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  leach out.
- ✓ Conductivity increase for higher contents of MBM or straw-ashes are more soluble.
- ✓ Non-Hazardous Cr leachability for substitutions :  $\leq 25\%$  of straw or  $<25\%$  of MBM:  
Cr leachability may be promoted by higher Cl content in ashes
- ✓ Leachability of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  depends not only on the Cl and S present in fuels, it also depends on the quality and quantity of ash produced.

## **ACKNOWLEDGEMENT**

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**Thank you for your attention**

## Considerations on Valorization of Biomass Origin Materials in Co-combustion with Coal in Fluidized Beds

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