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Biomass Co-firing: Research on Lignite, Wood and Peat Mixtures

Dr. Fernando Preto

CanmetENERGY, Natural Resources Canada

McIlvaine Company: "Hot Topic Hour"

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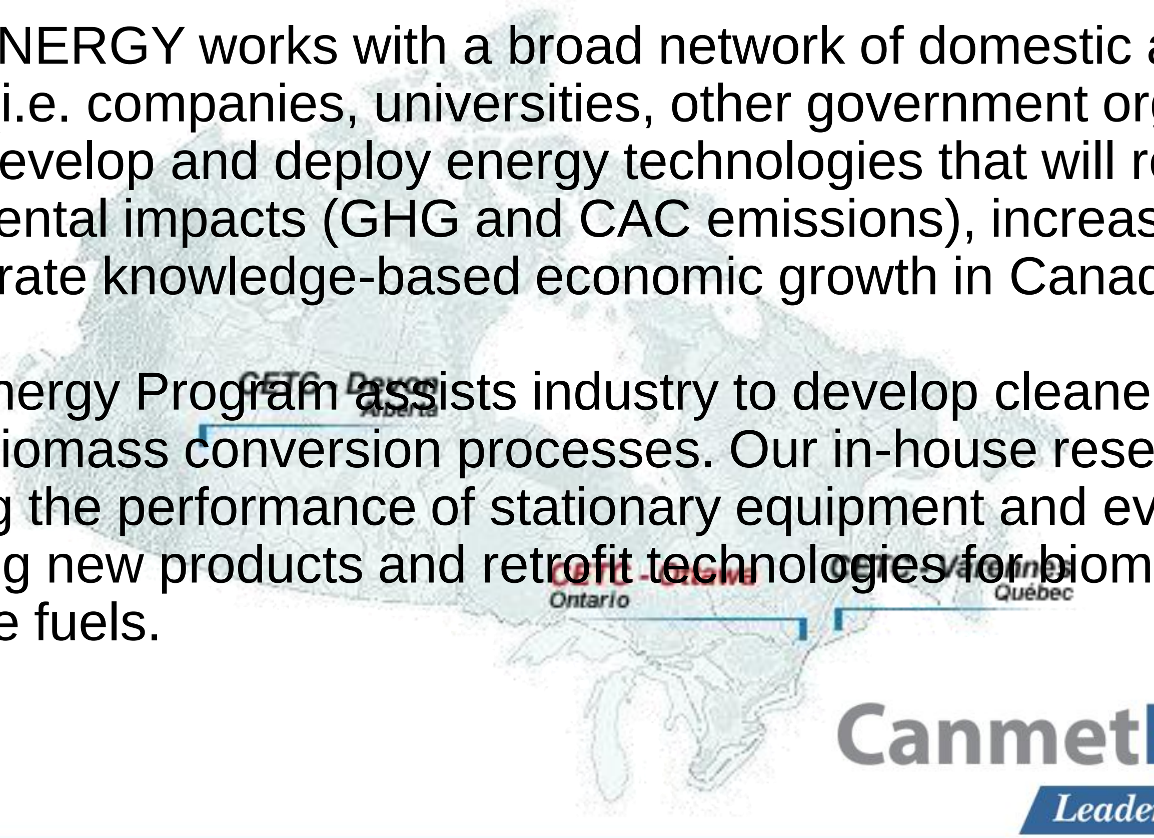
About CanmetENERGY

CanmetENERGY is the science and technology branch of Natural Resources Canada and operates three labs across Canada with over 450 scientists, engineers and technicians



CanmetENERGY works with a broad network of domestic and foreign partners (i.e. companies, universities, other government organizations) to assess, develop and deploy energy technologies that will reduce environmental impacts (GHG and CAC emissions), increase productivity and generate knowledge-based economic growth in Canada.

The Bioenergy Program assists industry to develop cleaner, more energy-efficient biomass conversion processes. Our in-house research focuses on optimizing the performance of stationary equipment and evaluating and developing new products and retrofit technologies for biomass and renewable fuels.

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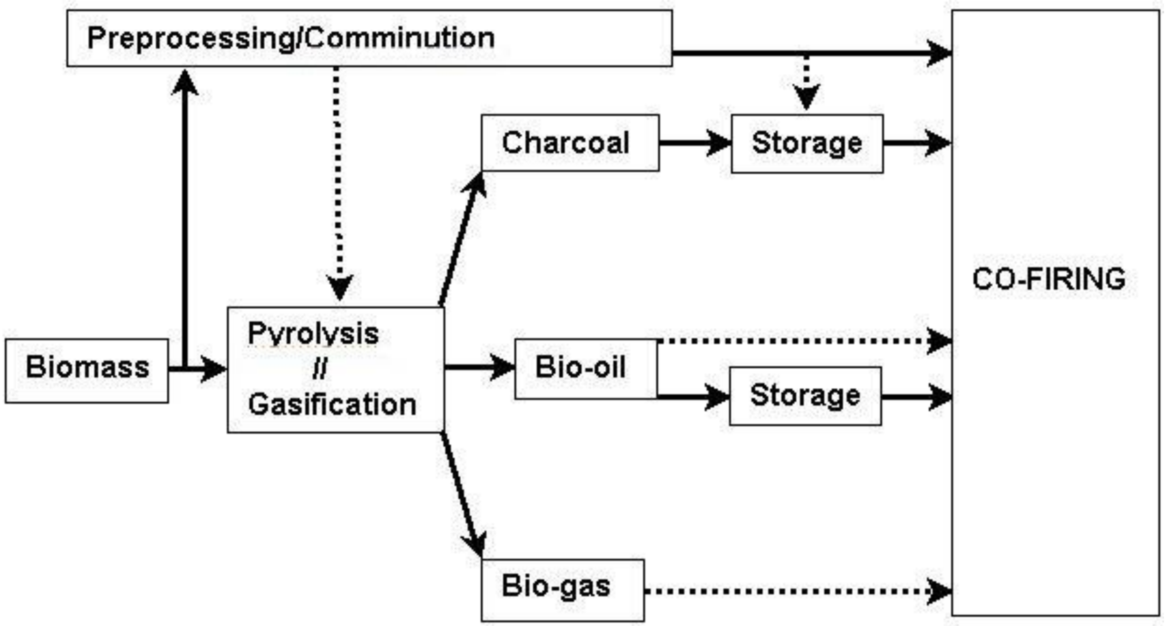
Biomass Co-Firing with Coal

- Biomass co-firing is seen as the most cost-effective method of introducing biomass into the power generation sector

- Biomass co-firing offers higher efficiency than biomass stand-alone and offers improved environmental performance with reduction in greenhouse gases and criteria air contaminants

- There has been significant worldwide experience although this has been associated with retrofit projects at co-firing ratios up to around 20%

Co-firing Methodologies



Preprocessing/Comminution

Charcoal

Storage

CO-FIRING

Biomass

Pyrolysis
//
Gasification

Bio-oil

Storage

Bio-gas

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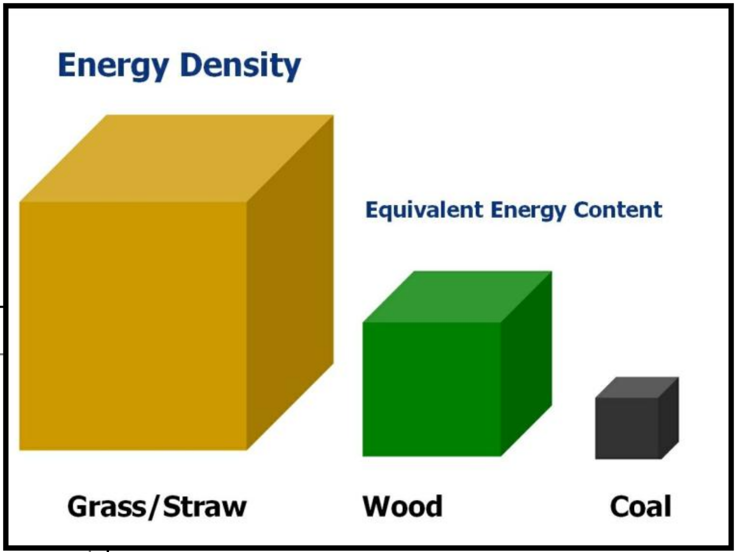
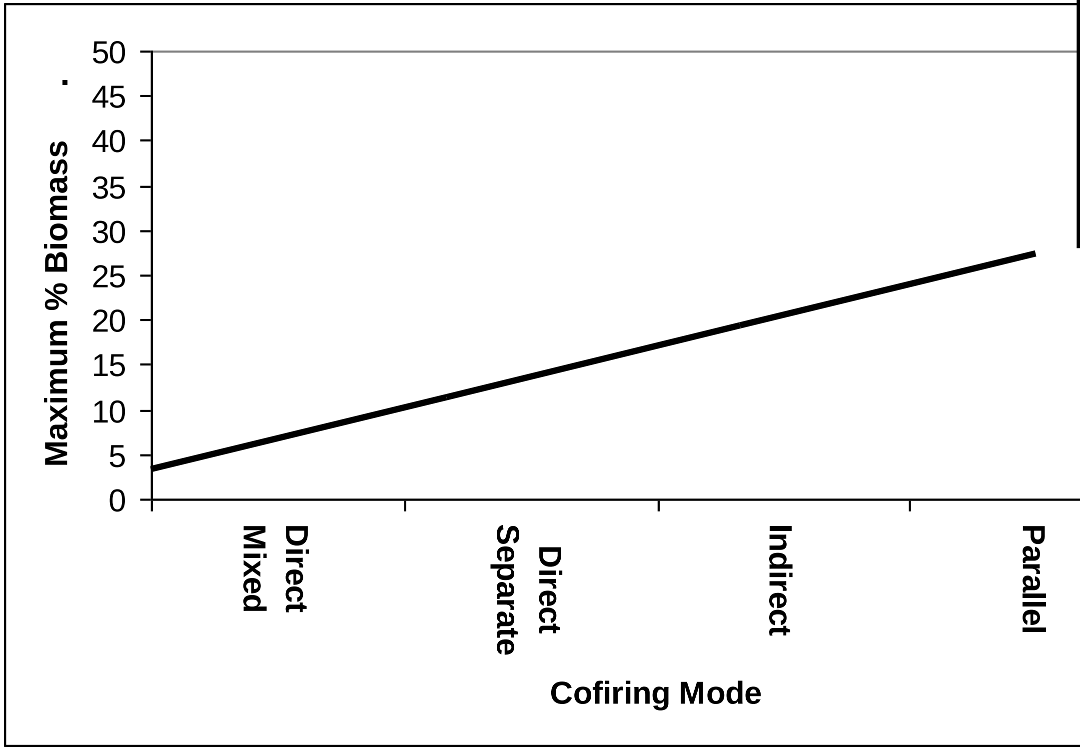
Co-firing Limitations





Techniques to Overcome Limitations

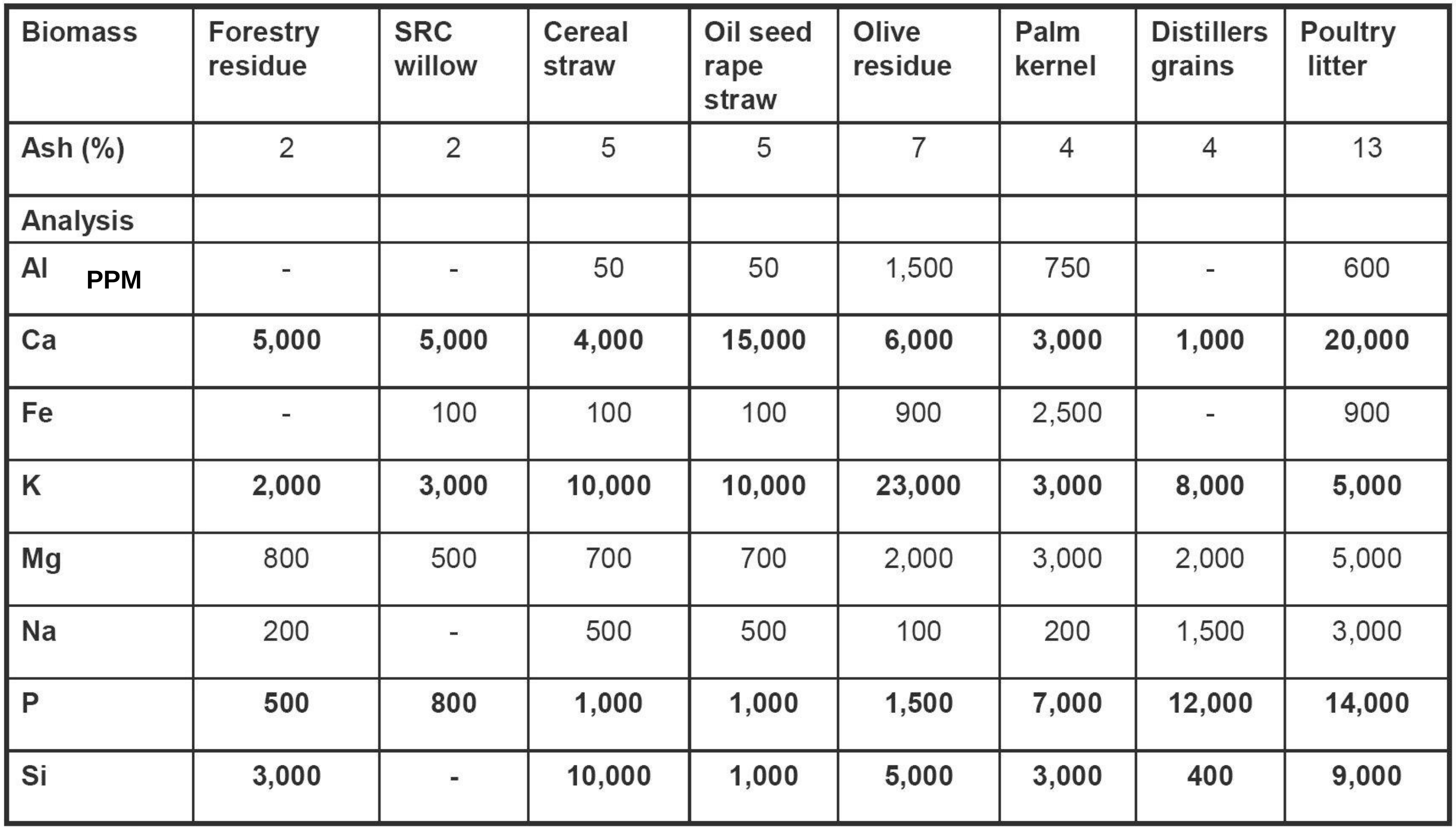
- **Pelletization**
- **Pyrolysis**
- **Torrefaction**

Fuel Analyses

	WOOD	FOREST RESIDUES	WHEAT STRAW	RDF	BITUMINOUS COAL
Fixed Carbon	**13.47**	**13.62**	**17.71**	**0.47**	**15-30**
Volatile Matter	**86.22**	**82.41**	**75.27**	**73.40**	**45-77**
Ash	**0.31**	**3.97**	**7.02**	**26.13**	**4-10**
Carbon	49.96	50.31	44.92	39.70	76-87
Hydrogen	5.92	4.59	5.46	5.78	3.5-5
Oxygen (diff.)	43.77	39.99	41.77	27.24	3-11
Nitrogen	0.03	1.03	0.44	0.8	0.8-1.2
Sulphur	0.01	0.11	0.16	0.35	1-3
MJ/kg	**19.43**	**20.12**	**17.94**	**15.54**	**28-33**

Biomass Ash

- **Biomass materials generally have low ash content (typically <5%), compared to power station coals.**
- **Biomass ashes are very different chemically from coal ashes, i.e. they are not an alumino-silicate system, but a mixture of simple inorganic compounds, of Si, K, Ca, P and S.**

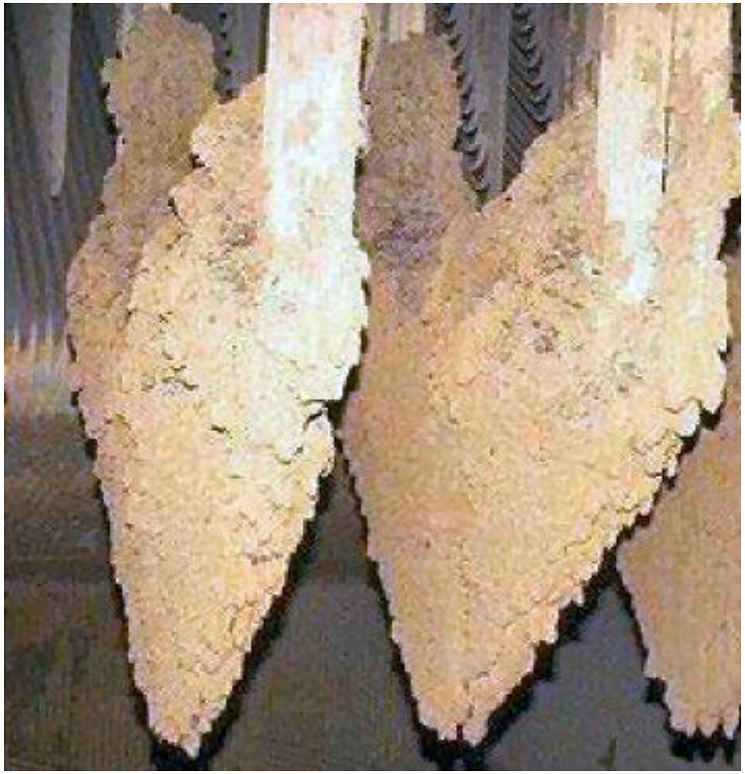


Biomass	Forestry residue	SRC willow	Cereal straw	Oil seed rape straw	Olive residue	Palm kernel	Distillers grains	Poultry litter
Ash (%)	2	2	5	5	7	4	4	13
Analysis								
Al **PPM**	-	-	50	50	1,500	750	-	600
Ca	**5,000**	**5,000**	**4,000**	**15,000**	**6,000**	**3,000**	**1,000**	**20,000**
Fe	-	100	100	100	900	2,500	-	900
K	**2,000**	**3,000**	**10,000**	**10,000**	**23,000**	**3,000**	**8,000**	**5,000**
Mg	800	500	700	700	2,000	3,000	2,000	5,000
Na	200	-	500	500	100	200	1,500	3,000
P	**500**	**800**	**1,000**	**1,000**	**1,500**	**7,000**	**12,000**	**14,000**
Si	**3,000**	**-**	**10,000**	**1,000**	**5,000**	**3,000**	**400**	**9,000**

(Data: W R Livingston)

Co-firing Risks

- Potential for increased rates of ash deposition on boiler surfaces, and on the surfaces of SCR catalysts
- Increased rates of high temperature corrosion of boiler components, particularly with high chlorine biomass materials
- Biomass tends to increase the level of submicron particulates which will impact particulate emissions control equipment
- Utilisation/disposal issues with mixed coal/biomass ashes



CanmetENERGY Research

Current State-of-the-Art

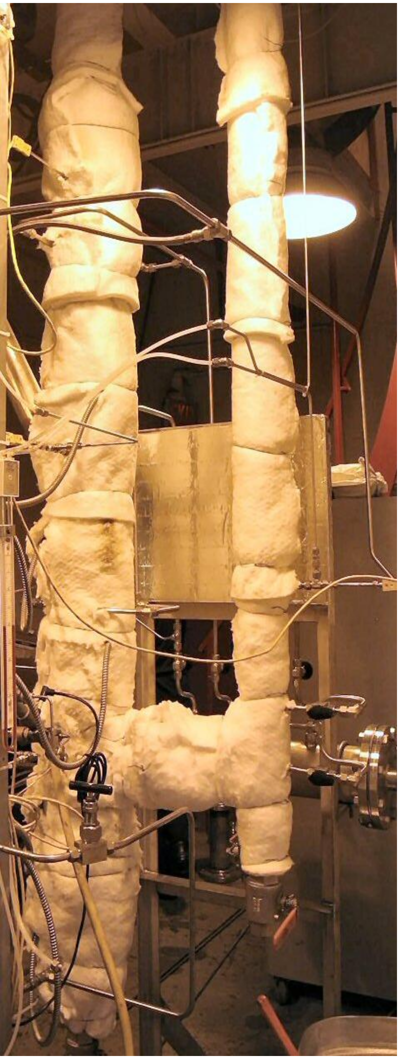
- Exisiting techniques for fuel characterization are optimized for coal
- Most testing has been at low biomass levels
- Full-scale tests are expensive and potentially risky

CanmetENERGY Approach

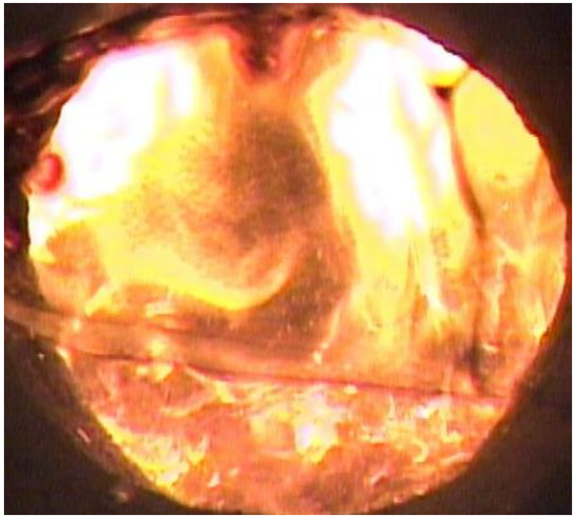
- Evaluate Biomass/coal co-firing:
  - Fuel handling, preparation, comminution, storage, delivery and blending
  - ash deposition
  - combustion performance with coal
  - pollutant formation

- **RD&D co-firing collaboration with Ontario Power Generation and Nova Scotia Power**

Mini-FluidBed Reactor



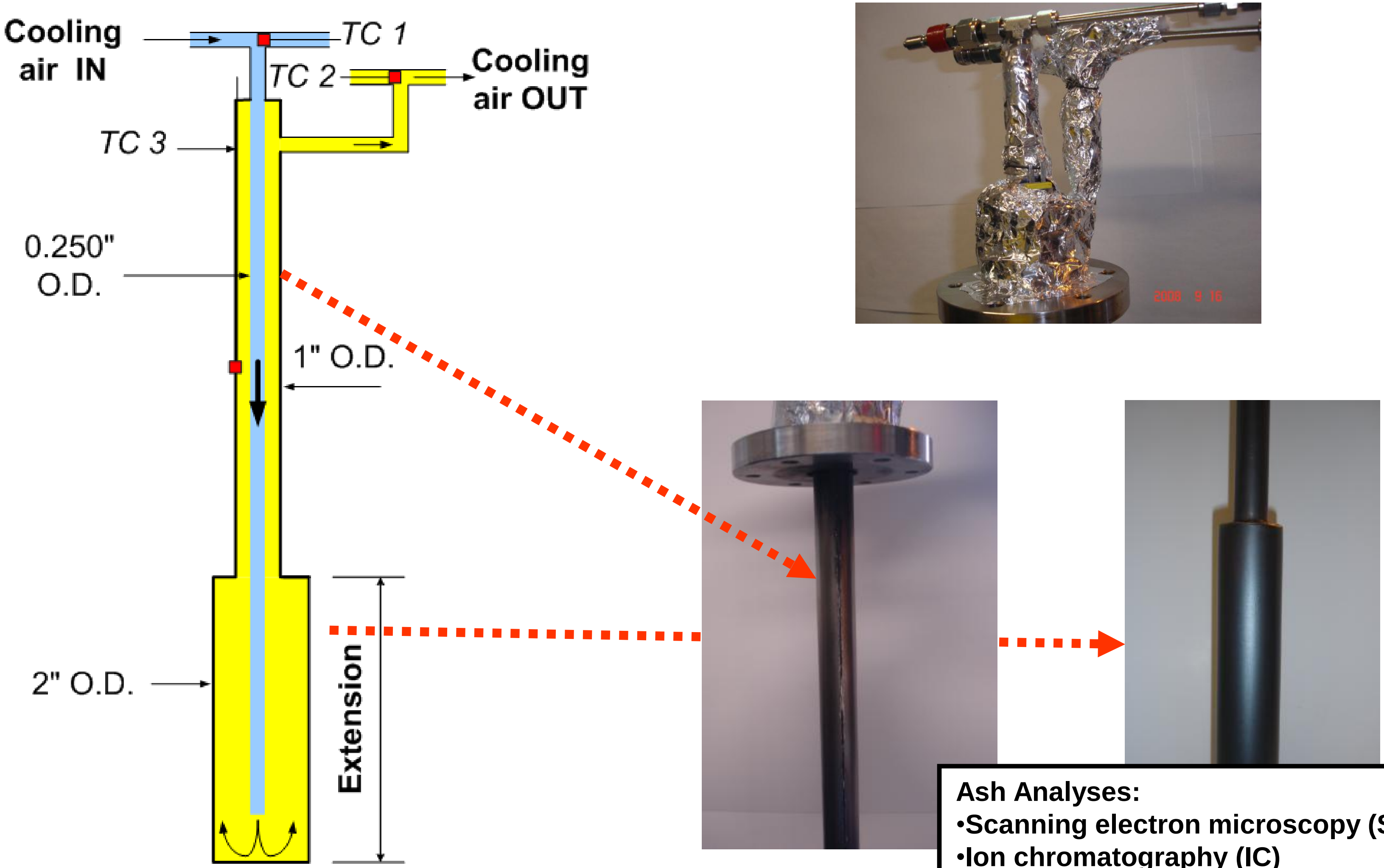
- Combustor or Gasifier
- Bubbling or Circulating Mode
- 5 - 20 kg/h Biomass
- Air-blown



Fuel Composition

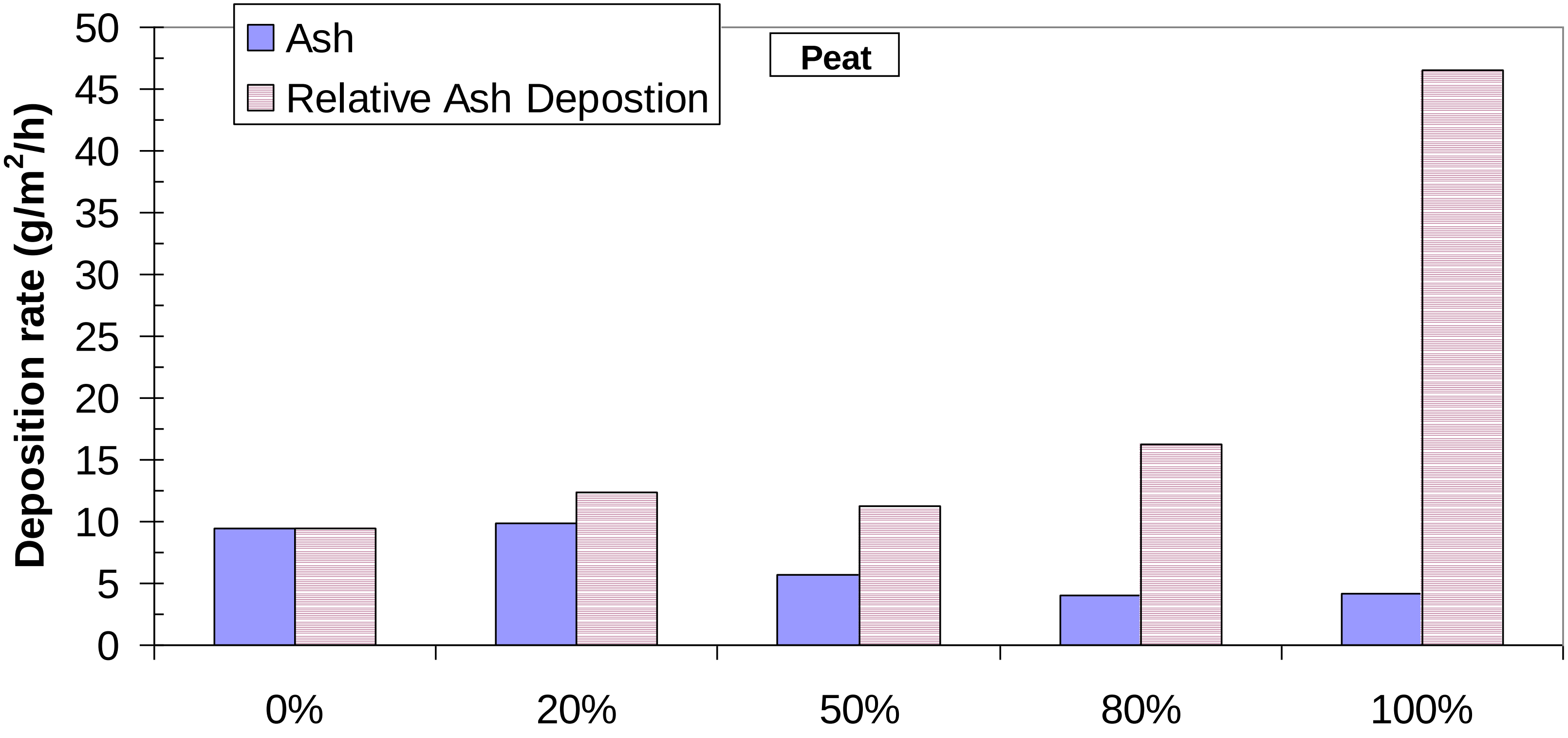
	Lignite	Pine	Pellets	Peat		Lignite	Pine	Pellets	Peat
***Proximate analysis**, wt% d.b.*					***Moisture,*** *wt% as received*	30.0	38.0	5.3	35.8
Ash	**22.0**	**0.4**	**3.13**	**2.0**	***HHV (MJ/ kg dry)***	**21.8**	**20.6**	**20.6**	**21.4**
Volatile matters (VM)	54.0	84.5	80.75	68.6	***Dry ash analysis**, wt% d.b.*				
Fixed carbon	24.0	15.1	16.12	29.4	$\mathbf{SiO_2}$	**49.76**	**6.70**	**3.80**	**28.05**
***Ultimate analysis**, wt% d.b.*					$\mathbf{Al_2O_3}$	**19.71**	**1.97**	**0.49**	**8.63**
Carbon	58.8	52.5	47.99	56.1	Fe_2O_3	3.82	1.46	0.58	5.56
Hydrogen	4.2	6.3	6.25	5.7	TiO_2	0.86	0.09	<0.03	0.48
Nitrogen	0.9	0.1	1.31	0.8	P_2O_5	0.30	3.52	23.13	1.31
Sulphur	0.5	<0.1	0.58	0.2	**CaO**	**9.91**	**31.10**	**23.36**	**12.65**
Oxygen	13.6	40.6	40.73	35.2	**MgO**	**2.11**	**4.34**	**6.86**	**17.72**
Chlorine, µg/g.	**25**	**39**	**312**	**2008**	SO_3	6.09	2.80	17.98	12.73
Bromine, µg/g.	< 21	< 29	203	153	$\mathbf{Na_2O}$	**4.20**	**0.36**	**1.29**	**2.84**
Fluorine, µg/g	100	< 29	<18	< 20	$\mathbf{K_2O}$	**1.04**	**15.45**	**16.46**	**1.14**

Ash Deposition Probe



Ash Analyses:
- Scanning electron microscopy (SEM)
- Ion chromatography (IC)
- X-ray fluorescence (XRF)
- X-ray diffraction (XRD)

Effect of Co-firing Ratio

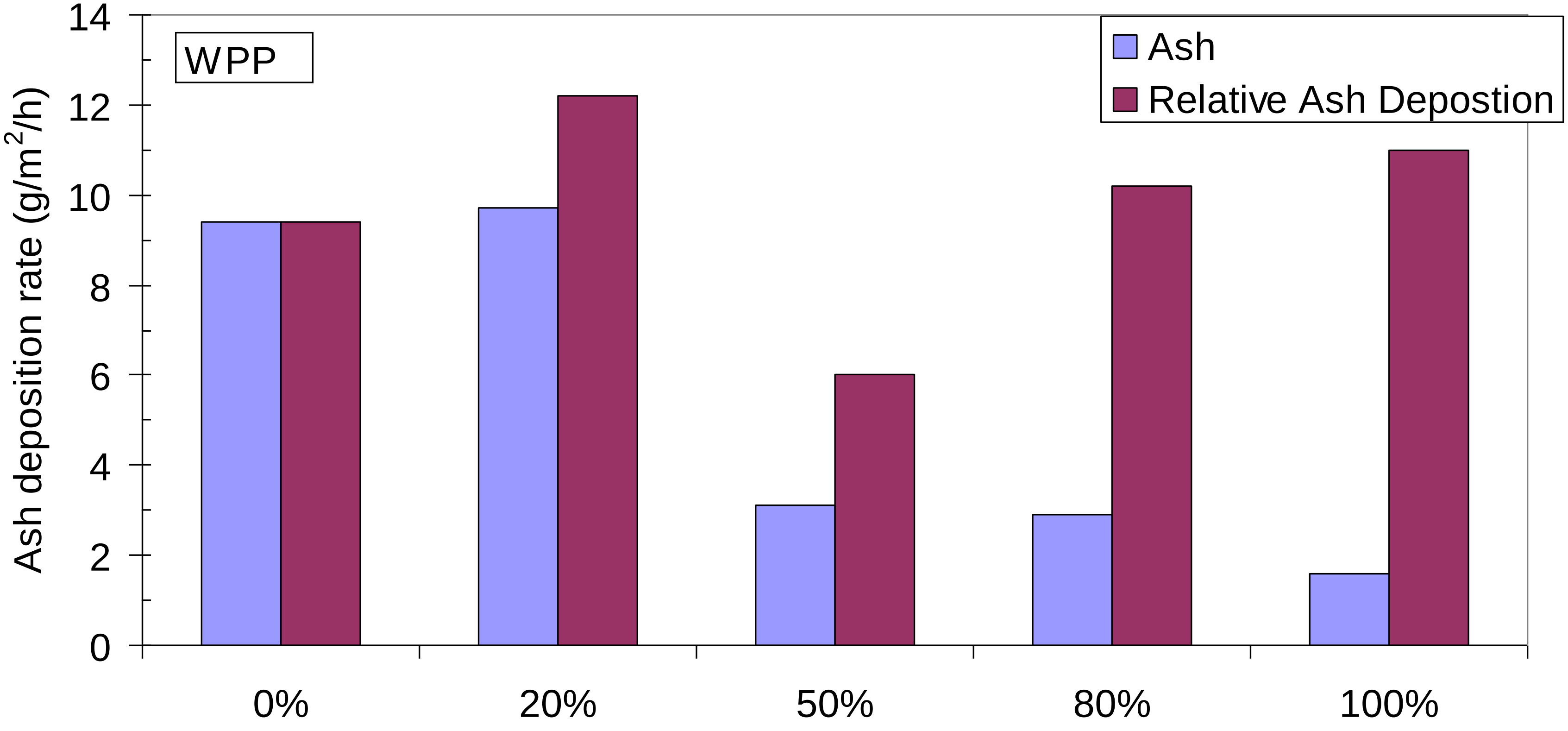


Blending ratio

Lignite alone

Peat alone

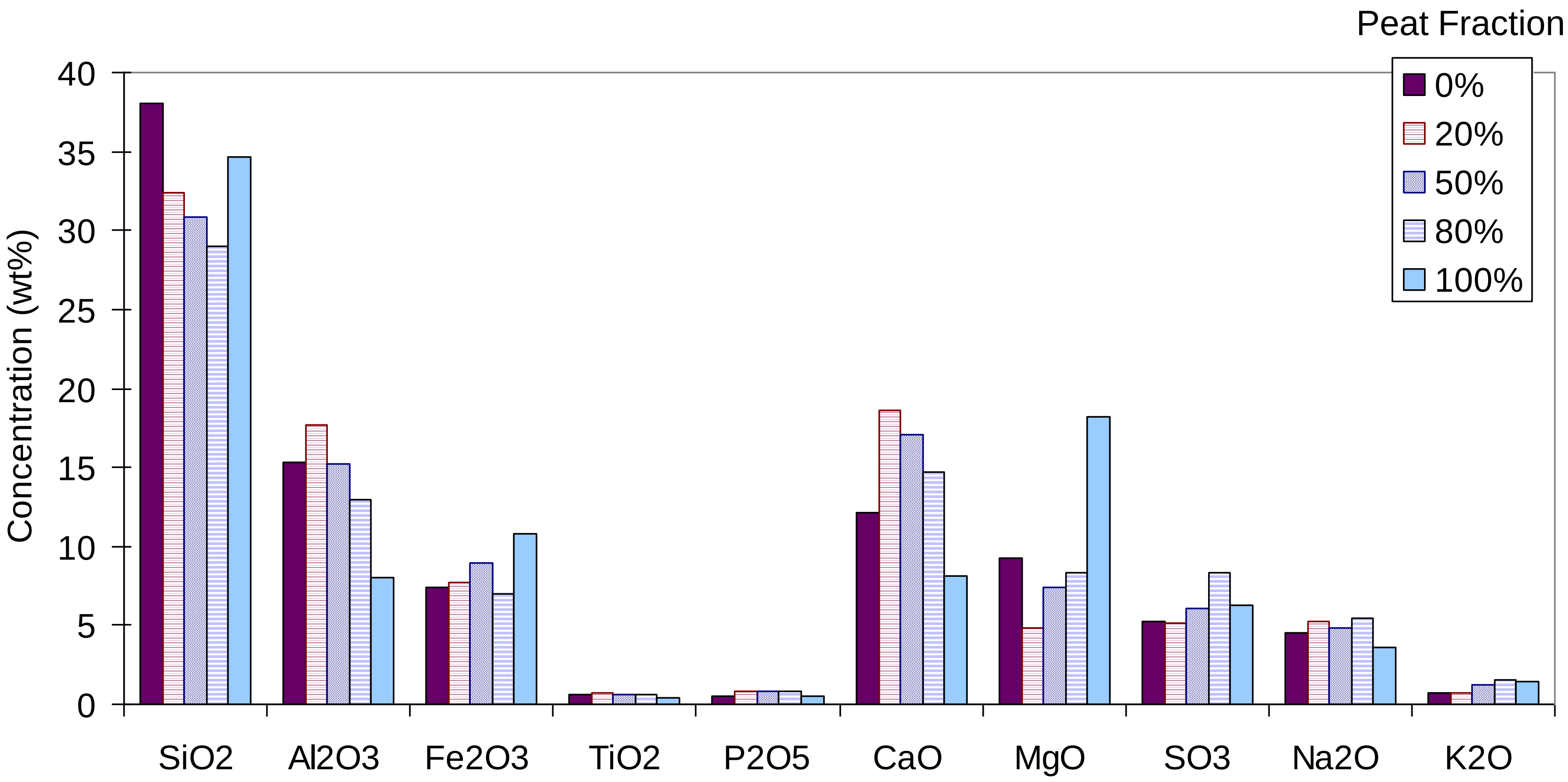
Effect of Co-firing Ratio (contd)



Lignite alone

Pine alone

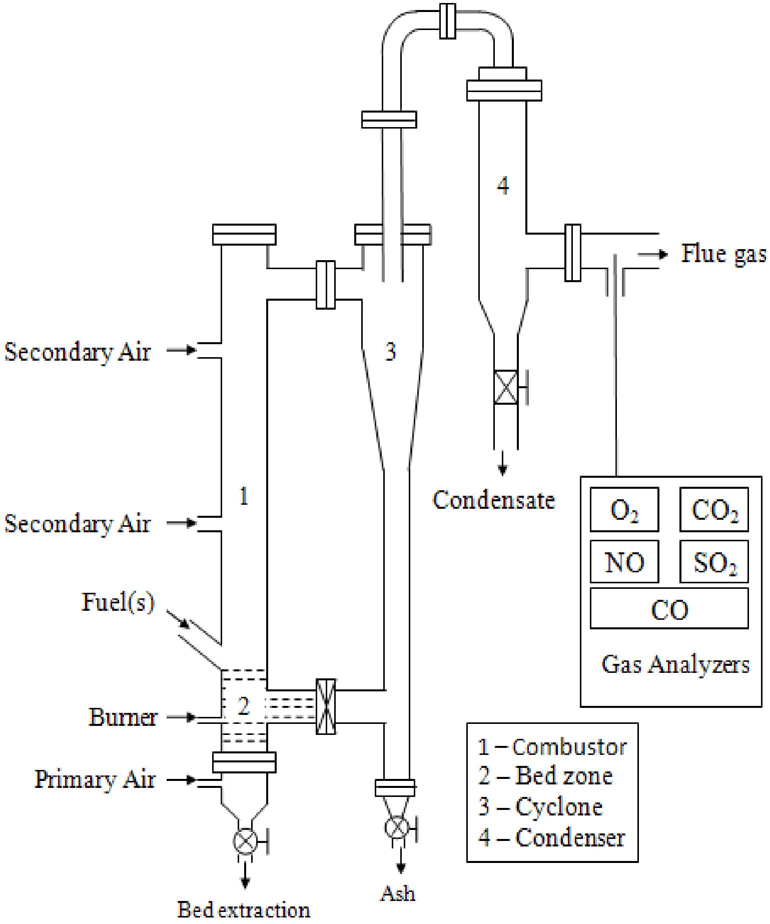
Comparison of XRF Results



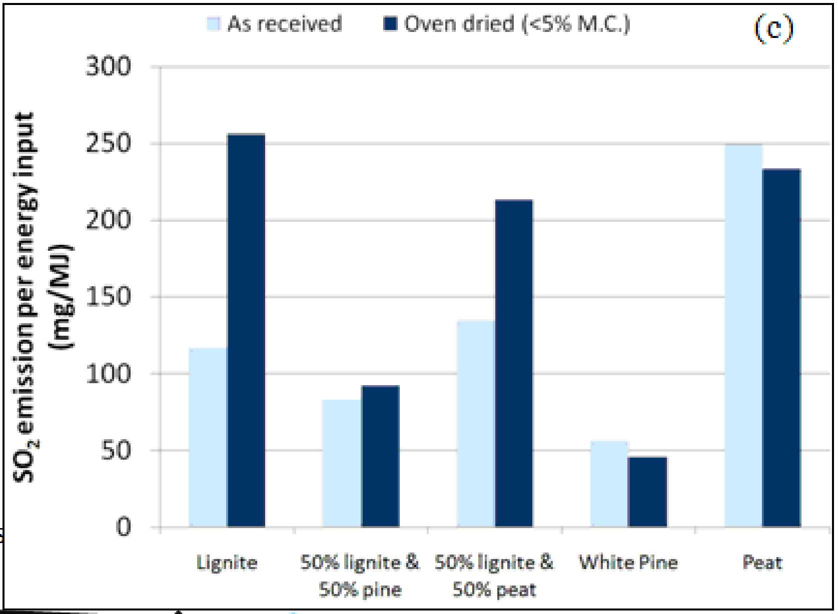
Summary of Ash Results

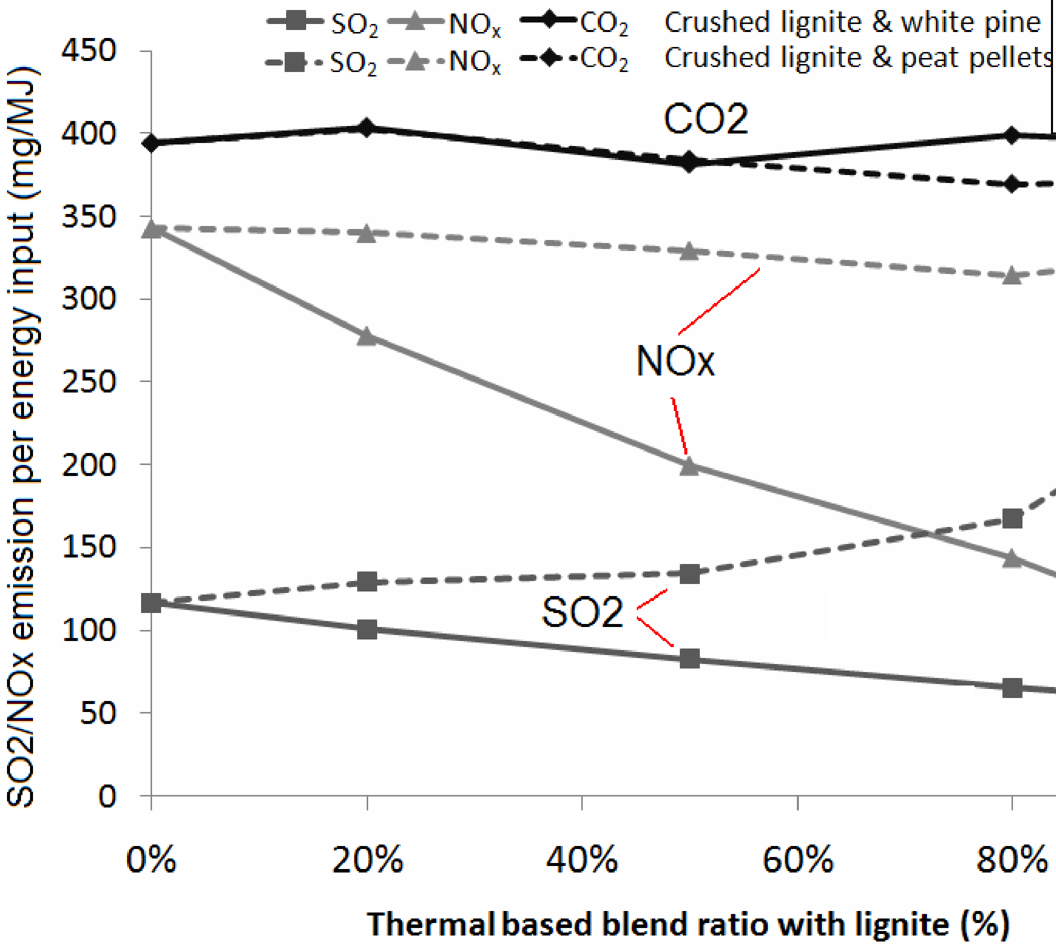
- The ash deposition rate strongly depended on the fuel type, showing that peat > crushed lignite > pine.
- Although the lignite used in this work contains a very high ash content (22 wt% db), the deposition rates was low which may be accounted for by the very high concentrations of SiO_2 and Al_2O_3 and low concentrations of alkali and alkaline-earth metals as well as low chlorine content in the coal ash.
- Co-firing fuel blend of lignite with either peat or pine at all the blending ratios tested between 20-80% generally increased the superficial ash deposition rates. However, in terms of relative ash deposition rates, the optimal blending ratio was found to be 50% (heat input).
- Generally, a smaller particle size or a higher moisture-content reduced the ash deposition rates regardless of the fuel type and composition.
- Sulphur addition could reduce corrosion, but it would generally enhance ash deposition rate, in particular for the woody biomass combustion!

Emissions Testing



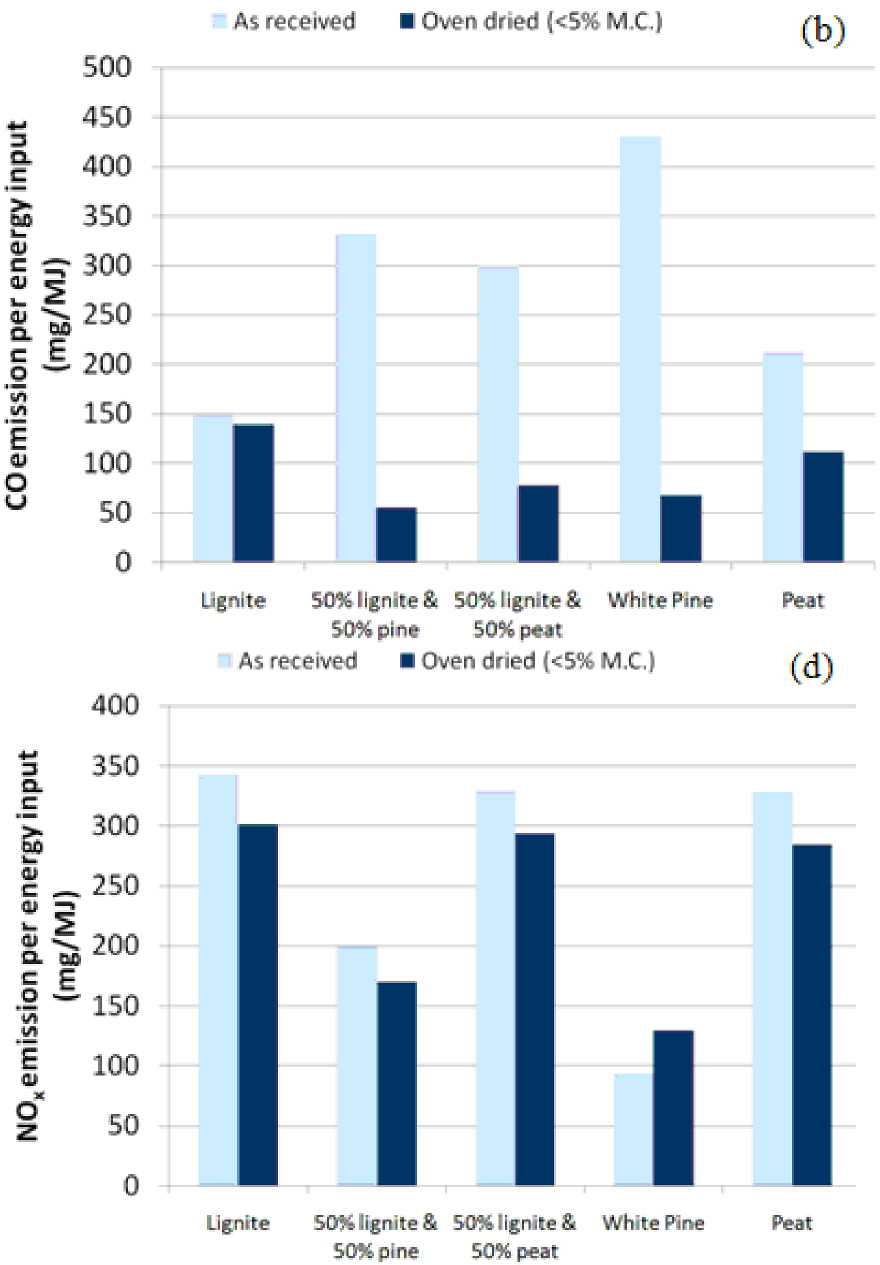
Emissions Trends





	Lignite	Pine	Peat
***Proximate analysis**, wt% d.b.*			
Sulphur	**0.5**	**<0.1**	**0.2**

Emissions trends (Contd)



$\mathrm{NO} + \mathrm{CO} \rightarrow 0.5\ \mathrm{N2} + \mathrm{CO2}$

Summary of Emissions Results

- The CO emissions were greatly reduced when using the oven-dried feedstocks. Lower excess air was also found to be effective for reducing the CO emissions from co-combustion of the wood pellets or the peat pellets.
- Even though lignite had a greater sulphur content than peat, peat combustion resulted in higher SO2 emissions. Furthermore, for combustion of lignite alone and co-firing of 50% lignite and 50% pine or peat, the SO2 emission could be lowered considerably when as-received fuels (with a higher moisture content) were used in the combustion, and operated at a lower excess air ratio. Clearly ash components such as CaO and ash particle residence time play a key role in SO2 emissions reduction for these fuels.
- As the excess air increased from 40% to 60%, the CO formation reduced and NOx increased when firing the feedstock of lignite, peat or white pine pellets alone. This might be owing to the increased secondary air flows, which could improve the combustion of volatile matters from these feedstocks all containing a high volatile content, hence resulting in a lower CO concentration in the process. The lower CO concentration in the process at a higher excess air can also account for higher emissions of NOx.

Conclusions and Outlook

- CanmetENERGY pilot-scale testing can generate reliable information on biomass fuel, ash and emissions behaviour. CanmetENERGY is broadening its testing to consider increased pre-treatment options such as pyrolysis (slow and fast) and torrefaction.

- Biomass fuels tend to have a lower sulphur content than coal and therefore emissions of SO2 can be reduced although for low sulphur coals the importance of ash (CaO) interactions should be considered.

- The impact of biomass co-firing on NOx emissions is much more complex. NOx emissions have been observed to either decrease or increase during biomass co-firing. Woody biomass has high volatile matter content and low fuel nitrogen than coal and generally results in NOx reductions. The high fuel nitrogen content of agricultural residues contributes to the generally higher NOx. The effect of CO on NOx levels means that partial fuel rich environments as generated by high volatile content fuels can help to reduce NOx emissions. The lower flame temperatures and different combustion stoichiometry of biomass systems can also result in lower thermal NOx production.

- Some biomass materials, such as straw, grass and peat can have higher potassium and chlorine than coal which may lead to problems such as slagging and fouling. There are also potential issues with respect to changes in the operation of pollution control technologies.

- At low (<50% co-firing) ratios the impact on ash deposition can be modest however at higher ratios ash deposition impacts can be substantial and require careful study of the biomass material being co-fired.

Thank You

Fernando Preto
preto@nrcan.gc.ca
Tel: 613-996-5589

http://canmetenergy.nrcan.gc.ca/