

Co-firing opportunities – knowing what to expect

Anthony H. Clemens and Desmond Gong

CRL Energy Limited, PO Box 31-244, Lower Hutt

1. ABSTRACT

The addition of biomass (a low sulphur and carbon dioxide neutral fuel) to the fuel at coal-fired plant has a number of benefits including reduced SO₂ emissions and effectively reducing CO₂ levels. However, before using biomass/coal blends in existing plant, it is worth carrying out fuel evaluation trials in order to understand and minimise operational problems and to optimise the properties of the coal/biomass blend.

This paper examines the co-firing of an 85:15 (by calorific value) mixture of coal to biomass (*E. nitens*) mixture on a laboratory scale (nominal 50 kW) combustion rig under a stoker fired combustion regime representative of conditions found at many existing coal-fired facilities. The biomass was similar to the *E. nitens* used in the accompanying paper on SRC Eucalypt Combustion and the coals included two sub-bituminous North Island industrial coals and a South Island West Coast sub-bituminous coal.

The addition of the *E. nitens* to the coals resulted in several changes in combustion performance compared to that of burning the coals alone. Positive aspects included reductions in SO₂ emissions and slight decreases in amount of slag formation. The high emission levels of carbon monoxide, methane and nitrous oxide gases observed for *E. nitens* combustion alone were now eliminated. Less favourably, increases in fouling rate and particulate carryover were observed and there were issues with fuel handling and feeding – none of which appear insurmountable.

2. INTRODUCTION

Utilisation of low sulphur, CO₂-neutral Short Rotation Crops as fuel at existing coal-fired plant has the potential to make a significant contribution toward New Zealand meeting its CO₂ reduction targets under the Kyoto protocol.

Included among the strategies being pursued to meet the protocol commitment is the use of renewable energy including bioenergy. While the use of biomass in standalone energy plants is technically feasible and sustainable, bioenergy plants struggle to compete economically in open markets with more traditional fossil fuel fired plants. Co-firing of biomass with coal in an existing coal-fired plant may represent a technically feasible, least cost renewable energy option.

Although implementation of co-firing could provide significant CO₂ emission reductions there are several important combustion-related concerns that need to be resolved. Not least of these is the need to understand the effect on combustion performance of the addition of a fuel with very different properties (biomass) than the fuel (coal) for which the plant may have

Short Rotation Crops for Bioenergy: New Zealand, 2003

been designed and optimised. It is known for example that in some circumstances the addition of the biomass can lead to enhanced ash depositional problems (slagging and fouling) compared to coal firing alone (1,2).

This paper reports results from an investigation in which samples of *E. nitens* – similar to that used in the accompanying paper – is co-fired in 85:15 by calorific value coal:biomass blends with samples of typical industrial New Zealand sub-bituminous coals under stoker conditions representative of those found at many coal-fired sites within New Zealand. It identifies issues that arise and possible means to alleviate them.

3. METHOD

The biomass was a sample of *E. nitens* similar to that used in earlier studies (3). The coals were sub-bituminous Kopako and Huntly representative of the industrial coals used in and around the central North Island region of New Zealand and a South Island sub-bituminous coal - Terrace.

The coals and *E. nitens* were mixed in the ratio 85:15 coal:biomass on thermal input basis. Representative splits of the fuel were analysed for selected parameters including moisture, ash, volatiles, calorific value, sulphur, ash fusion and ash composition using standard laboratory techniques.

Samples of the mixed fuels and coals alone were then burned in laboratory scale facilities using an underfeed stoker coal combustion unit. The coal and biomass were pre-mixed and fed in using the coal hopper on the side of the combustor (Figure 1). The stoker consisted of a small (200 mm diameter) retort with a ceramic hearth in a refractory lined chamber. No overfire air was used.

The gases exited the furnace and passed over a convective tube bank containing a fouling probe for capture of any fouling deposits. The tube bank controlled the stack sampling temperature. Fly ash was removed by a high efficiency cyclone. Inlet air flow and stack gas flow were measured using orifice plates and thermocouples were used for temperature measurement.

Flue gas was withdrawn from a sampling port, diluted with inert gas to lower the dew point to below room temperature, and passed to a pulsed UV fluorescence sulphur dioxide analyser for on-line measurement. Alternatively the sulphur dioxide was measured by passing the gas sample through an electrochemical Testoterm 350 analyser for measurement of NO_x and CO in addition to sulphur dioxide. Flue gas was also sent to an on-line MTI M200 gas chromatograph for rapid analysis of CO₂, O₂, nitrous oxide and methane levels. Measured volumes of flue gas were also withdrawn iso-kinetically and passed over a pre-weighed filter to trap particulates. After the run, the filter was re-weighed and the concentration of particulates per unit volume of flue gas determined.

After each run the bottom ash was sieved to determine the fraction passing through a 1.7 mm opening — an indicator of the extent to which slagging was occurring within the combustion chamber.

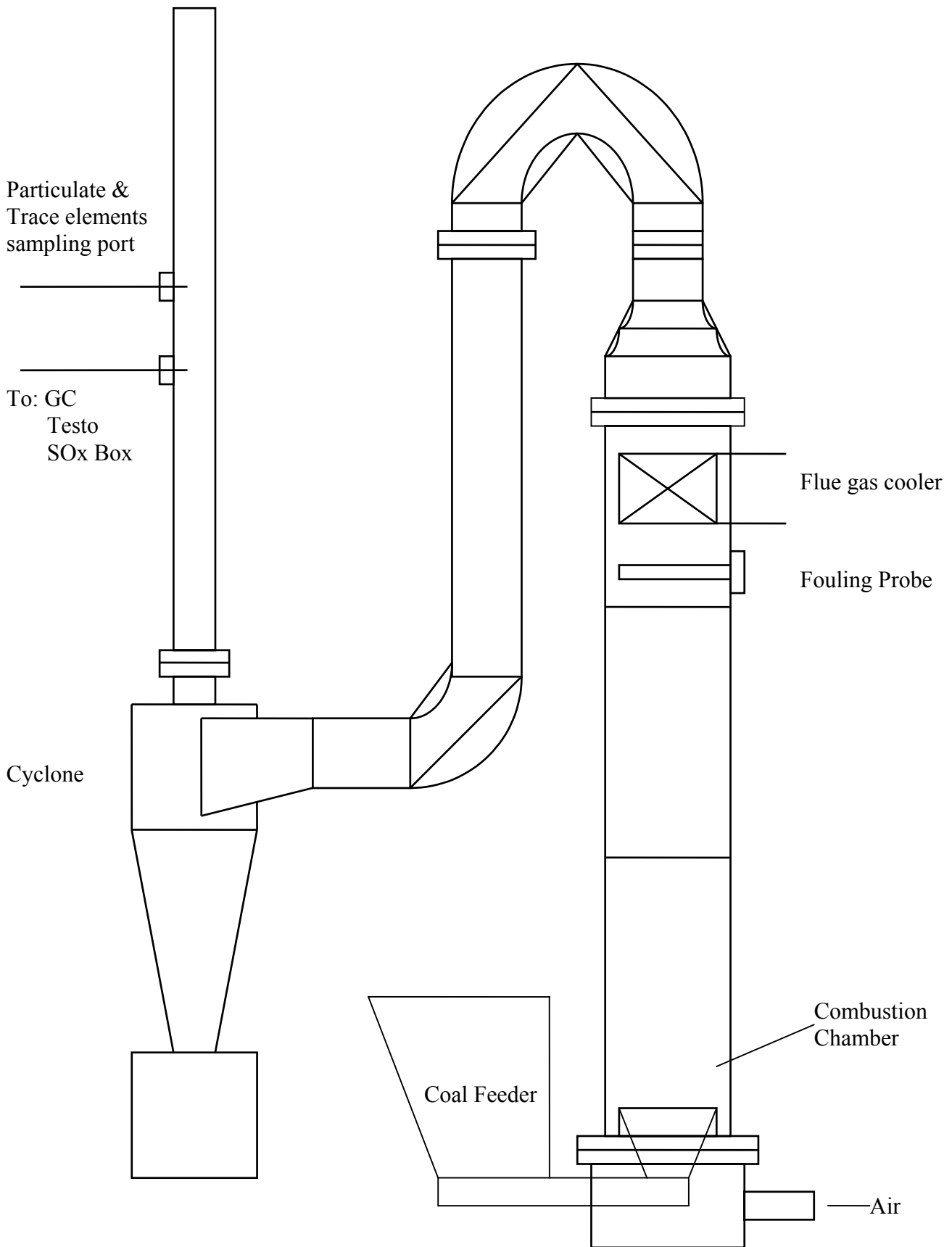


Figure 1. Stoker combustion rig

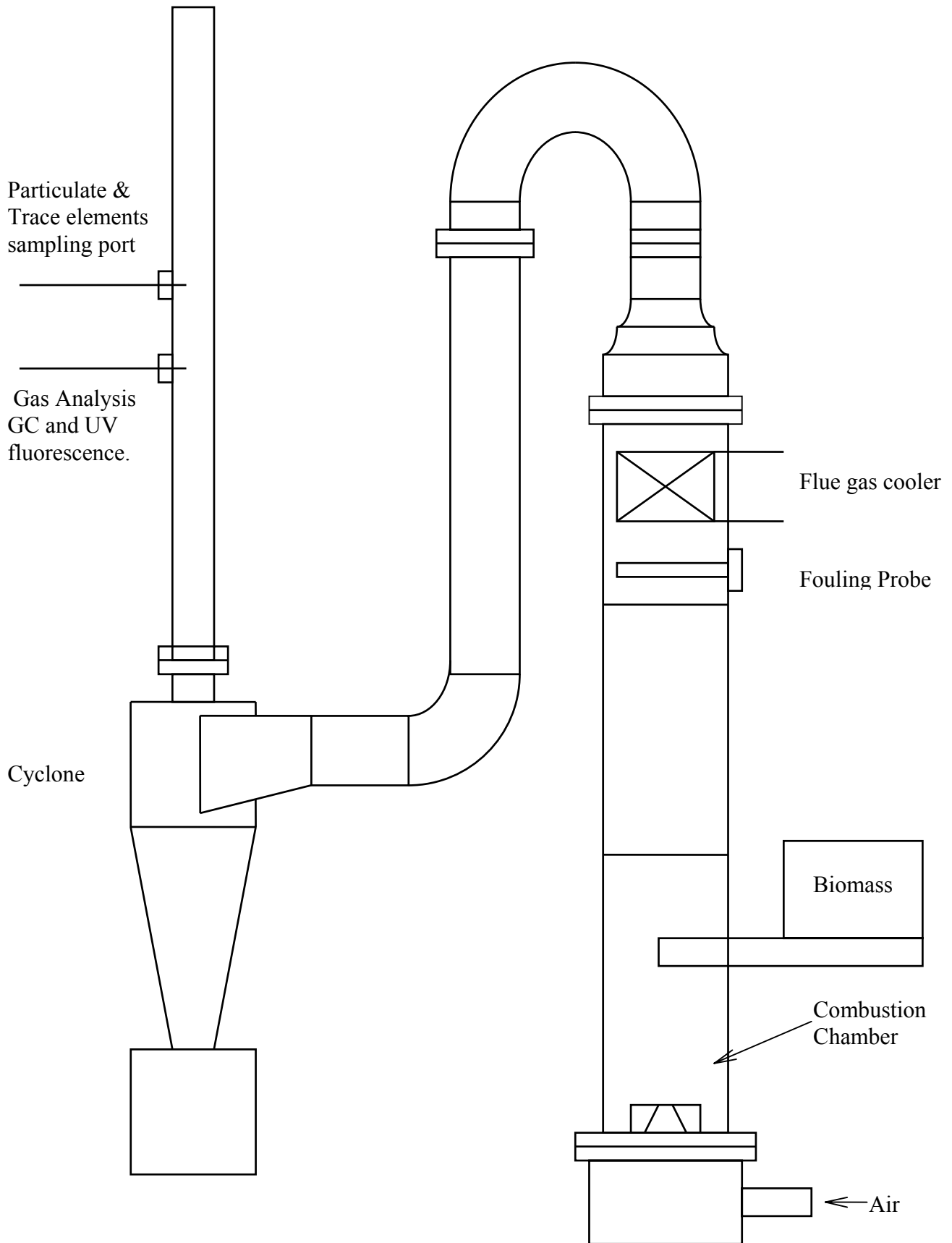


Figure 2. Biomass combustion rig

Short Rotation Crops for Bioenergy: New Zealand, 2003

The sample of *E. nitens* was combusted unblended on a biomass firing system. It was loaded into a hopper and fed by means of an auger into the biomass furnace where it dropped 300 mm onto a dispersion cone (Figure 2). Primary air was supplied from beneath this cone in a way similar to that found in a Vekos stoker. No secondary air was used. A shallow retaining ring around the cone ensured that the fuel could not be blown away from the air supply. The combustor was mounted onto the same assembly of convective cooling tube bank, stack, cyclone and associated sampling and monitoring equipment as that used above for the blended fuels.

4. RESULTS AND DISCUSSION

The properties of the *E. nitens*, coals and coal:biomass blends are given in Tables 1 and 2 and the combustion test conditions are shown in Table 3. Heat output was controlled to between 44 to 46kW output by controlling fuel feed rates and air flows. The combustion tests were carried out under similar conditions allowing for meaningful comparisons to be made. The combustion parameters such as oxygen level in flue gas and flue gas discharge temperatures are quite typical of those found at industrial sites. No difficulty was encountered in achieving and maintaining steady combustion conditions for any of the fuels or fuel blends.

Table 1. Fuel properties

Fuel	<i>E. nitens</i>	Kopak o	Huntly East	Terrace
Moisture %	56.0	24.3	15.9	20.6
Ash %	0.4	5.5	3.4	3.0
Volatile matter %	36.4	33.9	38.1	34.6
Fixed carbon	7.2	36.3	42.6	41.9
Calorific value MJ/kg (Gross)	8.65	20.89	24.47	23.5
Sulphur %	0.00	0.23	0.18	1.07
Ash composition				
SiO ₂ %	3.15	29.91	5.30	22.41
Al ₂ O ₃ %	0.79	17.38	8.40	10.61
Fe ₂ O ₃ %	1.20	5.81	5.70	6.34
CaO %	54.87	28.32	55.50	16.85
MgO %	8.02	2.97	3.30	8.91
Na ₂ O %	2.64	1.33	2.80	0.29
K ₂ O %	10.01	0.34	0.08	0.93
TiO ₂ %	0.13	2.23	2.40	0.56
MnO %	0.13	0.07	0.06	0.14
SO ₃ %	10.24	7.72	13.00	30.53
P ₂ O ₅ %	5.84	0.47	0.01	0.25
Ash Fusion, (Reducing)				
Softening °C	1520	1090	1250	1180
Spherical °C	1530	1130	-	1190
Hemisphere °C	1540	1150	1300	1200
Fluid °C	1560	1190	1340	1220
Volatile matter (dry ash free basis) %	83.6	48.3	47.2	45.2

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Table 2. Fuel blend properties - as fired basis

	Huntly: <i>E. nitens</i>	Kopako: <i>E. nitens</i>	Terrace: <i>E. nitens</i>
Moisture %	29.3	33.8	32.1
Ash %	2.4	4.0	2.1
Volatile matter %	37.6	34.7	35.2
Fixed carbon	30.8	27.6	30.6
Calorific value MJ/kg(Gross)	19.20	17.23	18.69
Sulphur %	0.12	0.16	0.73
Ash composition			
SiO ₂ %	5.18	29.09	21.22
Al ₂ O ₃ %	7.97	16.87	10.00
Fe ₂ O ₃ %	5.45	5.67	6.02
CaO %	55.46	29.13	19.20
MgO %	3.57	3.12	8.86
Na ₂ O %	2.79	1.37	0.44
K ₂ O %	0.64	0.64	1.49
TiO ₂ %	2.27	2.17	0.53
MnO %	0.06	0.07	0.14
SO ₃ %	12.84	7.80	29.28
P ₂ O ₅ %	0.34	0.63	0.60

Table 3. Combustion conditions and flue gas parameters

Fuel	Fuel weight (kg)	Test time (min)	Temperature at cooler entry (°C)	Discharge temp. (°C)	Flue gas velocity (m/s)	O₂ in flue gas (%)
Kopako	30.1	270	553	145	3.80	8.3
Huntly East	44.2	302	548	147	3.90	8.3
Terrace	38.1	302	557	139	3.71	7.8
<i>E. nitens</i>	46.5	258	523	126	3.80	10.5
Kopako: <i>E. nitens</i> 85:15	36.1	225	559	137	3.81	8.3
Huntly: <i>E. nitens</i> 85:15	35.0	243	597	137	3.76	7.9
Terrace: <i>E. Nitens</i> 85:15	35.0	230	602	138	3.79	7.3

Table 4 contains data relating to the flue gas composition and particulate emission levels from the various runs. Data relating to ash deposition and slagging is in Table 5.

Short Rotation Crops for Bioenergy: New Zealand, 2003

Table 4. Flue gas composition and particulates

Fuel	CO (ppm)	CH ₄ (ppm)	NO _x (ppm)	SO ₂ (ppm)	Particulates concentration at 12% CO ₂ (mg/dscm*)
Kopako	0	0	187	100	26
Huntly East	0	0	—	92	66
Terrace	0	0	394	888	53
<i>E. nitens</i>	2450	86	NM	2	191
Kopako: <i>E. nitens</i> 85:15	56	0	220	76	51
Huntly: <i>E. nitens</i> 85:15	31	0	196	70	105
Terrace: <i>E. nitens</i> 85:15	0	0	279	492	64

* dscm: dry standard cubic meter, at 101325 Pa, 0°C.

Table 5. Ash deposition

Fuel	Slagging fraction in bottom ash (%)	Slagging rate (kg/tonne fuel)	Slagging rate (kg/GJ)	Fly ash fraction in total ash (%)	Fly ash rate kg/tonne fuel	Fouling rate g/(h*m ²)
Kopako	61.7	30.3	1.4	5.3	2.4	14.3
Huntly East	62.7	18.6	0.8	6.0	1.5	8.3
Terrace	63.9	15.1	0.6	4.7	0.7	10.4
<i>E. nitens</i>	< 5	< 2	< 0.1			NM
Kopako: <i>E. nitens</i> 85:15	47.0	17.0	1.0	11.1	4.2	20.7
Huntly: <i>E. nitens</i> 85:15	49.7	8.6	0.4	16.6	2.6	14.4
Terrace: <i>E. nitens</i> 85:15	61.1	9.6	0.5	7.6	0.8	11.3

4.1 Environmental issues

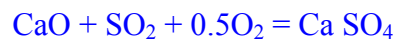
4.1.1 Particulates. Particulate emission levels tended to increase on addition of the *E. nitens* to the coals – in the case of addition to Kopako and Huntly coals the emission levels were (approximately) doubled (Table 4). Generally, biomass ash is lighter than coal ash and the cyclone in the test rig was designed specifically to capture higher density coal ash particulates. In practice it should be possible to at least minimise the increase by appropriate retuning of the cyclone assembly and by adjustments to flow rates and other operational parameters.

4.1.2 Sulphur dioxide. There is generally a decrease in sulphur dioxide emissions on addition of the *E. nitens* to the coals (Table 4). This is expected because the biomass has a significantly lower sulphur content than any of the coals but the extent of the decrease is in some cases considerably greater than expected purely on an arithmetic basis. In

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the case of Terrace coal for example, the sulphur concentration of the blend was approximately 68% of that of the coal alone while the emission level was 55% of that observed for coal combustion alone.

In addition to sulphur content of fuel, the levels of sulphur dioxide emitted from the stack are determined by firebox temperature and ash composition. As fed into the firebox the sulphur will be present as either a sulphate, a sulphide or as organic sulphur. Inside the firebox, the sulphates and sulphides may decompose and the organic sulphur is oxidised to sulphur dioxide. The alkaline oxides generated from the breakdown of minerals such as calcite and dolomite can capture sulphur dioxide and retain it within the ash. Calcium oxide is especially effective in this regard through the well-known reaction .



Calcium oxide is present in high concentrations in *E. nitens* ash and this is probably a major factor in the significant reduction in sulphur dioxide emissions seen in some instances.

4.1.3 Carbon monoxide and methane. It may be noted (Table 4) that the levels of both gases were quite significant on combustion of *E. nitens* alone but were essentially zero when the coals were burned on the well-tuned test rig. They remained very low for combustion of the blends with 15% *E. nitens* added. The firebox temperatures obtainable when combusting coals are significantly higher than those obtainable for the greater moisture content, lower calorific value *E. nitens* and this is helping to burn out carbon monoxide and methane. It can be calculated that for the coals under the prevailing combustion conditions, temperatures in excess of 1300°C may be achieved within the firebox. For the much higher moisture content *E. nitens*, temperatures not greatly in excess of 900°C are likely to be the maximum achievable.

4.1.4 Nitrogen Oxides (NO₂ and NO). It can be seen (Table 4) that there was a significant decrease in NO_x emissions on addition of *E. nitens* to the Terrace coal – a decrease of approximately 36%.

Nitrogen oxide generated from combustion is classified either as fuel NO_x or thermal NO_x. The nitrogen content of the fuel determines fuel NO_x while the firebox temperature plays a large part in determining thermal NO_x. The nitrogen content of the biomass is typically around 0.2% on a dry basis whereas that of the coal is typically nearer 1 %. The decrease in firebox temperature that accompanies addition of *E. nitens* contributes to decreased thermal NO_x and the combined overall effect is lowered NO_x levels.

4.2 Ash depositional Characteristics

4.2.1 Slagging. The quantity and hardness of slags are critical factors for boiler operation. Large amounts of slag or clinker formed in the bed will stop proper flow of air and lead to reduced combustion efficiencies. Hard slags will affect the ash removal system and serious levels of slagging can lead to unsafe, not to mention uneconomic, conditions.

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It can be seen (Table 5) that the addition of *E. nitens* has resulted in considerable reductions in the amount of slag formed and in slag formation rate. The reasons relate to the mineral chemical transformations taking place within the firebox.

As detailed in the accompanying paper on combustion of *E. nitens* alone, the major mineral phase present within this fuel as fed was whewellite – a monohydrated calcium oxalate – along with lesser contributions from silica and no clear evidence of aluminosilicate clay material. On heating through to 1050°C the major product was calcium oxide, along with smaller quantities of calcium aluminosilicates. Although calcium oxide is a well known fluxing agent, the low firebox temperatures associated with combustion of *E. nitens* coupled with the low levels of silica and alumina meant that very little slag formation occurred. On adding to coals, the effect is to lower firebox temperatures and reduce tendency toward slag formation.

4.2.2 Fouling. Fouling is ash deposition on heat exchange surfaces at high temperature. The initial driving force for fouling formation is evaporation of species such as sodium or potassium oxide from the firebox and reaction with sulphur dioxide to form alkaline sulphates which may condense on the heating surface as it passes the convective tube bank. Ash particulates entrained in the hot gas passing over the tube bank may then be trapped by the sticky condensates. When the ash deposition on the tubes reaches 1 mm thickness, the thermal efficiency of the boiler may drop by as much as 1 percentage point due to higher thermal resistance and reduced heat transfer.

It may be seen (Table 5) that when the biomass is added to the coals, there is an increase in fouling rate. However the fouling deposits are generally quite loose and, it may be expected that normal ash deposition removal equipment such as soot-blowers should be able to remove it and keep the convective surfaces sufficiently clear of build-up.

4.2.3 Biomass fuel handling and operational issues. The introduction of the biomass fuel did bring with it some, by no means insurmountable, difficulties in relation to fuel feeding. Unlike coal, the *E. nitens* may contain long stringy pieces that tend to block the fuel transport system typically used to convey coal to the boiler. It may also be noted that if the biomass has a high moisture content, extra heat is required to ignite the fuel at the correct time and location within the coal combustor. This can ideally be overcome by changes to operational conditions. In more severe cases it may require modifications to the existing firebox.

5. CONCLUSIONS

There are advantages and disadvantages associated with the addition of 15% *E. nitens* by calorific value to industrial sub-bituminous New Zealand coals.

The advantages include reduced sulphur dioxide emissions due to lower overall sulphur content of the fuel and to enhanced sulphur retention ability. There was also a reduced rate of slag formation, reductions in NO_x emissions and the high levels of carbon monoxide and

Short Rotation Crops for Bioenergy: New Zealand, 2003

methane sometimes seen when combusting the high moisture content *E. nitens* was greatly reduced when combusted with the coals.

One disadvantage was the increase in particulate emission levels and fouling deposit formation but it is likely that both of these difficulties could be dealt with readily enough by tuning operational conditions and the use of soot- blowers. Fuel feeding issues also arose but would be surmounted by use of a more suitable feed transport system.

The general conclusion is that the positive aspects outweigh the negatives when it comes to co-firing *E. nitens* with the New Zealand industrial sub-bituminous coals used in this evaluation.

The evaluations also show the wisdom of carrying out initial combustion tests of fuel blends prior to commercial application.

6. REFERENCES

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