ENERGY FOR INDUSTRY

# Co-firing of biomass with coal at the Dunedin Energy Centre

**A Report by Energy for Industry**
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# Acknowledgements

This report has been prepared by Energy for Industry (EFI), a business unit of Meridian Energy Limited. EFI's core business involves the development and operation of on-site industrial scale energy plants, in particular boilers and cogeneration plant.

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# Contents

# 1 Summary

This report summarises the results of Dunedin Energy Centre (DEC) boiler trials to investigate co-firing of biomass and coal.

## 1.1 DEC Overview

Energy for Industry purchased the Dunedin Energy Centre from the Otago District Health Board (ODHB) in 2002 under a BOOT partnership (Build, Own, Operate, Transfer). The energy centre comprises four coal-fired steam boilers with a total capacity of 30 MWth and a steam reticulation system. Energy in the form of steam and hot water are supplied to ODHB, Cadburys, the University of Otago, NZTS and a number of smaller customers.

Following acquisition of the Energy Centre, Energy for Industry carried out an extensive upgrade programme to extend the life of the plant and bring it up to modern best practice standards. Projects completed include the installation of a baghouse to reduce particulate emissions, upgrades of the control system and boiler feedwater treatment, installation of new standby power plant to support the Energy Centre, and installation of a new steam pipeline to Cadburys.

The co-firing trials were carried out using DEC Boiler 2 which is a 6.8 MW unit designed for coal firing with 2 spreader stokers, a 2 section dumping grate, multicyclones and bag filters. This boiler is currently fired with Ohai coal.

## 1.2 Wood Residues

Properties of the wood residues and coal used for the trials are shown below. Photographs of the fuels are provided in Section 2.6

| Material | Calorific Value (GJ/t) | Moisture Content (% w/w) | Bulk Density (kg/m³) | Predominant Size (mm) |
|---|---|---|---|---|
| Ohai Coal | 24.1 | 19.9 | 725 | 0 to 19 |
| Dry Wood Chips | 19.2 | 11.5 | 220 | 6.3 to 25 |
| Seasoned Wood Chips[1] | 14.3 | 33.8 | 270 | 6.3 to 25 |
| Green Wood Chips | 11.0 | 49.2 | 320 | 6.3 to 25 |
| Green Sawdust | 8.2 to 9.0 | 56.4 to 61.9 | 300 to 410 | 0 to 3.35 |
| Wood Pellets | 19.4 | 0 | 710 | 6.3 to 10.0 |

Notes: 1. Mix of green and dry wood chips simulating semi-dried chips.

## 1.3 Objectives

The trials were carried out to establish whether, and how, the co-firing of wood residues and coal affect fuel handling, boiler combustion conditions, ash volumes, baghouse filter operations and boiler emissions.

## 1.4 Anticipated performance issues

Project planning work by EFI identified a number of key fuel related performance issues (compared to Ohai coal) that were likely to effect the trials. These were:

### 1.4.1 Specific Fuel Density

Wood fuels typically have lower bulk densities and lower energy densities (on a solid volume basis) than coal. This means that fuel feed systems designed for coal may limit co-firing rates.

### 1.4.2 Fuel Moisture

Wood fuels can have a wide range of moisture content because wood absorbs water into its cells. This means that fuel properties are harder to predict and, when the fuel is wet, boiler efficiencies are lower and combustion air requirements are higher. In turn, these effects may derate the boiler.

### 1.4.3 Fuel Volatility

Wood fuels have much higher proportions of volatile matter (than fixed carbon) compared to coal. This means that wood produces more volatiles that burn in the furnace above the grate, and there is less heat release on the grate. This introduces the risk of higher back end temperatures and fires.

### 1.4.4 Ash Content

Solid wood has very low ash content which may make it harder to maintain a protective ash cover on the grate. On the other hand, mixed wood residues can be contaminated and have much higher ash content than pure wood fuels. The contamination may cause damage to equipment and limit co-firing rates.

### 1.4.5 Safety

Co-firing introduces more fuel variability, because of issues noted above, and the potential for fuel segregation. This has the potential to introduce serious safety hazards and operability problems.

## 1.5 Results and Conclusions

The results and conclusions below are based on short term trials of less than 24 hours duration. Further longer term trials are required to confirm the results of these trials, test reliability issues and determine the long term life cycle costs.

The maximum biomass energy contents that were co-fired with Ohai coal during the trials are shown in the table below. These represent the maximum blend ratios that were achieved during short term trials. As discussed in Section 1.6, longer term practical limits are expected to be lower than the values shown below.

| **Co-fired Biomass** | **Maximum Biomass in Fuel by Energy (%)** | **Mixed Fuel Energy Density ($GJ/m^3$)** | **Calculated Boiler Efficiency (%)** | **Observed Reason for Limit to Biomass Co-firing** |
|---|---|---|---|---|
| Ohai Coal | 0 | 17.5 | 80 | Not Applicable. |
| Dry Wood Chips | 49 | 6.9 | 78 | Size of fuel feeders. With larger feeders exhaust gas temperature may be limiting. |
| Seasoned Wood Chips | 31 | 8.4 | 78 | Size of fuel feeders. With larger feeders exhaust gas temperature may be limiting. |
| Green Wood Chips | 38 | 7.0 | 75 | Poor combustion due to wet fuel and/or limited forced draught air capacity. |
| Green Sawdust | 30 | 8.3 | 72 | Poor combustion due to wet fuel and mounding of green sawdust on grate. Higher percentages of green sawdust would smother the grate. |
| Wood Pellets | 44 | 15.6 | 80 | No limitation. Exhaust gas temperature might become limiting with more pellets in the blend. |

The trials showed that:

a) Co-firing with biomass reduces the energy density of the fuel from 17.5 $GJ/m^3$ with Ohai coal to, for example, 7.0 $GJ/m^3$ for 38% green wood chips on an energy basis. Segregation of co-fired fuel was not observed during the trials but, if it did occur, a boiler co-firing biomass could be accidentally over-fired.

b) Because of a) above, the preferred method for co-firing coal and biomass would use separate feeders for the two fuels.

c) The reduced energy density of biomass and coal blends will significantly reduce the inventory of fuel that can be held in reception hoppers and boiler day bins and it will increase the frequency of truck deliveries to the boiler site.

d) The trials showed that combustion conditions and the capacities of the coal feeders can limit the amount of biomass that can be co-fired and that bag filter temperatures could be a concern with increased amounts of biomass firing.

e) The trials did not show any other significant issues relating to fuel handling, ash volumes or boiler emissions.

f) The boiler efficiency reduces when the amount of wet biomass in the fuel blend is increased. This is due to the extra water in the biomass and to an increase in exhaust gas temperatures due to the combustion of more volatiles and char towards the back end of the boiler.

## 1.6 Recommendations

With appropriate precautionary safety margins, the recommended limits for biomass co-firing with coal in similar boiler plant are:

| **Co-fired Biomass** | **Biomass in Fuel by Energy (%)** |
|---|---|
| Dry Wood Chips | 35 |
| Seasoned Wood Chips | 30 |
| Green Wood Chips | 25 |
| Green Sawdust | 15 |
| Wood Pellets | 35 |

The preferred biomass fuels for co-firing are dry or seasoned wood chips, provided they are sized appropriately, have minimal contamination and the fuels have separate feed systems. This is based on good operability shown by these fuels with a moderate impact on boiler efficiency and fuel logistics (site fuel inventory and frequency of truck deliveries).

While green wood chips were compatible with the fuel handling systems, they are not preferred because reliable combustion was more difficult to achieve and blends with this fuel would significantly impact on boiler efficiency.

Green sawdust is not preferred due to the erratic and unreliable combustion conditions shown. This fuel may also increase the risk of damage to the furnace and bag house filters.

Wood pellets showed good compatibility and are expected to have low impact on boiler efficiency and fuel logistics. Wood pellets are not preferred in this application however, as they are currently a premium fuel that is unlikely to be economic for industrial scale facilities.

# 2 Introduction

This report summarises the results of Dunedin Energy Centre (DEC) boiler trials to investigate co firing of coal with biomass residues.

The DEC is owned and operated by Energy for Industry (EFI) which is a business unit of Meridian Energy Limited. The DEC is located at 169 Castle Street, Dunedin, New Zealand.

## 2.1 DEC Boilers

### 2.1.1 Boilers

The trials were carried out using the DEC Boiler 2 which is a 6.8 MW Daniel Adamson Cross Drum coal fired water tube boiler with a 3 pass convective bank, 2 spreader stokers and a 2 section dumping grate. The boiler has a maximum capacity rating (MCR) of 10.5 t/h steam at 10.3 bar g from feed water at 105°C.

During the trials, Boiler 2 was operating in conjunction the other DEC boilers with details as follows:

| | |
|---|---|
| Boiler 1: | 6.8 MW Daniel Adamson boiler identical to Boiler 2. |
| Boilers 3 and 4: | 7.4 MW and 7.6 MW John Thompson boilers with configurations similar to Boiler 2 and respectively rated to produce 11.4 t/h and 11.7 t/h of 10.3 bar g steam from water at 105°C. |

The boilers currently operate on Ohai coal with a calorific value of approximately 24 MJ/kg.

### 2.1.2 Ancillary Boiler Equipment

The DEC boilers include ancillary equipment as follows:

a) Feed water treatment and condensate return systems.

b) An in-ground hopper for fuel reception from tipping trucks and trailers.

c) A bucket elevator and conveyor system for the delivery of fuel to 2 day bins on each boiler; i.e. to a total of 8 day bins.

d) A wet scraper conveyor system for grate ash removal to a skip.

e) Multicyclone and bag filter systems for the removal of particulate material from boiler exhaust gas streams and pneumatic conveying systems to discharge fly ash to a skip.

## 2.2 Biomass Fuels

### 2.2.1 Planned Trials

The trials were carried out by co-firing Ohai coal with either dry wood chips, seasoned wood chips, green wood chips, green sawdust or wood pellets. The programme did not include trials with hogged wood residues because hogged material would not be compatible with the fuel handling equipment on the DEC boilers.

On an energy and volume basis, the targeted co-firing ratios for biomass and coal were as follows:

| Co-fired Biomass | Biomass Moisture Content (% w/w) | Biomass : Biomass + Coal | |
|---|---|---|---|
| | | Energy Ratio (%) | Estimated Volume Ratio (%) |
| Dry Wood Chip | 20 | 20, 40, 60 | 50, 70, 85 |
| Seasoned Wood Chip | 52 | 10, 20, 30 | 50, 70, 85 |
| Green Wood Chip | 60 | 10, 20, 30 | 45, 66, 75 |
| Green Sawdust | 60 | 10, 20 | 45, 65 |
| Wood Pellets | 10 | 40, 60 | 55, 70 |

### 2.2.2 Fuel Analyses

Table 2.1 lists the measured properties of Ohai coal and the biomass wood materials.

Ohai coal has a calorific value (CV) of approximately 24 MJ/kg, a bulk density of 725 kg/m$^3$ and a dry ash free basis volatile content of 44% w/w.

In contrast the biomass wood materials have:

a) Lower CVs of 8.2 to 19.2 MJ/kg.

b) Lower bulk densities of 300 to 710 kg/m$^3$.

c) Higher volatile contents of approximately 82% w/w on a dry ash free basis; i.e. approximately twice the volatile content found in sub-bituminous coal.

**Table 2.1** Analyses of Coal and Biomass Fuels

| **Fuel** | **Ohai Coal 1** | **Ohai Coal 2** | **Dry Wood Chip** | **Green Wood Chip** | **Green Sawdust 1** | **Green Sawdust 2** | **Green Sawdust 3** | **Wood Pellets** |
|---|---|---|---|---|---|---|---|---|
| **Bulk Density** (kg/m$^3$) | 725 | 725 | 220 | 320 | 300 | 410 | 370 | 710 |
| **Analysis** (as received) | | | | | | | | |
| Calorific Value (MJ/kg) | 24.1 | 23.3 | 19.2 | 11.0 | 9.1 | 8.2 | 9.0 | 19.4 |
| Moisture Content (% w/w) | 19.9 | 19.2 | 11.5 | 49.2 | 56.4 | 61.9 | 56.6 | 0.0 |
| Ash Content (% w/w) | 3.6 | 4.6 | 0.5 | 0.4 | 0.2 | 0.3 | 0.3 | 0.6 |
| Volatiles (% w/w) | 33.5 | 34.6 | 71.9 | 42.8 | 35.5 | 32.6 | 35.2 | 81.3 |
| Fixed Carbon (% w/w) | 42.9 | 41.6 | 16.1 | 7.5 | 8.0 | 5.3 | 7.7 | 18.2 |
| Sulphur (% w/w) | 0.3 | 0.2 | - | 0.1 | - | 0.1 | - | - |
| **Size Distribution** (% w/w) | | | | | | | | |
| Plus 50 mm | 0 | 0 | 0 | 0 | 0 | | | 0 |
| 25 to 50 mm | 0 | 0.3 | 5.2 | 0.6 | 0 | | | 0 |
| 19 to 25 mm | 0.8 | 0.6 | 20.1 | 13.1 | 0 | | | 0 |
| 10 to 19 mm | 45.2 | 30.8 | 46.0 | 50.6 | 0 | | | 0 |
| 6.3 to 10 mm | 24.8 | 18.2 | 14.9 | 18.9 | 0 | | | 98.3 |
| 3.35 to 6.3 mm | 18.1 | 24.1 | 8.8 | 11.9 | 1.1 | | | 0.9 |
| 2 to 3.35 mm | 6.1 | 12.4 | 2.2 | 2.9 | 29.7 | | | 0.2 |
| 1 to 2 mm | 2.8 | 7.9 | 1.1 | 1.3 | 49.1 | | | 0.3 |
| Minus 1 mm | 2.1 | 5.7 | 1.7 | 0.7 | 20.1 | | | 0.3 |

### 2.2.3 Fuel Energy Density

The differences in the CVs and bulk densities between Ohai coal and the biomass fuel result in significant variations in the energy densities when the fuels are co-fired.

Ohai coal at 24.1 GJ/t and 0.725 t/m³ has an energy density of 17.4 GJ/m³.

In contrast, a 1:1 by volume mixture of Ohai coal and green wood chips at 11.0 GJ/t and 320 kg/m³ gives a Biomass:Total Energy ratio of 15% and a fuel with an energy density of 10.5 GJ/m³.

A 15% energy blend of green wood chips in coal therefore results in a fuel energy density that is only 60% of the energy density for Ohai coal on its own. This example shows that biomass and coal blends:

a) Reduce the amounts of energy that can be stored in the reception hopper and the boiler day bins.

b) Increase the volumetric flow rates of fuel that has to be moved through the boiler fuel feeders to operate a boiler at a given steam output.

### 2.2.4 Biomass Combustion

An overview of biomass properties is provided by "Biomass Fuel Properties and Basic Principles of Biomass Combustion" Earthscan, London, 2008.

Using this reference, features of biomass combustion, which may differ from the behaviour observed for the combustion of Ohai coal, are as follows:

a) Wet biomass may require prolonged drying and heating prior to ignition on the grate.

b) Some devolatilisation may occur while water is being driven off from biomass and this may result in incomplete combustion.

c) With reference to Table 2.1 (in this report), the dry ash free volatile content of the wood residue is 82% w/w as opposed to 42% w/w for Ohai coal. Light particles of char from the wood residue will also be entrained in the exhaust gas and carried out of the radiant zone of the boiler. The higher volatile content of the wood residue and the generation of light char particles during wood combustion may result in high exhaust gas temperatures due to increased combustion towards the back end of the boiler.

d) Wood residues may contain up to 70% w/w moisture content. The boiler combustion efficiency will decrease with increasing wood moisture content and combustion will not be self supporting if the moisture content is over approximately 66% w/w. This is because the cooling effect of water evaporation will prevent ignition.

e) Solid wood has very low ash content which may make it harder to maintain a protective ash cover on the grate.

f) The fuel properties of wood residues are harder to predict due to the variable moisture and ash contents.

## 2.3 Objectives

The trials were carried out to assess boiler operability with each of the biomass:coal fuel blends and to identify the risks associated with co-firing biomass.

## 2.4 Methodology

The trials were planned to minimise the risk of disruption to DEC steam supply customers and to maximise the information obtained from the trials. Table 2.2 provides a summary of the trials carried out with calculated biomass ratios and energy densities for each blend.

**Table 2.2** Summary of Biomass Trials

| Trial | Biomass blend | Ohai Coal (% Volume) | Biomass (% of total by) | | | Energy Density (GJ/m³) |
|---|---|---|---|---|---|---|
| | | | Volume | Mass | Energy | |
| 3.1 | Dry wood chip | 50 | 50 | 23 | 19 | 10.8 |
| 3.2 | Dry wood chip | 33 | 67 | 38 | 33 | 8.6 |
| 3.3 | Dry wood chip | 20 | 80 | 55 | 49 | 6.9 |
| 4.1 | Seasoned wood chip | 33 | 67 | 43 | 31 | 8.4 |
| 5.1 | Green wood chip | 33 | 67 | 47 | 29 | 8.2 |
| 5.2 | Green wood chip | 25 | 75 | 57 | 38 | 7.0 |
| 6.1 | Green sawdust | 50 | 50 | 36 | 17 | 10.6 |
| 6.2 | Green sawdust | 33 | 67 | 53 | 30 | 8.3 |
| 6.3[1] | Green sawdust | 33 | 67 | 53 | 30 | 8.3 |
| 7.1 | Wood pellets | 50 | 50 | 49 | 44 | 15.6 |

Notes: 1. Trial 6.3 is a repeat of trial 6.2.

### 2.4.1 Risks

A risk register was developed to help identify specific risks, the potential impact of the risk, mitigation measures and the planned response to the risk should it occur.

The key risks associated with the trials were judged to be as follows:

a) Large flexible wood chip materials jamming or breaking fuel feed stokers.

b) Wet fuels extinguishing fires on the grate if coal and biomass fuels become segregated.

c) Carry over of combustible char into the bag filters with the associated risk of fires and bag damage.

d) Furnace explosions due to accumulated wet fuel drying out on the boiler grate leading to reducing conditions in the furnace.

e) Excessive fly ash flow rates and conveyor overloading due to char carry over.

f) Piles on the grate due to the accumulation of wood materials that cannot be thrown significant distances by the coal feeders.

g) Elevated temperatures at the back end of the boiler due to wood volatiles and char carry over.

h) Reduced boiler capacity due to lower fuel energy densities as discussed above.

i) Blockages in fuel handling systems due to breakdown of wood pellets when combined with the free moisture in the coal.

j) Inconsistent fuel blends due to segregation of coal and large wood chips in the day bins.

k) Dust emissions due to the discharge of wood residues from trucks dumping into the in-ground hopper.

l) Grate damage due to lower biomass ash contents and reduced ash cover on the grate.

m) Blockages in the wet grate ash discharge systems due to ash that floats.

### 2.4.2 Approach to Trials

Peak DEC steam demand occurs between 7.00 am and 1.00 pm when all of the major steam users are operating. The trial programme used to minimise the risks associated with each new fuel blend were therefore as follows:

a) Empty the day bins on the trial boiler (Boiler 2) during the afternoon.

b) Deliver a minimum quantity of the trial fuel to Boiler 2 by approximately 6.00 pm.

c) Run a short test with the new trial fuel between 4.00 pm and 8.00 pm.

d) Fill the Boiler 2 day bins with trial fuel material if the initial trial had proven suitable operating conditions and then bank the boiler overnight.

e) Commence the main part of the trial with the new trial fuel blend at 7.00 am the following morning.

The short test the night before the main trial allowed time for the Boiler 2 day bin to be emptied of trial fuel during the night if it proved to be unsuitable.

The trials were also carried out starting with dry biomass blends and progressing towards increasing ratios of wet biomass blends. This allowed the identification of operating problems that would affect boiler operability before they were present as major problems preventing boiler operations.

#### 2.4.3 Preparation of Blends

Blends were prepared in a coal yard approximately 1.5 km away from the DEC site.

Approximately 0.8 $m^3$ front end loader scoops of biomass and coal were loaded into a 10 tonne truck. Following loading the truck was weighed and driven to the site and dumped into the fuel reception hopper. The mixed fuel was then elevated and dumped into the Boiler 2 day bin.

The 3 fuel pickups and fuel dumps by the loader, the truck and the elevator provided good mixing of the coal and biomass materials.

### 2.5 Reporting of Results

A summary of the results for blends for each biomass are provided in Sections 3 to 7.

### 2.6 Photographs

Photographs relating to the trials are provided for general interest below.

#### 2.6.1 Wood Chip Photographs

Typical wood chip.

Typical wood chip.

Dry wood chip.

Dry wood chip.

Loader.

Wood chip and coal.

Wood chip blend, 3m3 in truck.

Wood chip blend, 6m3 in truck.

Wood chip blend at coal reception.

Wood chip blend at coal reception.

Wood chip blend, grate low fire.

Wood chip blend grate, high fire.

### 2.6.2 Green Sawdust Photographs

Green sawdust.

Green sawdust.

Green sawdust.

Green sawdust zoom.

Sawdust blend, 6m3 in truck.

Sawdust blend at coal reception.

### 2.6.3 Wood Pellet Photographs

Wood pellets.

Wood pellets.

Wood pellets on truck.

Wood pellet blend on truck.

Pellet blend at coal reception.

Pellet blend on fuel feeder.

## 2.6.4 Fuel Yard Photographs

Ohai coal pile.

Ohai coal pile.

Fuel yard.

Wood chip pile.

# 3 Results for trials with dry wood chips

Three trials were carried out with dry chips using blend ratios as follows:

| Trial | Biomass % | | | Energy Density (GJ/m³) | Calculated Boiler Efficiency (%) |
|---|---|---|---|---|---|
| | By Volume | By Mass | By Energy | | |
| 3.1 | 50 | 23 | 20 | 10.8 | 80 |
| 3.2 | 66 | 38 | 33 | 8.6 | 79 |
| 3.3 | 80 | 55 | 50 | 6.9 | 78 |

The key conclusions from the trials co-firing coal and dry wood chips are as follows:

a) Co-firing dry wood chips and coal elevates boiler back end temperatures as shown in Figure 3.1. With reference to Figure 3.1, the economiser outlet temperature at MCR of approximately 205°C with coal increases to 215°C when a 4:1 volume mixture of dry wood chips and coal is burnt in the boiler.

b) For Trial 3.3, Boiler 2 operated close to the Maximum Continuous Rating (MCR) of 10.5 tph steam production on 50% (by energy) dry wood chips. Fuel feeders were operating at 100 Hz for this steam production rate, which is more than twice their normal operating speed of 48.5 Hz. It is likely that long term operation at high speeds would result in chain damage and excessive wear.

c) The fuel feeder throat areas would have to be increased, or the fuel feeders would have to be replaced with larger units, to operate Boiler 2 on dry wood chip blends.

d) Short duration trials indicate that dry chips and Ohai coal can be co-fired at the blend ratios shown above without any operating problems as long as the coal and biomass blend is consistent.

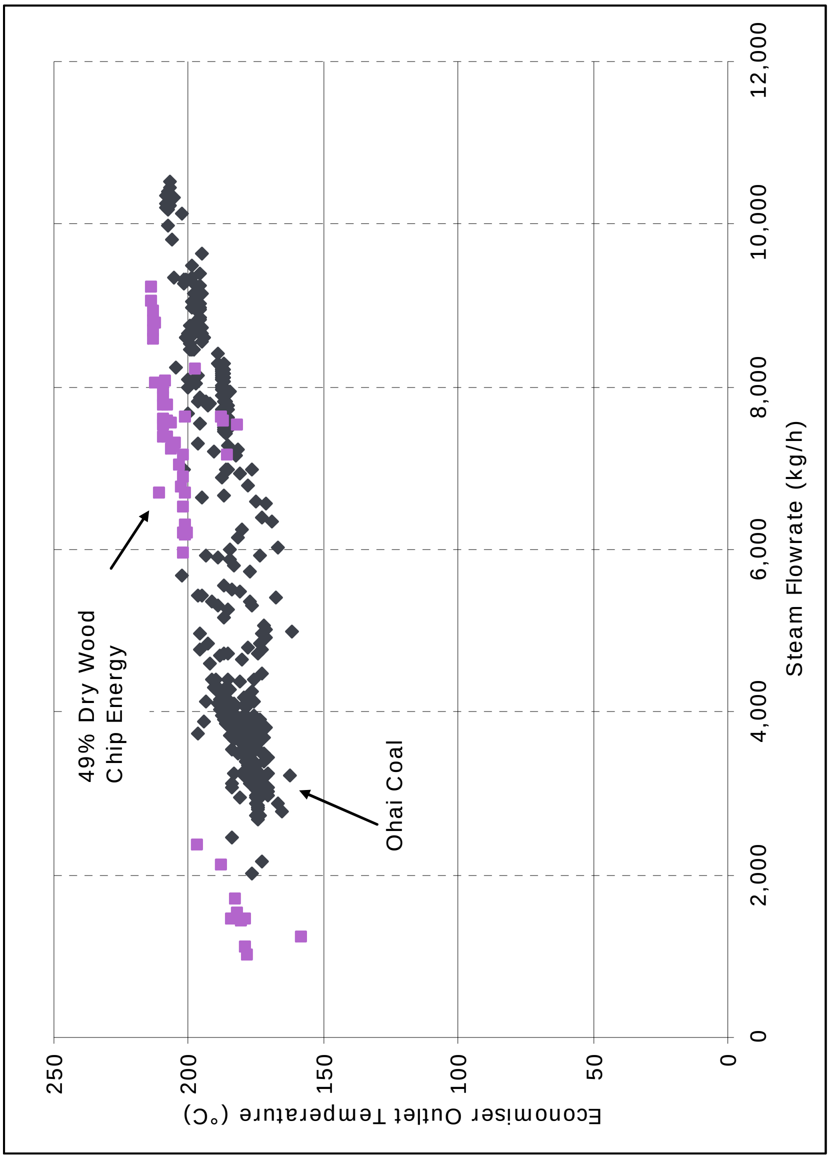


**Figure 3.1** The effect of steam flowrate on economiser outlet temperature.

# 4 Results for trial with seasoned wood chips

One trial was carried out by blending equal quantities of wet and dry wood chips with coal. The mixture of wet and dry wood chips was used to simulate seasoned wood chips; i.e. chips which have been partially dried by storage in a covered heap. The blend ratios for the trial were as follows:

| Trial | Biomass (%) | | | Energy Density ($GJ/m^3$) | Calculated Boiler Efficiency (%) |
|---|---|---|---|---|---|
| | By Volume | By Mass | By Energy | | |
| 4.1 | 67 | 43 | 31 | 8.4 | 78 |

The trial showed that:

a) Boiler 2 can operate close to the MCR of 10.5 tph steam production with 31% seasoned wood chips by energy but the fuel feeders were operating at 100 Hz for this steam production rate. This is more than twice their normal speed of 48.3 Hz on Ohai coal.

b) The fuel feeder throat areas would have to be increased, or the fuel feeders would have to be replaced with larger units, to operate Boiler 2 on seasoned wood chip blends.

# 5 Results for trial with green wood chips

The trials were carried out with green wood chips using blend ratios as follows:

| Trial | Biomass (%) | | | Energy Density (GJ/m³) | Calculated Boiler Efficiency (%) |
|---|---|---|---|---|---|
| | By Volume | By Mass | By Energy | | |
| 5.1 | 67 | 47 | 29 | 8.2 | 76 |
| 5.2 | 75 | 57 | 38 | 7.0 | 75 |

The key conclusions from the trials co-firing coal and green wood chips are as follows:

a) Co-firing green wood chips and coal elevates the boiler back end temperatures as shown in Figure 5.1. With reference to Figure 5.1, maximum economiser outlet temperatures of 200°C with coal increase to more than 225°C when a 3:1 volume mixture of green wood chips and coal is burnt in the boiler.

b) Boiler 2 achieved MCR on 29% green wood chips by energy with good firing conditions and a fuel feeder speed that was 2.75 times the speed required for MCR steam production on Ohai coal.

c) Boiler 2 achieved MCR on 38% green wood chips by energy but flue gas carbon monoxide readings were high at 2,500 ppm indicating poor combustion. This may be due to clinkers which were observed on the grate or limitations in the air flow rate that was supplied by the forced draught (FD) fan.

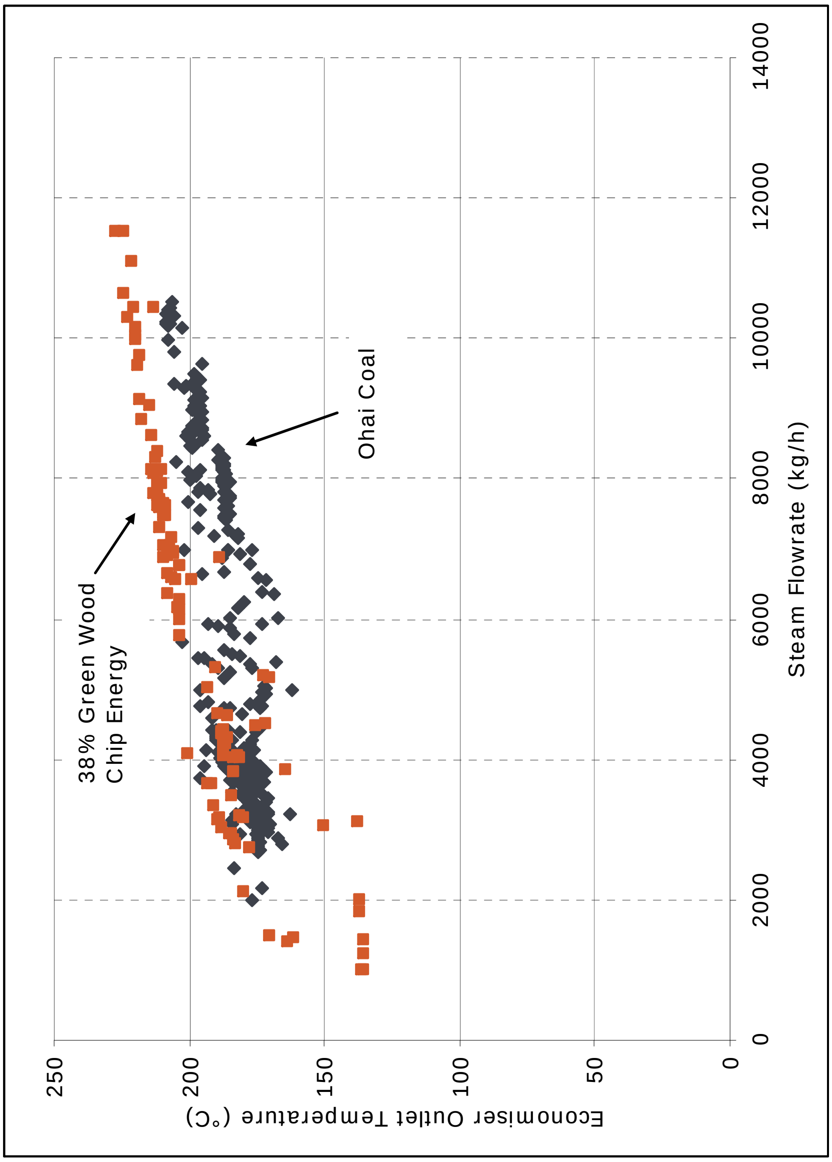


**Figure 5.1** The effect steam flowrate on economiser outlet temperatures.

# 6 Results for trial with green sawdust

Two trials were carried out with green sawdust and the second of these trials was repeated to confirm initial results.

The blend ratios used were as follows:

| Trial | Biomass (%) | | | Energy Density (GJ/m³) | Calculated Boiler Efficiency (%) |
|---|---|---|---|---|---|
| | By Volume | By Mass | By Energy | | |
| 6.1 | 50 | 36 | 17 | 10.6 | 77 |
| 6.2 | 67 | 53 | 30 | 8.3 | 72 |
| 6.3 (1) | 67 | 53 | 30 | 8.3 | 74 |

Notes: 1. Repeat of Trial 6.2 but the green sawdust moisture content was 56% w/w instead of 62% w/w.

The green sawdust moisture content ranged from 56% to 62% w/w.

The key conclusions from the trials co-firing coal and green sawdust are as follows:

a) Co-firing coal and green sawdust led to increased economiser exit temperatures of more than 220°C as opposed to approximately 200°C for 100% coal firing; see Figure 6.1.

b) When Boiler 2 was co-fired with 17% green sawdust energy, mounds of unburnt green sawdust formed across the grate 1 to 2 m into the boiler from the coal feeders. This appeared to be the location where green sawdust with a particle size of 3 mm to 6 mm landed on the grate. Some clinker formed within the mound of unburnt green sawdust and the grate was manually raked and on one occasion dumped to maintain a good fire.

c) When Boiler 2 was co-fired with 29% green sawdust energy, mounds off unburnt green sawdust formed 1 to 2 m into the grate and these mounds were emitting smoke. At a given firing rate the steam production rate varied by up to 2 tph. This indicated that the fuel was lighting erratically after it was fed into the boiler.

d) Based on the results of Trials 6.1, 6.2 and 6.3 it was concluded that Boiler 2 could not be reliably operated by co-firing with more than 30% green sawdust on an energy basis.

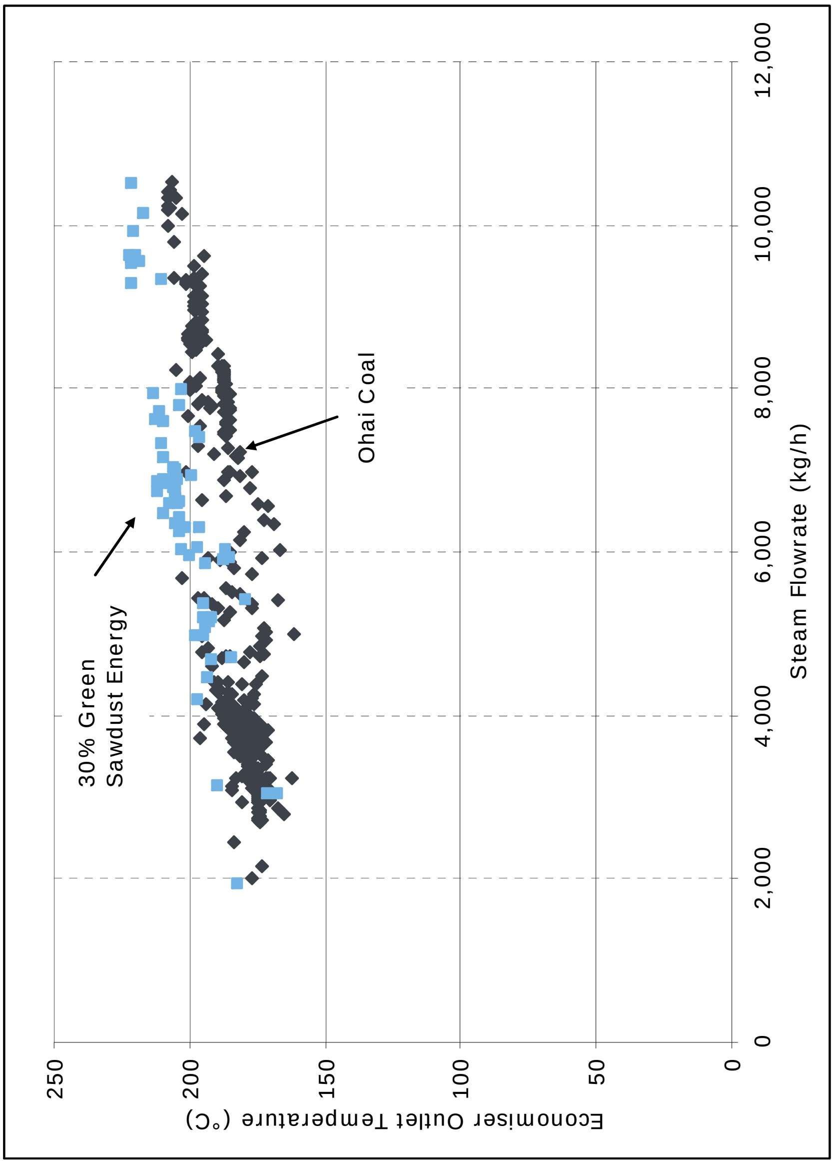


**Figure 6.1** The effect steam flowrate on economiser outlet temperatures.

# 7 Results for trial with wood pellets

One trial was carried out with a coal and wood pellet blend as follows:

| Trial | Biomass (%) | | | Energy Density (GJ/m³) | Calculated Boiler Efficiency (%) |
|---|---|---|---|---|---|
| | By Volume | By Mass | By Energy | | |
| 7.1 | 50 | 49 | 44 | 11.9 | 80 |

The key conclusions from the trial co-firing wood pellets are as follows:

a) The pellets did not break down due to moisture in the Ohai coal.

b) Boiler 2 co-fired on 44% pellets by energy without any operating problems to produce MCR steam production rates without any changes to the control settings used for Ohai coal.