Final report

Biomass Energy

Multi-Fuel Biomass Boiler Pilot

Project code	Prepared by	Date submitted
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Contents

1.0 Executive summary

Two sites have now hosted the biomass pilot: JBS at Riverina (NSW) and Thomas Foods International (TFI) at Lobethal (SA). Key highlights of the project were:

- For a red meat processor (RMP) with rendering, approximately 10% to 15% of boiler fuel energy could come from paunch with an additional ~5% from unrecyclable paper and cardboard, broken pallets, demolition wood and dewatered sludges. The remaining 80% of boiler energy would be biomass hauled to site, such as woodchip (or other biomass such as shells). Woodchip was procured at $85/tonne delivered (~$28.05 / m^3), which at 13.45 GJ/t results in fuel costs of approx. $6.32 / GJ at current east coast Australia woodchip prices, hence a final boiler fuel price of $5.06 / GJ, which **is considerably lower than current LPG costs (~$40/GJ), natural gas (~$20 to 30/GJ) and coal (~$12 to 16 / GJ).**

- The first pilot in NSW successfully combusted 100% paunch, and blends of paunch/sludge, woodchip and nut shells (walnuts), all sources from local businesses. This project was a true example of industrial ecology / circular economy.

- This project deployed a 523 kW containerised boiler at two Australian locations, utilising the fuels outlined in the table below.

Location	Fuels utilised
NSW	Paunch / sludge (air dried for 6 weeks). Air dried woodchip. Walnut shells. Mixtures of the above fuels.
South Australia	Green woodchip

- Some high level estimated economics for biomass boilers: For an 11 MW boiler[1] (2 shifts per day, 5 days per week, 50 weeks pa) the fuel cost savings are estimated at $7.3mil pa versus LPG, $5.2mil pa versus natural gas and $1.4mil versus coal. Additionally, the value of emissions abatement (assuming $35.05 / t CO_2-e)[2] is in the range of $0.6 mil pa for coal to $0.3 mil pa for natural gas. The simple payback period assuming $12.2mil for an 11 MW biomass boiler is estimated at 1.6 years for LPG, 2.2 years for natural gas and 5.8 years for coal. Some additional advantages not included in the above economics:
    - Reduced paunch / waste haulage costs,
    - Reduced landfilling / waste management costs,
    - Reduced greenhouse gas emissions (Scope 3) associated with reduced landfilling of organics.
    - Compared to coal, towards 90% or more reduced ash due to the very low ash content of woodchip (<1% w/w).

[1] This sized boiler supports a RMP of approx. 880 – 1100 head per day; ~66,000 – 82,500 HSCW pa.
[2] ACCUs.com.au, accessed 29th August 2024.

How the project came about: the GHG emissions intensity of Australia's RMPs is trending in the right direction, however aggressive targets of carbon neutrality by 2030 called upon the industry, represented by AMPC, for step changes in GHG emissions intensity. Of particular interest is how to reduce Scope 1 GHG emissions associated with on-site boilers. RMPs have a range of biogenic fuels available within existing supply chains hence this project considers how to generate heat with dramatically less GHG emissions at the same or better price point than coal. AMPC is funding this core project, motivated by the recent results in the 2020 Environmental Performance Review which showed that on average, total site GHG emissions were reduced by 8.1% compared to 2015 (397 kg / t HSCW vs 432 kg / t HSCW), which is encouraging considering that energy use intensity increased by 10.4% in the same period

This project is beneficial to Australia's RMI as a biomass boiler replacing a fossil fuel boiler addresses the **"Energy Trilemma"** facing Australia of:

[1] Lower GHG emissions energy (refer calculation below),

[2] Mitigate rising costs / energy at the most affordable rate (i.e. a biomass boiler has a stretch target of heat at $3/GJ as opposed to $12-16/GJ for coal, $20-30/GJ for nat gas (depending upon region / scale of off-take) and $30-40/GJ for LPG).

[3] Stable energy supply (i.e. fuel from within the supply chain, from renewable sources and from local sources as opposed to imported fuel or fuel transported over long distances).

Figure 1: Biomass Pilot installed in NSW. The 40' containerised boiler is in the front of the image, with the 20' fuel hopper located behind.

Figure 2: Biomass Pilot installed in SA.

The biomass pilot works completed at Riverina NSW (using the same pilot then installed at Lobethal) was announced as a Finalist for the Institute of Chemical Engineering Australasian awards 2024 for two (2) areas:

(1) Industry Project Award, and

(2) Sustainability Award.

Winners will be announced at the CHEMECA Conference, Monday 30th Sept 2024.

Industry Project Award

FOR ORGANISATIONS, PARTNERSHIPS AND TEAMS

Recognises the best chemical engineering project, undertaken in the last four years*, to be implemented in industry. This includes, but is not limited to, construction of new plant and the adaptation of existing facilities. *project started no earlier than 1 January 2020.

Sustainability Award

FOR ORGANISATIONS, PARTNERSHIPS AND TEAMS

Recognises the project, process or product demonstrating an excellence in sourcing and consuming materials, reducing waste, and/or optimising the product life cycles.

2.0 Introduction

Industry has traditionally utilised “easier” fuels, specifically: natural gas, LPG, or coal. This fuels have traditionally been considered easier due to availability, consistency and ease of use. However due to increasing costs, scarcity, and a greater focus on sustainability and social license to operate, there is motivation to consider biomass as a thermal fuel.

Biomass requires more effort to use as a fuel:

- The feedstock is variable
- Biomass starts with a high moisture content and must either be dried to the boiler specification or used in a boiler with technology that is suited to handling high moisture biomasses i.e. hoppers and augers designed to prevent bridging; moving grate; grate at an angle to enable biomass ash to be moved to outlet auger; automated oxygen % / combustion air control to maximise combustion; high fuel and gas residence times to ensure complete combustion, often including multiple (3-4) points of combustion air addition and multiple gas passes.
- Compared to natural gas, the fuel needs to be trucked to site followed by the above challenges of materials handling.
- Compared to LPG and natural gas, bottom and fly ash is created.

However, there are a number of distinct advantages of using biomass for energy. Addressing the energy trilemma of cost, emissions, and security requires different fuels utilising different technologies. The engineering process to implement a biomass boiler using a previously unproven fuel was

1. Detailed sampling of prospective fuels from a diverse source of biomasses. Lab analysis of moisture, higher and lower heating values, ash content, ash deformation and fusion temperatures, and particle size. Fuels included dissolved air floatation (DAF) sludge, solid screenings from waste water, pond sludges, walnut shells, cotton gin trash, timber milling by-product (woodchips) and paunch. [Figure 1]

2. Produce a trend of moisture vs LHV for specific biomass feedstocks.

3. Using an innovative process, produce a solid boiler fuel from 30% dewatered pond sludge and 70% paunch with low moisture and calorific value approximately equivalent to woodchip. Compared to raw biomass, advantages of this fuel are easier materials handling, reduced emissions, reduced risk of fires in stockpiling, improved fuel homogeneity and burn performance.

4. Consult with forestry and sawmill industry experts on stockpiling practices to ensure optimal and safe air-drying and materials handling

5. Assess the highest impact value of low grade heat in a red meat processing plant. Demand for hot water peaks at the beginning, middle, and end of shifts for hand washing, knife sterilisation, and cleaning. After periods of extended boiler downtime (e.g. weekend) this represents a large amount of fossil fuel usage to generate high pressure steam that is then heat exchanged to create 85 DegC water.

6. The polit biomass system maintained temperature in a lagged hot water tank (average dT 10 degrees vs baseline). Over a 5 month period, this pilot saved $34,000 in natural gas costs at $20/GJ, up to $51,000 for LPG at $30/GJ. [Figure 2 and 3]

Biomass has traditionally been considered difficult due to materials handling issues, high moisture, fuel variability and perceived limited availability. This project showed that biomass can be utilised providing energy at a lower cost that has lower GHG emissions and can be reliable by being sourced on-site from by-products or from adjacent industries, rather than being imported.

All of the innovative fuel blends exceed the recommended thresholds for biomass boilers in some way, be it the moisture content (paunch), the ash content (sludge) or calorific value with all blends. However, plant operators and service providers brought their experience to the project to find operational modes that delivered acceptable thermal outputs. As a specific example, a primary learning of the pilot was to run the moving grate hard (high mass transfer rate) to ensure complete evaporation of entrained moisture, homogenous combustion, and optimal usage of the full grate surface area minimising particulates and CO, increased thermal output and a high operating temperature (as opposed to a lowered fuel addition rate & grate movement with high primary / secondary air). [Figure 4 and 5]

This project aimed to be a true example of industrial ecology: rather than wastes and by-products of an industrial processing plant being unutilised / a disposal problem, organic wastes were utilised to generate energy onsite for a food manufacturing facility. Note: Lobethal pilot only utilised woodchip and wood shavings (for start-up).

3.0 Project objectives

The project objectives were:

• Demonstrate process plant wastes as a viable fuel source. Historically, the perception of wastewater sludges and paunch (grass/grain wastes) was being too moist and of no inherent value, and either disposed to landfill or at-best, composted for land application.

• Prove the materials handling, combustion, and safety of these bio-wastes in addition to locally sourced biomass (walnut shells, and timber milling by-product). A demonstration was completed over a six (6) month period at the JBS Riverina site in Yanco (NSW, Australia) testing blends of locally procured biomass (walnut shell, woodchip), paunch, and paunch / sludge blends.

• A critical risk area was that the onsite wastes did not adhere strictly to any of the fuel specification listed by any boiler vendors. Due diligence on feedstock-boiler combinations was completed and ultimately feedstock drying and blending to obtain a final renewable energy source that was fit for purpose. That is, specifications that had moisture, ash, particle size, ash fusion temperature and chemical composition workable for a boiler.

• Assess GHG emissions performance of biomass combustion and implications for environmental and work health and safety approvals.

• Enable knowledge sharing and skill development in the industry, and provide economically viable pathways forward for GHG reduction, energy security, and landfill reduction.

• CAPEX, RoI and GHG emissions assessment for a scaled-up industrially relevant system (11 MWt).

4.0 Methodology

The Project Methodology is defined as follows:

- Member EoI process to short list suitable sites for hosting biomass boiler pilot
- Assessment of participant on-site biomass fuel tonnages and composition (e.g. paunch moisture and ash), and situational analysis around access to circular economy type agricultural wastes that are suitable such as biomass, and likelihood of council / EPA approval
- Consideration of ease of pilot installation and tie-ins (Steam, treated water, power, blowdown)
- Selection of participants
- Confirm final design and costings
- Council and EPA applications and permits (responsibility of site; technical support as required)
- Procure pilot
- Install, commission, pilot trial and demobilisation of pilot for 3 plants (i.e. a further 3 plants may be selected after the mid-term major review with go / no go / redirection decision). A specific area for consideration is the suitability of towards 100% paunch utilisation with a biomass boiler. Up to 6 months of time has been allocated to each site which includes transportation, installation, commissioning, feedstock pre-treatments and operations
- Interim and Final reports to include a full scale design, business case, detailed fuel considerations and funding options.

Whilst extensive efforts have been invested to accurately estimate the costs for the installation of a modular boiler, site specific costs for safety requirements, installation and tie-ins were unknown as the project was budgeted before site selection. Any costs over the allocated per site budget were funded by the host site. An allowance for funding has been allocated per site to assist with some of the costs (i.e. see included and excluded items from the modular pilot listed below):

- Bag filter (where additional emissions control is required), all at hosts expense
- Stainless ducting where boiler turned on/off daily, all at hosts expense
- Foundations / Civils / Boiler house/ Fuel slab / Fuel shed
- Treated (softened / RO) water supply
- Blow down drain
- Steam Piping, Control Valves, Etc from boiler outlet
- Elec tie-in to battery limits (42kW installed motors)
- Front end loader for fuel mixing and operator (bucket to 2.5m width loading 1.5m high hopper), all at hosts expense
- Approvals (e.g. council DA and state EPA; pressure vessel registration), all at hosts expense
- Ash cleanout of 20mins per week (estimated), all at hosts expense
- Crane & equipment hire for installation
- Installation supervision, commissioning and operator training

5.0 Project outcomes

5.1 GHG Emissions Calculations

Combustion of fossil fuel for process steam and hot water is the largest contributor to red meat processing Scope 1 GHG emissions, and one of the largest operating costs along with labour and electricity. Fossil fuels are exposed to international markets (natural gas, LPG, fuel oil) or sourced from a reducing number of domestic coal mines. This is a significant business continuity risk as these fuels are uncertain in their supply, subject to international pricing fluctuations, forthcoming carbon border tariff adjustments in the EU, and are increasing in their risk-adjusted price disproportionately to CPI inflation. A significant proportion of red meat processors are exposed to risks around the future reliability and cost of fossil fuels. While government has signalled the development of unconventional gas (i.e. fracking & shale gas) as a means to secure affordable gas in the future, there is widespread disagreement on this. What AMPC understands is that the development of unconventional gas in Australia is strongly opposed by two community groups that are close to the heart of red meat processors, first Australians and farmers.

Using fuels generated by RMP supply chains provides an opportunity for industrial ecology and materials re-use or biogenic materials that are otherwise landfilled or have very low alternate value. These fuels include paunch (grass / grain from gut material), sludges / screenings and woodchip. Into the future (not pursued as part of the pilot), other materials could include cardboard and paper not able to be recycled (e.g. has food on it), construction / demolition wastes, broken pallets and other biomass materials.

Obtaining fuels from local sources reduces Scope 3 emissions (transport) and provides businesses continuity (reduces risk of fuels being brought over long distances). Utilising solid fuels, such as woodchip, can also lend itself to stockpiling to provide more fuel onsite as opposed to LPG or fuel oil.

The following GHG emissions reduction estimate adheres to the Australian Federal Government's NGERS Determination.

- Base case: 30 year old coal fired boiler without an economiser producing 523 kW of thermal energy.
- Fuel: Bituminous coal. 27.0 GJ/tonnes; 90.24 kg CO2-e/GJ[3].
- Coal Boiler efficiency: 75%.
- Fuel consumption pa: 357.03 tpa.
- GHG emissions pa: 869.91 t CO2-e pa.
- EOS 45 Uniconfort: producing 523 kW of thermal energy. Efficiency: 89%.
- Fuel: "Biomass municipal and industrial materials, if recycled and combusted to produce heat or electricity", 12.2 GJ/t, 1.8 kg CO2-e/GJ.
- Fuel consumption pa: 665.86 tpa.
- GHG emissions pa: 14.62 t CO2-e pa (N2O and CH4; no CO2 emissions).
- **Estimated % GHG emissions reduction using biomass rather than coal: 98.32%**
- **Estimated % GHG emissions reduction using biomass rather than nat gas: 97.06%**

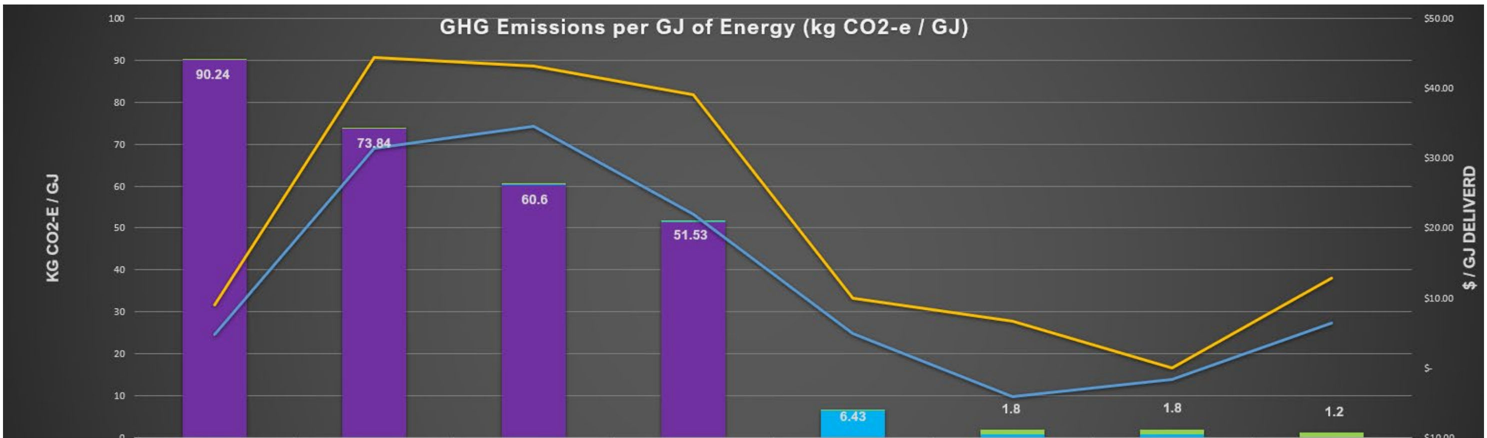
Note: the EOS 45 is able to utilise fuel of 11 GJ/t, hence if operating at capacity could consume ~4.62 tonnes per day (~14m^3/day).

A biomass boiler is able to generate ACCUs under the Australian Federal Government's ERF scheme using the "Industrial and commercial emissions reduction (ICER) method". More information: Industrial electricity and fuel efficiency (cleanenergyregulator.gov.au).

[3] Note that in southern states where high grade bituminous or anthracite coal is in limited supply and lignite coal is typical, the calorific value is lower and resultant emissions higher compared to bituminous coal.

General note: due to the auditing and set-up costs, ERF projects will have better economics for larger biomass boilers.

The following Figure 3 was generated by All Energy Pty Ltd utilising the data from the National Greenhouse and Energy Reporting (Measurement) Determination 2008[4]. It is acknowledged that the Determination is silent on gross heating value versus lower heating value for materials and that in practice, especially for biomass, lower heating values can range dramatically especially as a function of moisture. However, the Determination is used for emissions reporting within Australia hence the numbers presented below are calculated for the main thermal energy sources utilised within Australia red meat processing plants.



	Coal (~37kg)	Fuel Oil (~25 L)	LPG (~39 L)	Natural Gas (~25.4 m^3)	Biogas (from CALs, etc)	Recovered biomass from municipal / industrial wastes	Other biomass (e.g. paunch, sludge, shells, etc)	Woodchip (~61 to 93kg)
N2O (kg CO2-e / GJ)	0.2	0.2	0.2	0.03	0.03	1	1	1.1
CH4 (kg CO2-e / GJ)	0.04	0.04	0.2	0.1	6.4	0.8	0.8	0.1
CO2 (kg CO2-e / GJ)	90	73.6	60.2	51.4	0	0	0	0
$/GJ - Upper	$8.98	$44.36	$43.16	$39.00	$9.90	$6.67	$-	$12.85
$/GJ - Lower	$4.70	$31.40	$34.50	$22.00	$4.89	-$4.17	-$1.67	$6.32

Figure 3: GHG emissions comparison between common RMP boiler fuels presented as kg of CO2 equivalent (CO2-e) per GJ based upon NGERS energy content and emissions factors. Energy cost estimates for "delivered including storage" on a $ per GJ Lower Heating Value (i.e. taking moisture into account) have been estimated based upon H1 2024 east coast Australia data.

[4] National Greenhouse Emissions Reporting Scheme, Measurement Determination, https://www.legislation.gov.au/F2008L02309/2022-07-01/text

5.2 Fuel Considerations

The biomass boiler vendor has provided the following fuel specifications:

- 11 MJ/kg LHV or higher
- Moisture: 35%
- Recommended particle size: 30mm.
- Ash: up to ~7%
- Fuel density: 230 - 400 kg/m^3.

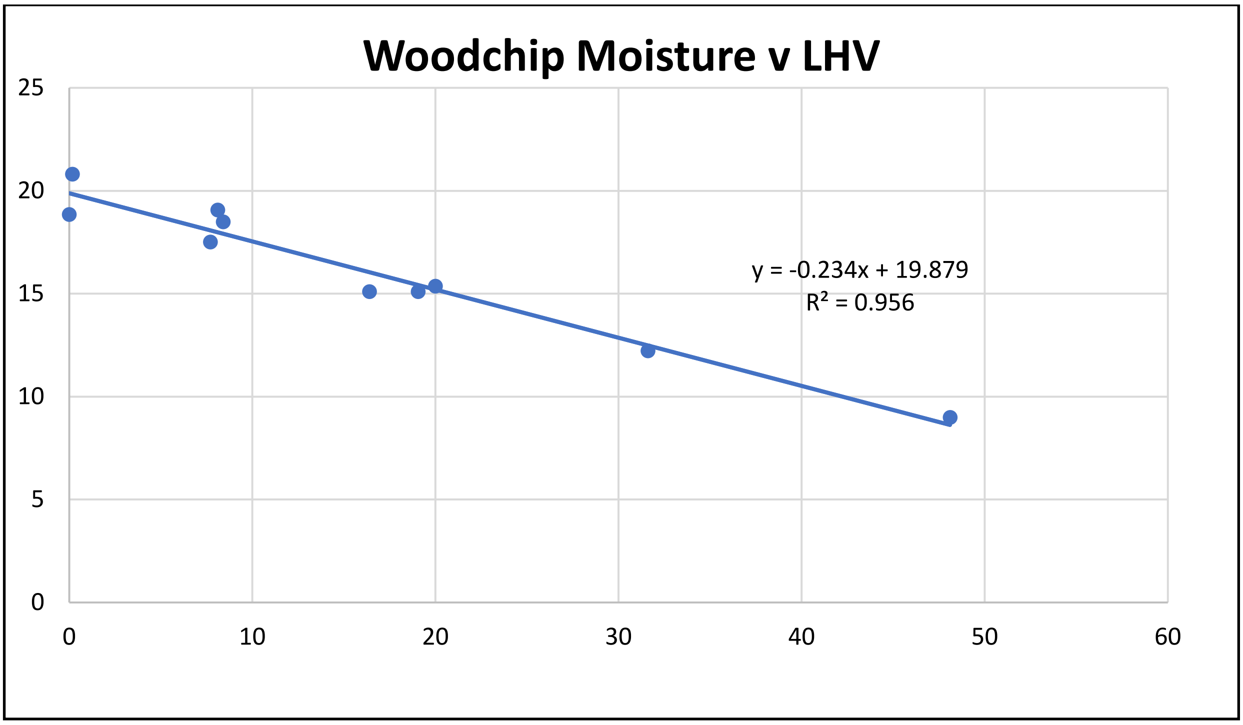
Being a biomass boiler, fuels that have too high an energy content may burn too hot and are not suited to the combustion chamber layout, hence the following table provides a guide as to available fuels and a possible walnut-paunch fuel mix suited to the EOS 45.

The trial pushed the boiler beyond these limits with paunch down to ~9 GJ/tonne used with 11.1% ash and moisture of around 40%. The negatives were noticeably higher soot and increased ash handling (i.e. over 10 times more ash with paunch compared to woodchip).

Table 1: EOS 45 fuel spec and potential fuel blends

Assay	**Vendor Specification for Fuel**	**Walnut**	**Paunch (6 weeks air dried)**	**Air dried Woodchip (NSW)**	**Walnut-Paunch Mixture to match vendor CV @ high level**	**Walnut-Paunch Mixture to match vendor CV @ low level**	**Green woodchip (SA, straight from mill)**
Net CV (LHV ar)	11 MJ/kg or higher. Ideally 13 to 16 MJ/kg	19.0	11.3	Calculated at 13.45 MJ/kg as received	16.0 achieved with 61% walnut and 39% paunch	13.0 achieved with 22.1% walnut and 77.9% paunch	Calculated at 8.89 MJ/kg as received
Moisture	35% (up to 45%)	7.5%	37.6%	31.63%	19.2%	30.95%	46.95%
Ash	~7%	1.0%	11.1%	~0.9% to 1.37%	4.94%	**8.87% - slightly above vendor threshold**	Literature: 0.88% (untested)
Fuel density	230 - 400 kg/m^3	251	440	330	325	398	300
Particle size	30mm (up to 50mm manageable)	~<45mm	<30mm	~<50mm (may be spearing through screen)	~<45mm	~<45mm	Screened to 25mm.
$ /GJ LHV		$2.63/GJ (transport only)	$0.00 (available at plant)	$6.32GJ	$1.60/GJ	$0.58/GJ	$12.85/GJ. 2.67 GJ/m^3; $34.32/m^3.

A key finding from this project is the approximately linear correlation between lower heating value and moisture for woodchip and paunch as shown in the trends below. These plots can be used to dry and blend biomass to achieve a target moisture of 35% and a target lower heating value of 11 to 15 GJ/t. The woodchip is sold per cubic metre rather than per tonne, hence drying the woodchip to a target moisture of 20% would result in ~15 GJ/tonne.



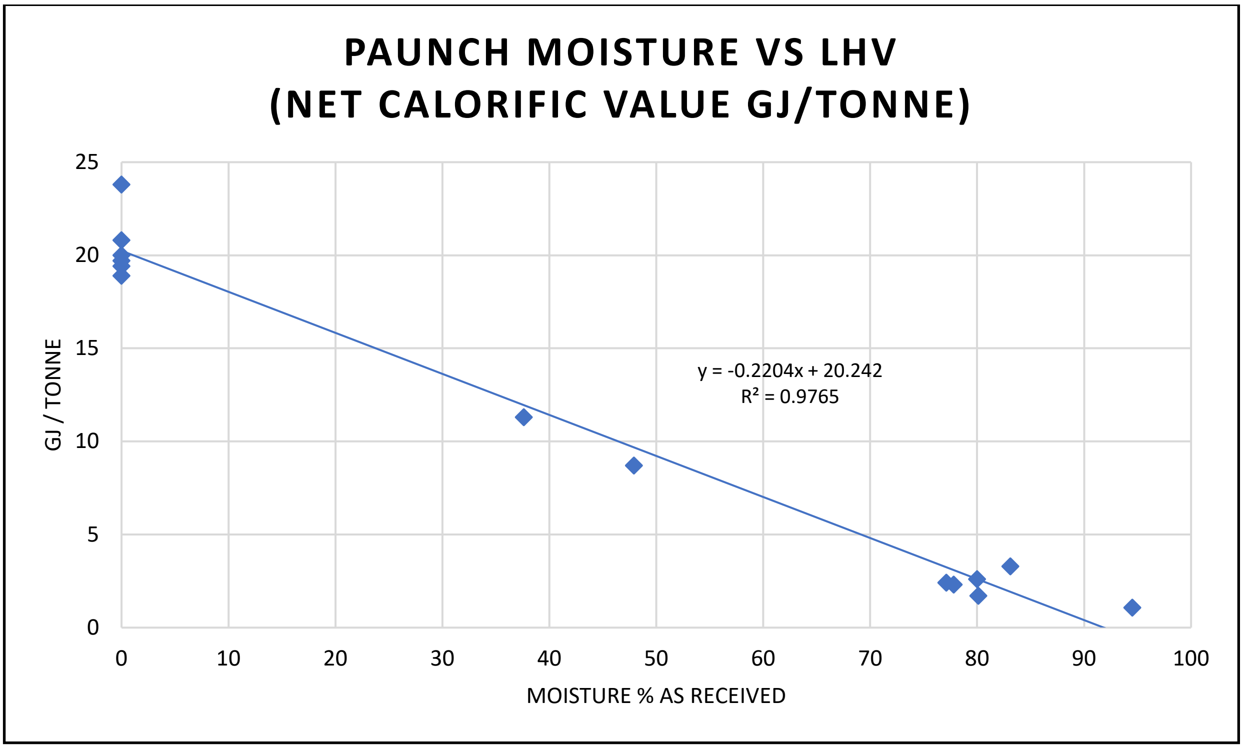


Figure 4: Strong correlation (R^2 0.956 and 0.977) between moisture and lower heating value of woodchip and paunch respectively.

5.3 Pilot Performance

The following section provides a detailed analysis for continuous operation of the pilot over the period 15th Feb 2024 7:14pm to 16 Feb 2024 12:45pm.

SCADA data and run analytics for the system. The **heat exported by pilot was calculated at 453 kWt (based upon** Ave. dT = 6.14 DegC and water flow as per Site #1), which was ~86.8% of 523 kWt rated capacity. The system was running better during this period compared to site #1 due to the large and steady heat sink for the system provided by the low temperature potable water (as opposed to pre-heating warm water).

Table 2: Pilot performance summary data.

SCADA Parameter	**Furnace T**	**Flue T**	**Outlet water T from Pilot**	**Inlet Water T to pilot**	**dT**	**mmH2O Vacuum**	**O2 %**
MAX	639.000	186.000	90.0	81.0	28.0	13.600	17.8
Ave	568.192	164.290	73.65	67.5	6.1	8.030	10.2
St Dev	39.414	9.816	3.826	3.204	3.9	1.329	1.206
Co-eff of variation	0.069	0.060	0.052	0.047	0.640	0.166	0.118

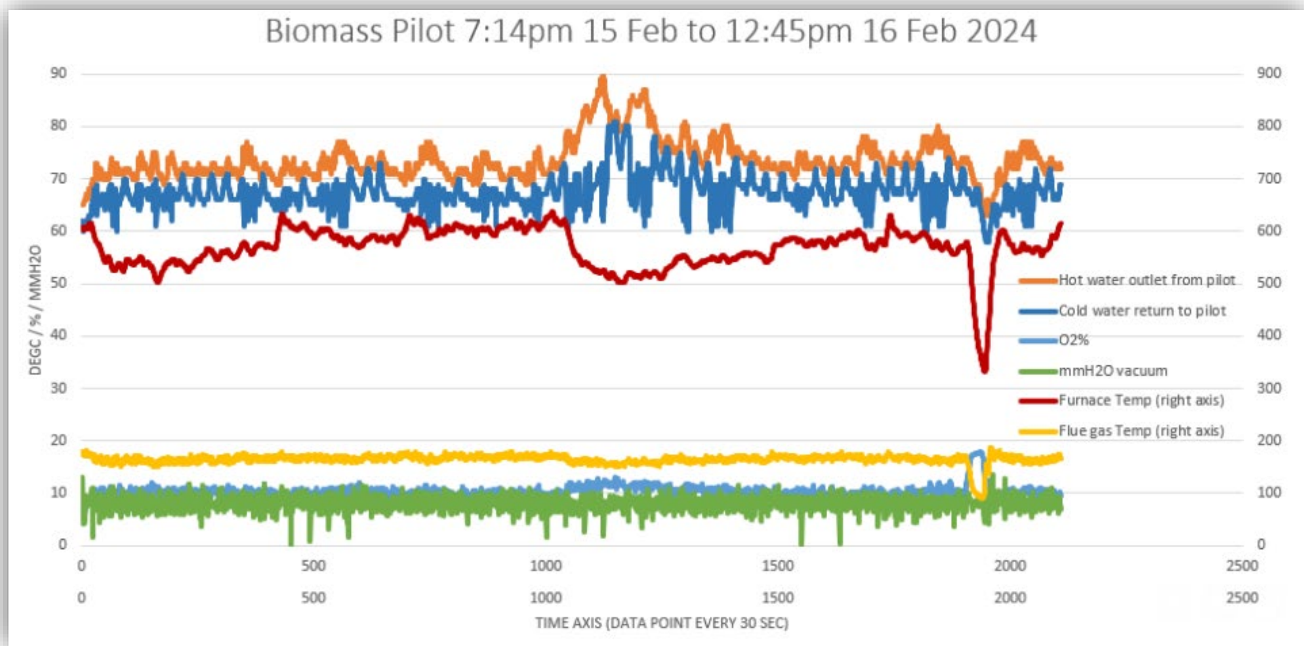


Figure 5: SCADA data for biomass pilot.

Commentary:

(1) the variation in the dT as shown by the coefficient of variation (in comparison to the other parameters) is due to the change in temperature of the potable water on the utility side.

(2) For short periods of time, towards 2086kWt of heat was able to be supplied (this is due to the high outlet water temp up to 90 DegC, the high thermal inertia of the closed loop hot water system and the cold potable water on the plant size (i.e. large dT) enabling a high rate of heat transfer).

(3) Fuel consumption estimated as follows:

Table 3: Pilot performance calculations.

Operation 15 & 16 Feb 2024 - PERFORMANCE REVIEW		
Parameter	Value	Units
kW	453	kWt in P&F HX
GJ/day heat exchanged	39.139	GJ/day in P&F HX
Boiler efficiency	0.839	Efficiency fraction
Woodchip LHV	11.689	LHV GJ/t
Tonnes woodchip per day consumed	3.989	t woodchip / day
Woodchip density t/m^3	0.310	t woodchip/m^3
Woodchip per day m^3	12.866	m^3 woodchip/day
Woodchip per week m^3	90.065	m^3 woodchip/week
Woodchip LHV consumed GJ/week	326.36	woodchip LHV GJ/week
LPG value per week (accounting for ATO rebate)	$ 12,893.88	$/week LPG equivalent

Using the above data, biomass consumption estimated at 74 m^3 per week under continuous operation for the above performance. In practice, there is less load during evenings and weekends.

(4) Between ~4am and 6am you can see the load drops right off (almost zero at 4:44am; pilot briefly went into Phase 5 to decrease temperature towards the set point).

(5) This woodchip fuel does take more effort to get started as it is “green” or straight from the mill with no drying. We have the kiln dry shavings to help with the startup in a bulka bag. It took a handful of goes to get going.

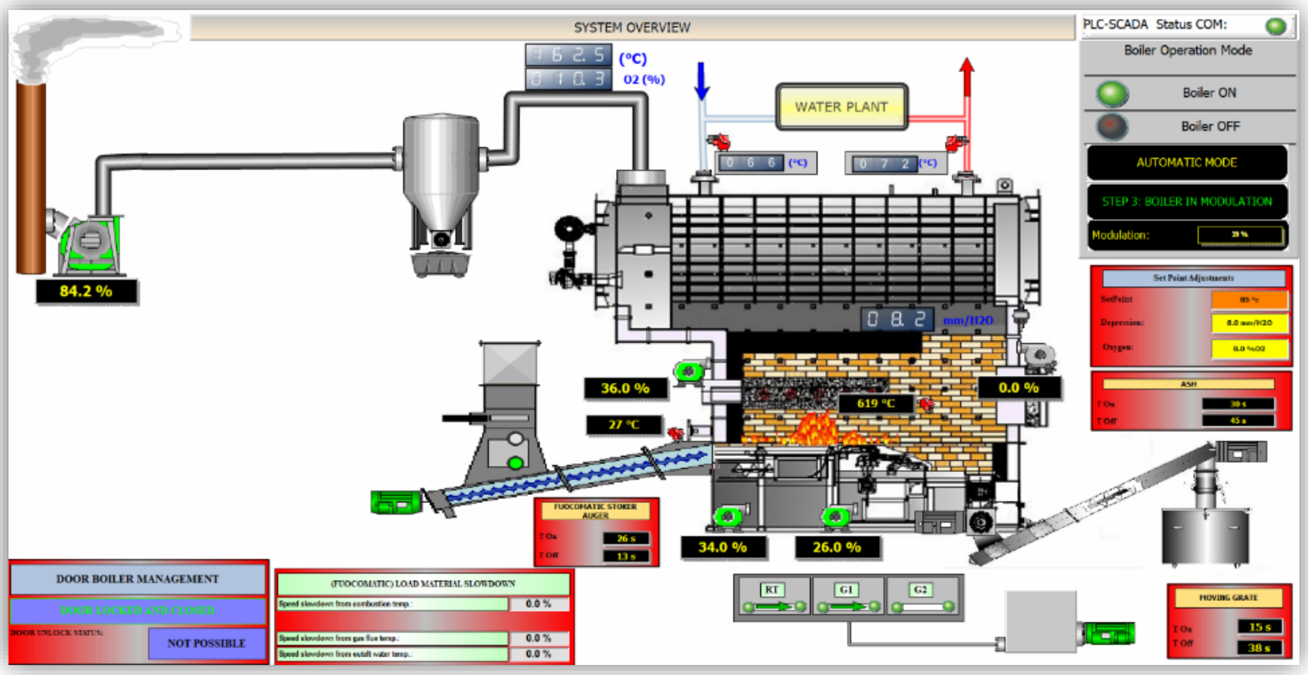


Figure 6: Human-Machine Interface (HMI) System Overview Screen for day-to-day boiler monitoring.

Figure 7: detailed SCADA system output for pilot plant showing steady state operation with likely a fuel bridging event ~11am, shown as the dip in furnace temperature (green)..

(6) there was a “little bump” from ~11am (see below), there was no alarm or switch back to manual, hence appears that the system solved whatever happened automatically by about 11:30am. The first parameter to pick something up

is O2% which starts increasing from the average of ~10% towards 18%. This suggests that combustion ramped down within a 5 min period which suggests the fuel stopped. There does not appear to be an alarm or manual intervention, and the main auger appears to have been OK, hence one of the sections / augers upstream may have bridged (does not appear to have been an over temp or blockage requiring auger reverse, where you would see a log like Alarm#165 "Feeding material jam extraction silo"), but the fuel stopped for about 15mins. However system then continued to run OK. Fuel bridging, especially with moist and hence more claggy biomass, is one of the main reasons for automated shutdown. A secondary key reason for automated shut down is long periods of low load due to nothing to heat exchange to, causing the system to go into an automated shutdown cycle.

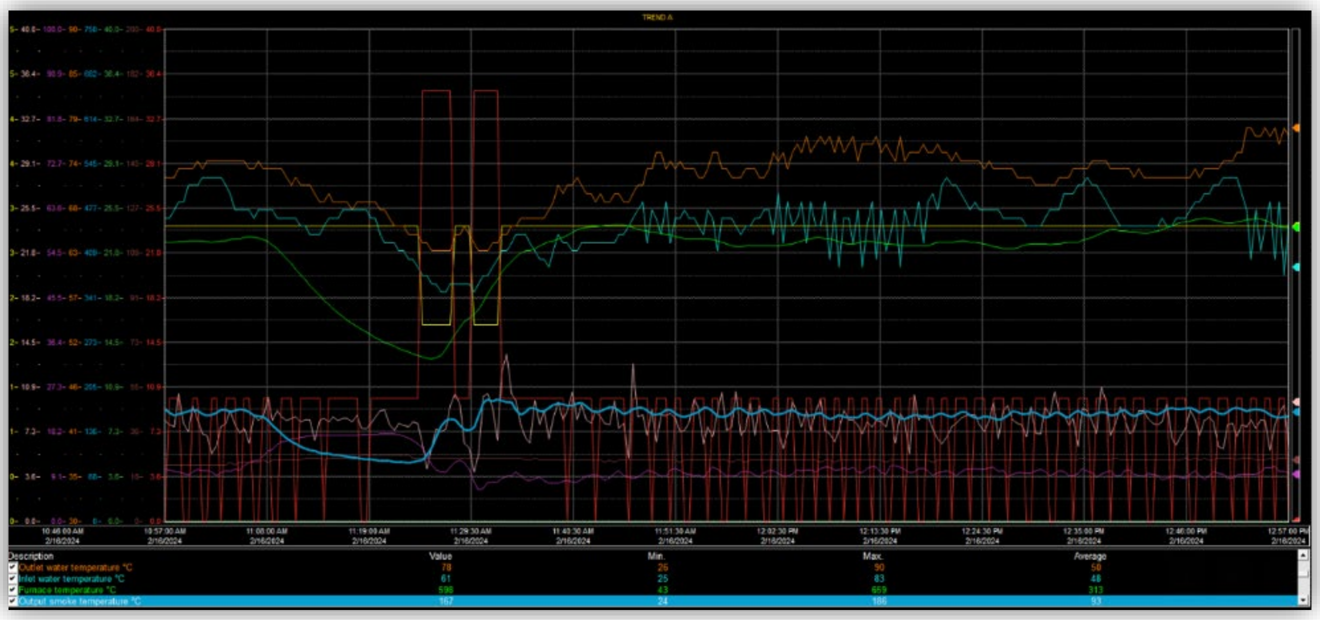


Figure 8: detailed SCADA system output for pilot plant, showing likely a period of very high hot water demand ~11:25am where the pilot when into maximum fire mode, before returning to modulation ~11:40am.

The system operated for approximately 2780 hours in NSW and 1378 hours in SA.

5.4 SCADA Trend for High Fire (weekday) versus Low fire (weekend) to High Fire.

The following SCADA trends shows a period of high load (during production times) versus modulation / low load during a weekend when only small amounts of biomass are added to maintain the target setpoint.

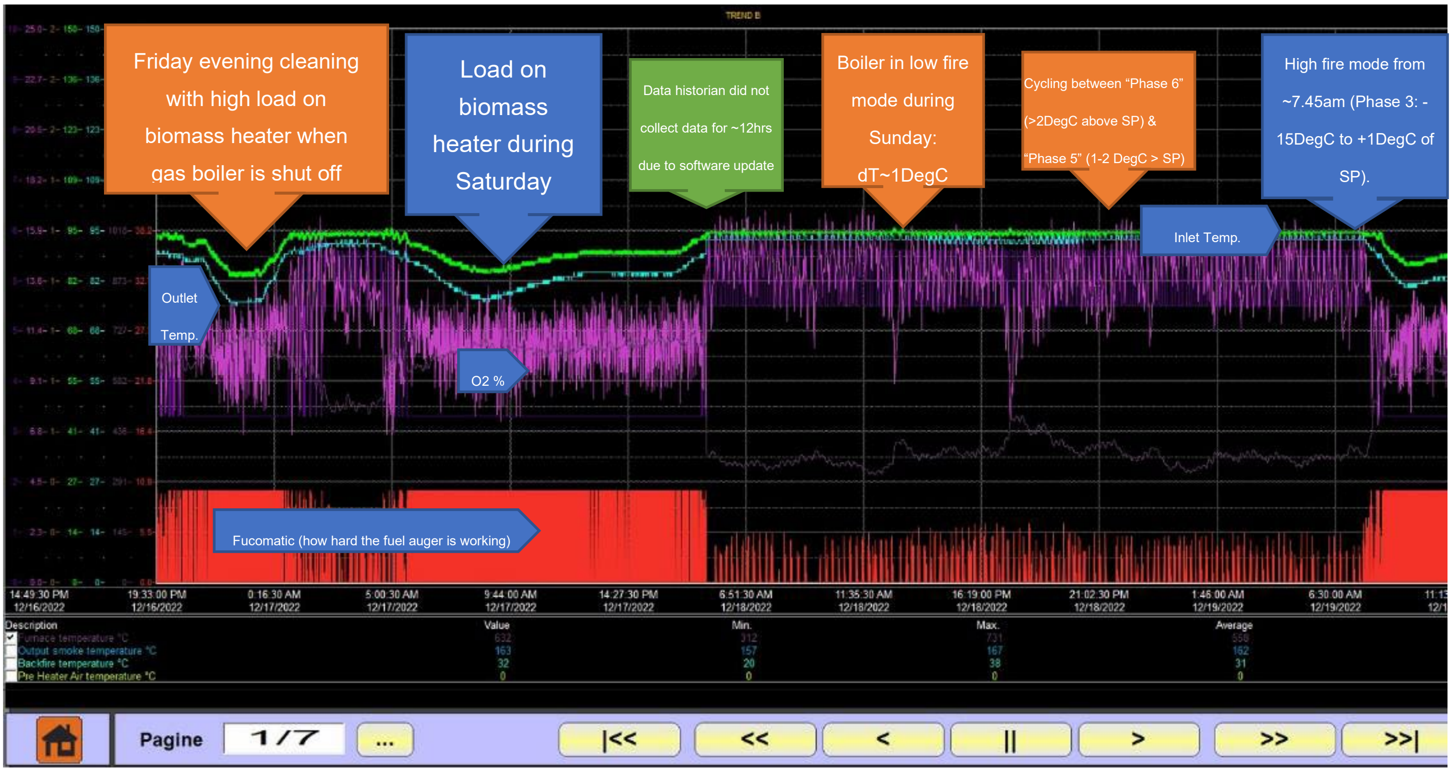


Figure 9: detailed SCADA system output for High Fire (weekday) versus Low fire (weekend), then returning to High Fire.

The different PHASES of operation for the SCADA system are:

- PHASE 0: BOILER TURNED OFF or working in manual mode. When a primary alarm is triggered, the boiler switches to phase 0 and to the STOP mode.
- PHASE 1: Boiler has been turned on. The boiler ignition and heating phase continues until the value of a series of temperatures ensures that everything is going smoothly, in order to switch to Phase 2.
- PHASE 2: FULL OPERATION. The boiler is fully operational and reaches the best operating conditions and fuel process optimization.
- PHASE 3: MODULATION. The system automatically controls parameters in order to better manage its performance when the system is operating around the set-point.
- PHASE 4: NEGATIVE HYSTERESIS. This phase is used to check if the actual heating needs are being met and to act accordingly in the process. This is a maintenance / optimisation phase not usually encountered during general operation.
- PHASE 5: POSITIVE HYSTERESIS. After having verified that the system's needs have been met, the system decreases the boiler burned power until reaching an ignition upkeep temperature. This is a maintenance / optimisation phase not usually encountered during general operation.

- PHASE 6: Standby or upkeep. The minimum quantity of fuel is added to maintain the boiler being switched on. All the fans are switched off, except for the fume extractor, which remains on and follows the vacuum set-point. Phase 6 occurs when the system is quite hot but does not have any thermal load to heat exchange with. Relatively uncommon - occurred at Site #1 when rendering heat recovery was occurring hence the pilot had nothing to heat exchange with.

- PHASE 7: BOILER SAFETY SWITCH-OFF.

5.5 Heat Exchanger Transfer Pump Clogging

The following trend shows a slow reduction in the difference between the inlet and outlet water temperature for the Uniconfort system due to clogging on the TN200 circulation pump filter.

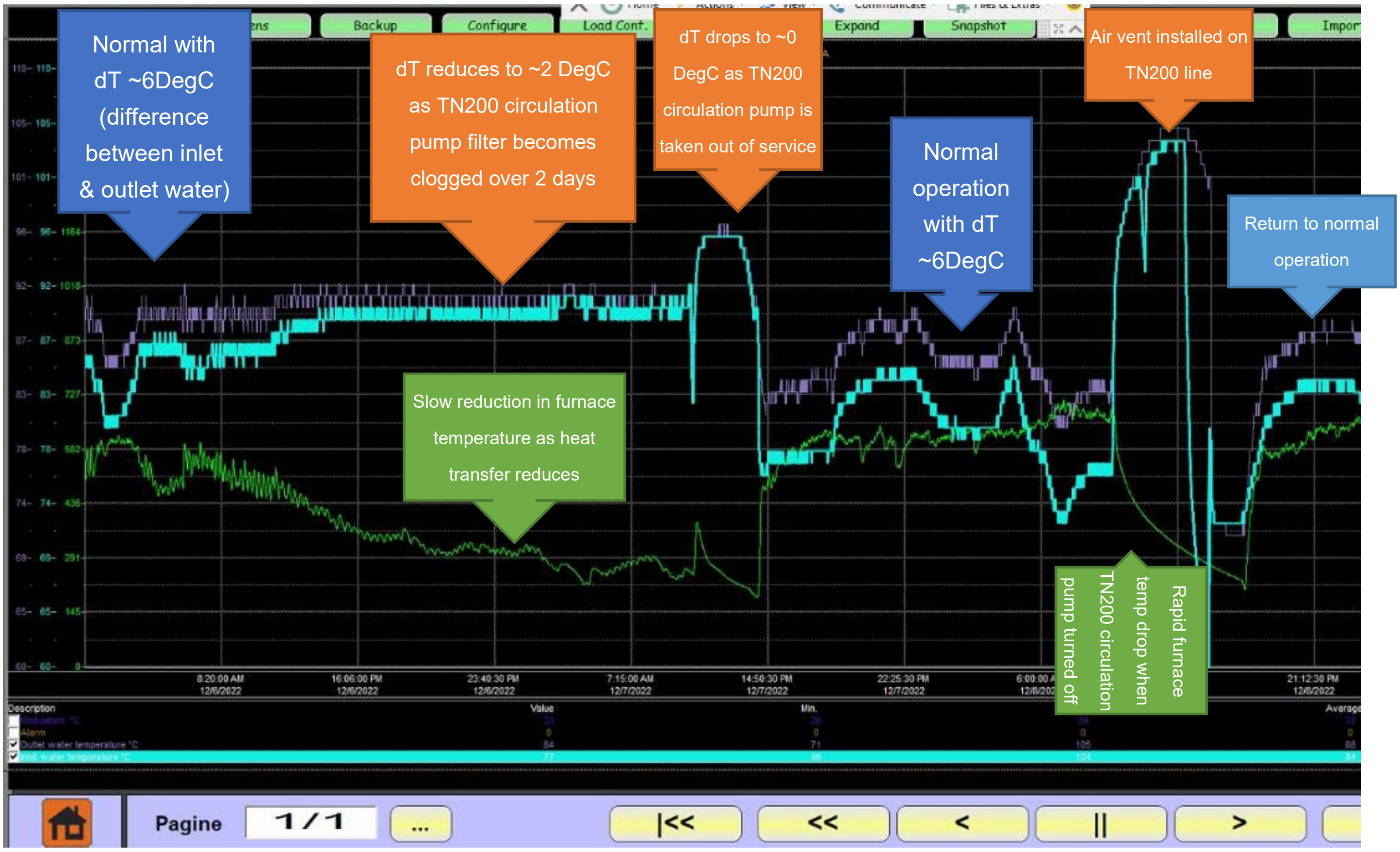


Figure 10: detailed SCADA system output showing heat exchanger clogging.

5.7 Emissions Testing

Assured Environmental completed emissions testing on 14 & 15 March 2023 at the biomass pilot plant, JBS Riverina; then again 12 and 13 June 2024 at Lobethal. Provided below are images of the Assured Environmental testing equipment.

Figure 11: Left to right: real time emissions data readouts, data logger and HMI, in-stack probe using the 110mm port at NSW pilot location.

Table 4: Stack emissions results, NSW.

AVERAGE (1 hour)	% O2	ppm CO	ppm SO2	ppm NO	ppm NO2	ppm Nox "Oxide of nitrogen"
Pellet - High	14.805	242.554	85.554	110.286	0.000	110.286
Pellet - Low	15.433	365.467	83.900	111.967	0.000	111.967
80% paunch/20% woodchip - High	14.464	147.000	17.200	85.517	0.248	85.783
80% paunch/20% woodchip - Low	15.793	295.317	1.917	48.500	0.537	49.117
100% woodchip - High	15.188	163.817	0.000	84.567	0.958	85.517
100% woodchip - Low	15.822	245.883	0.000	64.483	0.247	64.817
100% woodchip - High, no flue gas recycle	15.535	101.855	0.200	73.964	0.520	74.455
mg/m^3 (Version: 6.10.2022, Published under the Legislation Revision and Publication Act 2002, South Australia, Environment Protection (Air Quality) Policy 2016 under section 28 of the Environment Protection Act 1993)		1000	1000			500
ppm (Kansas State University)		872.903	381.676			256.703
g/mol		56.02	64.06			46.01
mg/m^3 Group 6 (after 2005) A boiler operating on a fuel other than gas; NSW Protection of the Environment Operations (Clean Air) Regulation 2022 under the Protection of the Environment Operations Act 1997		None listed	None listed	500	500	500

ANOVA (single factor) data analysis were completed to determine if the difference in the data sets are statistically significant. The results are summarised in the following table.

Table 5: ANOVA analysis of results from 14 & 15 March 2023 emissions testing of the UNICONFORT 523 kW biomass pilot, NSW.

ANOVA: Single Factor	P-value	Summary
SO2: 80% paunch / 20% woodchip and 100% woodchip	2.86 x 10^-22	Very strong evidence of a statistically significant variation in SO2 levels between 80% paunch / 20% woodchip and 100% woodchip
CO: 80% paunch / 20% woodchip and 100% woodchip	0.010845	Evidence of a statistically significant variation in SO2 levels between 80% paunch / 20% woodchip and 100% woodchip
NOx: 80% paunch / 20% woodchip and 100% woodchip	0.873	No evidence that there was a statistically significant variation in NOx levels between 80% paunch / 20% woodchip and 100% woodchip
Comparing all fuels for NOx, SO2 and CO.	2.8 x 10^-121; 2.5 x 10^-262; 6.4 x 10^-103	Very strong evidence of a statistically significant variation in chemistry between all fuels.

The stack concentrations are then used to model the ground level concentrations. Not all jurisdictions nominate stack concentrations, but rather nominate the ground level concentrations which are impacted by stack height, flue velocity, flue temperature (buoyancy), topography, surrounding buildings / vegetations, prevailing wind direction and speed, etc.

When undertaking approvals, proponents must ensure that gaseous and particulate emissions, from the proposed plant in isolation and in combination with the emissions from neighbouring sources and background concentrations, do not exceed ambient ground level concentrations criteria, including the NEPM standard for Air Quality, or cause an environmental or human health / amenity problem.

A second round of testing was completed on 13 June 2024 at Lobethal, South Australia. This round of testing was utilised a high moisture fuel (green woodchip stored outside) hence the pilot did not reach a “high fire” mode (i.e. relatively low furnace and stack temperatures). The moistures of the fuels were measured at

Table 6: Stack emissions results, SA.

AVERAGE (1 hour)	vol% O2	mg/Nm3 CO	mg/Nm3 SO2	mg/Nm3 Oxides of nitrogen (as NO2)
Green woodchip	20.6	427	12.9	6.28
mg/m^3 (Version:6.10.2022), Environmental Protection (Air Quality) Policy 2016, South Australia.		1000	1000	500 (solid fuel >150 GJ/hr).

Figure 12: Assured Environmental testing rig at Lobethal (SA).

5.8 Implications of Biomass for Australia's Red Meat Industry

The table below summarises the estimated thermal energy used by entire RMP industry in a year for the 12 months to end March 2024.

Table 7: Current estimated energy costs for Australian RMPs.

	FY21/22 Env Report		$/kWh for power; $/GJ LHV all other fuels		$ pa Australian Red Meat Industry	
	%	GJ pa	High approx. estimate	Low approx. estimate	High estimate	Low estimate
Grid power	32	3,501,282	0.290	0.18	$ 282,047,923	$ 175,064,228
Nat gas	30.3	3,315,276	39.00	22.0	$ 129,295,770	$ 72,936,076
Coal (procured and delivered to site)	14.5	1,586,518	8.98	4.7	$ 14,252,223	$ 7,535,962
Biomass (procured and delivered to site)	8.3	908,145	9.80	6.1	$ 8,899,821	$ 5,621,417
Biogas (onsite system)	7.7	842,496	-	-	$ -	$ -
Fuel oil	3.3	361,070	44.36	31.4	$ 16,018,548	$ 11,344,044
Diesel	1.9	207,889	61.83	43.7	$ 12,854,270	$ 9,103,160
LPG	1.9	207,889	43.16	34.5	$ 8,972,318	$ 7,177,854
Wind / solar (behind the meter)	0.1	10,942	-	-	$ -	$ -
Petrol	0.1	10,942	59.38	43.75	$ 649,652	$ 478,691
TOTAL GJ		10,941,506			$ 472,990,524	$ 289,261,433

Basis of calculations:

t HSCW ABS Data (beef, mutton, lamb): 3185300

MJ/t HSCW (FY21/22 Env Report): 3435

Note: Red meat produced is shown in carcass weight and excludes offal and veal.

Assuming 20% of fuel is generated onsite (paunch, sludges, broken pallets, unrecyclable paper and cardboard) is "free-issued" then blended with 80% procured woodchip ($6.32 / GJ LHV woodchip delivered) at a total cost of $5.06/GJ. 68% cost reduction in thermal energy fuel cost overall. 80% lower cost compared to natural gas.

The “total addressable market” is the current GJ pa of fossil fuel used in RMP boilers, which equates to 5,479,753 GJ pa (~407 kt pa of woodchip equivalent). This equates to 0.21% of the estimated 2,610 Petajoules pa of bio-waste and bio-residues available for bioenergy production in Australia each year (22% forestry residues, 41% agri-residues, 37% organic wastes)[5].

Table 8: Opportunity for energy cost reductions for RMPs via biomass.

Business as usual – Estimated Fossil Fuel for Heating Costs i.e. excluding power & transport[6].	Biomass Replacing Fossil Fuel for Heating	Annual Saving
Lower estimate from above table	Biomass @ $/GJ	$ pa
$ / GJ: 15.41	$ / GJ: 4.94	
$ per annum: 111,245,906	$ per annum: 35,702,570	$ **75,543,336**

5 https://arena.gov.au/assets/2021/11/appendix-resource-availability-australias-bioenergy-roadmap.pdf
6 AMPC Environmental Report FY21/22; Livestock Products, Australia methodology, March 2024 | Australian Bureau of Statistics (abs.gov.au).

6 Discussion

6.1 Using Higher Moisture Fuels

A number of important issues must be considered and may require discussion with boiler vendors and retrofits to auxiliary plant when using higher moisture fuels (such as sludges). These include:

- More fuel tonnage, more air, and more fluegas – ID fan capacity limit

A larger fuel tonnage feed rate to reach the same delivered energy rate requires a larger volume of combustion air. Check the available capacity of the ID fan for combustion air, and any FD fans for moving fluegas. The inherent variability of biomass presents a further challenge in setting the optimal combustion air flow rate without delivering excess and sacrificing efficiency. A monitoring system, or at the minimum, regular moisture analysis on fuel can adjust air flow rate to maintain optimum combustion and heat transfer efficiency.

- Higher moisture leads to more fluegas, which can lead to possible overall efficiency drop

Related to the above point, more combustion air required results in more fluegas, absorbing heat from the fuel – showing as low temperature in the combustion chamber. Economisers may mitigate this by recovering heat from fluegas, but the amount of combustion air should be investigated first and compared to the stoichiometric amount.

- More milling / fuel delivery power

The additional fuel milling requirement is primarily dependant on the boiler type (e.g. fluidised bed, chain grate, heap etc) and allowable fuel particle size. For the Babcock and Wilcox BFB boiler with 25mm fuel size spec, this may be significant depending on chip size as delivered.

- Tendency for slagging in the furnace and solidification of sintered deposits, especially when ash deformation / ash melting temperatures are lower compared to higher rank coal. e.g. sudden shut down / cooling or inability to remove melted ash results in the need to jack hammer out slag during shut-downs

Higher ash contents in lower quality biomasses may result in slagging issues, and should be considered in light of maintenance schedules. Slagging results in: less HX in radiant section more heat in convective section; possible increase in flue gas temperature and drop in efficiency; damage / blockage due to lumps of slag; impacts on burner / flame front pattern; excessive soot and erosion. Check clinker / slag is not blocking ash hopper.

- More variable / less predictable ash performance; higher particulate emissions.

As above, the variability in ash content of biomass, especially if coming from multiple sources will need to be considered before substitution into an existing boiler.

- More difficult ignitability; possible fuel carry over to ash / char in ash due to slower / lower rate of combustion. Consider fuel residence time (target >3secs); boiler trip where loss of flame is detected.

A large increase in biomass fraction may necessitate a review of boiler control philosophy, along with increased monitoring of performance to catch and rectify any issues with ignitability. This may present issues with Increased chance of fouling (deposition in convective sections) and erosion (due to higher fuel consumption, lower ash melt temp, fuel carry over). Fouling results in increase in flue gas temperature and drop in efficiency; lower steam temp; excessive soot and erosion.

- Materials handing issues

Sticky fuel (higher moisture, higher clay, smaller particles) can block chutes, hoppers and conveyors. Check the angle of hopper walls and conveyors inclines. Wet fuel can cause burner duct blockages, reduced efficiency. Contaminants and inerts (rocks, steel, bricks) can block / damage hoppers, chutes and conveyors, which may be a possible issue especially if taking construction / demolition wood (less likely for sawmill and forestry residues). Sorting is often complex requiring multiple stages and hence significant capital and operating costs, thus, good selection of clean biomasses is the best strategy to prevent contaminants and inerts in the first place.

Low CV fuel can be more reactive in stockpiles leading to stockpile fires; strong winds aggravate stockpile fires; compacting, management and detection can reduce problem.

6.2 Critical Fuel Parameters to Match the Fuel with the Boiler

Listed below, in approximate order of importance when considering paunch and other biomass fuel in order to match the fuel with the boiler:

Moisture: Generally, coal fired boilers are designed for managing up to ~20 to 25% moisture, hence specially designed boilers are required for managing fuel with higher moisture levels with most biomass specific boiler designs being able to manage 40% moisture with some approaching 55% moisture. Ultimately, it is actually the Lower Heating Value which is the parameter of interest rather than moisture itself, however moisture is a much more rapid and lower cost assay hence moisture can be correlated to LHV for a given fuel source.

Lower Heating Value: coal fired boilers have designs suitable for the high LHV of coal, whilst biomass boilers are designed for combusting fuels down towards 15 GJ/tonne.

Ash: minimising ash in the fuel reduces the tonnage of bottom ash / fly ash that is created. Hence, routinely biomass boilers target towards 2% ash,

Corrosive chemicals (i.e. high alkali and chlorine content) can lead to boiler corrosion hence boiler fabricators commonly nominate the threshold concentration of such species in fuel (e.g. rice straw historically has high alkali and chlorine levels).

Ash fusion temperatures, outlined below, guide the operation of a boiler such as to prevent the creation of hardened slag in the boiler during temperature cycling. For example, due to the results of ash fusion temperature testing it is recommended for the temperature within a boiler to not exceed 1100 DegC. Ash that softens / melts in the boiler will stick to the inside of the boiler, making maintenance difficult (e.g. high effort to remove slag from inside boiler) and reducing heat transfer efficiency.

Ash Shrinkage Starting Temperature (SST): This is defined as the temperature at which the area of the test piece falls below 95% of the original test piece area at 550 C. This shrinkage may be due to a number of factors, including the liberation of carbon dioxide, volatile alkali compounds, and/or sintering.

Ash Deformation Temperature (DT): This is the temperature at which the first signs of rounding of the edges of the test piece occurs due to melting. Also called Initial Deformation Temperature (IDT). DT for woodchip may be >1500, for bituminous Australian coal is routinely 1250 to 1600 DegC, whilst for paunch is comparatively low (towards 1200 DegC or lower).

Ash Hemisphere Temperature (HT): This is the temperature at which the test piece forms a hemisphere (i.e. the height becomes equal to half the base diameter).

Ash Flow Temperature (FT): This is the temperature at which the ash is spread out over the supporting tile in a layer, the height of which is half of the test piece at the hemisphere temperature.

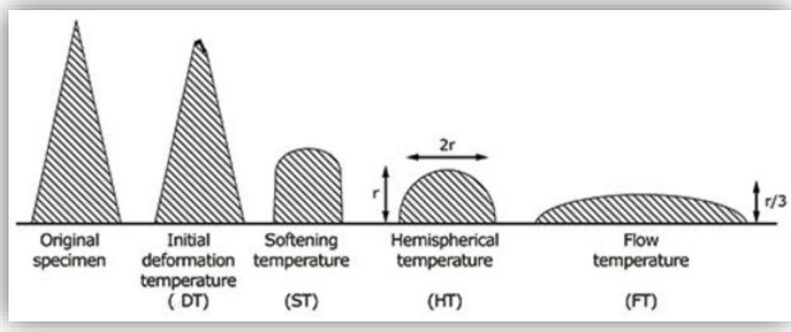


Figure 13: Characteristic shapes of ash fusion analysis[7].

With this analysis package all of these temperatures are determined under oxidising conditions, using air or carbon dioxide, however the characteristic temperatures can also be determined in a reducing atmosphere using a carbon monoxide/carbon dioxide gas mix or a hydrogen and carbon dioxide gas mix using analysis package P42 - Ash Melting Behaviour (Reducing Conditions).

6.3 Different Boiler Technologies

A range of different boiler technologies are available for combustion of different fuels. Presented in the table below are boilers for the combustion of solid fuels. The moving / reciprocating grate worked well on the pilot to load fuel and remove ash.

It would appear that a reciprocating grate system at an angle suited to the fuels (i.e. sharper angle for higher ash fuels; flatter for spherical fuels) is the preferred options for biomass fuels. The rate of grate movement can be controlled to obtain optimum bed performance and ash removal.

[7] Hobbs, H., "The future of ash fusion analysis", World Coal, February 2016.

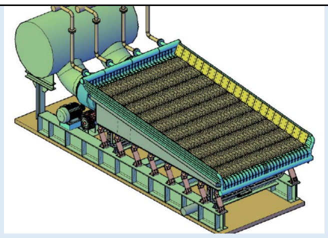
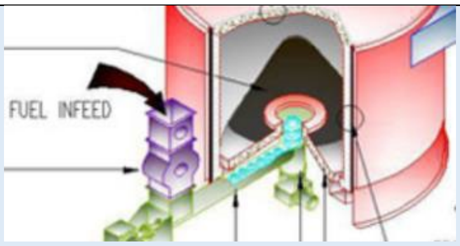
Boiler Type	Information	Image
Chain belt mobile grate	Grate surface of the chain belt grate is the chain itself. The chain belt grate is driven by the sprocket chain. As the grate moves the fuel fires and burns until it burns out. The speed of the grate is adjusted by the gear transmission according to the difference between the fuel type and the boiler load requirements. Chain Grate operation is reliable, combustion is stable, and fuel adaptability is wide.	
Reciprocating grate	Reciprocating grate consists of a set of fixed grate slices and a group of reciprocating (moving backwards and forwards) grate slices, divided into steps. The reciprocating motion of the active grate gradually pushes the fuel to the rear combustion area, so the grate has a wide adaptability to fuel types.	
Vibrating grate	Regular vibration (e.g. produced via an eccentric wheel) constantly moves the fuel layer toward the rear of the furnace, so that the ash (after fuel burnout) falls into the ash pit at the end of the grate. This type of grate is characterized by its simple structure.	
Fixed Grate	The grate strips or plates are fixed on the bottom of the hearth or combustion chamber by a frame mounted around it. Higher labour intensity / de-ashing requirements hence not suited to industrial or continuous operational environments.	
Understoked pile (lower feeding grate)	Fuel is fed (e.g. via an auger) from the bottom up, into the high temperature combustion zone. When the ash exceeds the stacking angle, it falls by gravity to the sides (and can then be discharged). This kind of boiler has advantages in its simple internal design, but it has certain requirements for the granularity / flowability of the fuel.	
Fluidised Bed	Offers advantages of high efficiency, however, has operational challenges of optimising air flow simultaneously for fuel fluidisation and air/fuel ratio. Fuel must have consistent and optimal particle size and density to achieve fluidisation i.e. not suited to mixed / heterogeneous fuels such as paunch mixed with woodchip.	

Figure 14: Summary of boiler technology options suited to biomass combustion.

7 Conclusions / recommendations

Biomass is one of a limited options for RMPs to reduce GHG emissions AND reduce costs. Shifting to biomass to replace fossil fuels for heating could save an estimated $ 75.5 mil pa for the industry.

For a plant with an 11 MW boiler[8] (2 shifts per day, 5 days per week, 50 weeks pa) fuel cost savings are estimated at $7.3mil pa versus LPG, $5.2mil pa versus natural gas and $1.4mil versus coal. Adding in the value of emissions abatement, the simple payback period assuming $12.2mil for an 11 MW biomass boiler is estimated at 1.6 years for LPG, 2.2 years for natural gas and 5.8 years for coal. Other advantages of reduced trucking or organic wastes, reduced Scope 3 landfill emissions and less ash for biomass compared to coal also exist but were excluded from the economic analysis.

Fuel Economics is an important consideration for the cost of running boilers. Vehicles delivering biomass to a facility will generally be limited by volume due to the low packed density of biomass. Hence, ***the aim is to find fuel with the maximum GJ per cubic metre*** which is achieved by:

(1) finding dryer starting fuel (e.g. kiln dried rather than green; moisture removed via screening; less fines)

(2) fuel with a higher bulk density (i.e. higher kg per m^3) which can be obtained via optimal grinding / chipping and screening.

(3) Larger deliveries to reduce cost per m^3.

(4) Lowest ash (i.e. woodchip is lower ash than bark, leaf matter, shells or husks).

Optimising these four parameters will reduce the $/GJ LHV of fuel delivered.

Pre-chipping is recommended as a commercial wood mill or industrial scale forestry contractor will routinely have chipping / milling equipment at scale hence can complete chipping and sieving as a service using much larger equipment and hence can enjoy economies of scale, as opposed to chipping / sieving the comparatively small quantities of biomass required for a boiler at an RMP.

Larger fuel supply operations will be able to air dry before transporting to the point of use.

The lowest cost delivery option for most sites is a “walking floor B-Double” which is a typical vehicle for delivery of bulk biomass such as woodchip, sawdust and recycled wood either source segregated (e.g. forestry operations; timber mill) or from a waste transfer station (e.g. recycled chipped wood; mulch). It is possible that B-doubles could also be used for transporting Refuse Derived Fuel (RDF) from a waste sorting facility. These vehicles have ~ 42.5 tonne payload, but bulkier / lower bulk density materials such as un-chiped wood may not achieve this payload, with estimated costs for supply and delivery of $49 to $55 / tonne depending upon delivery distances, biomass availability, etc. Avoided landfill gate fess and state based landfill levies could occur for material that would otherwise be landfilled such as RFD and recycled wood.

The wider benefits to society of demonstrating multi-fuel biomass and co-product biomass combustion in Australian industry include:

[8] This sized boiler supports a RMP of approx. 880 – 1100 head per day; ~66,000 – 82,500 HSCW pa.

1. Reduced GHG emissions,

2. Reduced cost of production. The original target of the project was to deliver a levelized cost of heat from biomasses equivalent to coal. Due to the rapid fossil fuel inflation over the last 3 years, this has been easily achieved, with biomass heat achievable as low as $3/GJ,

3. Reduced organic wastes being sent to landfill, reduced fugitive emissions,

4. Improved energy security through reduced reliance on international fuels. With the exception of coal or natural gas, almost all of Australian industry's process heat comes from international fuels,

5. By locally sourcing biomass fuels rather than international fuels, truck movements are reduced, reducing scope 3 emissions and improving safety in the supply chain,

6. Improved onsite safety from reduced stockpiles of coal and no need for high pressure natural gas lines onsite.

7. Improved knowledge and skills transfer for circular economy processes.

Life Cycle Assessments are becoming more prevalent when considering industrial systems. Energy from waste in a controlled boiler system, when offsetting fossil fuels, has a better overall LCA result compared to landfilling. Regulators are circumspect with regards to refuse derived energy, perhaps due to a lack of knowledge or the perception that these systems are consider waste incinerators, as opposed to a way to dramatically reduce GHG emissions, energy costs, improved waste stewardship and generating local jobs. Hence, a key element of this project has been to bring statutory authorities "along for the ride" to educate them on new emissions reduction technologies and the chemical / biochemical composition of biomass fuels.

Detailed emissions to air (both chemistry and particulates) data were collected on paunch / sludge blends, woodchip and paunch / woodchip blends. This information was then shared with industry to ease the environmental permitting process with regards to stack and ground concentration modelling.

The Australian red meat industry has an aggressive goal to be NET ZERO GHG emissions by 2030, hence renewable process heat will be a core component of Scope1 emissions reduction for the industry.

The stretch target of $3 / GJ can be achieved where only free issued fuels are utilised and the cost of the fuel is associated with haulage. Such materials could include:

- Organics generated onsite by the RMP: paunch, sludges, unrecyclable paper and carboard, broken pallets, demolition wood.
- Agri-wastes such as shells. Detailed ultimate analysis and composition will need to be conducted to ensure the things like silicates and chlorines are not an issue.
- Chipped / ground and screened green waste and refuse derived fuels diverted from landfilling operations. For part of Australia with state based landfill levies, local councils may be able to supply this material as it reduces their landfill levy costs.

Presented in the table below is a summation of the costs for different sources of heat and provides the basis of the motivation for a biomass boiler in that biomass fuels are competitive on a $/GJ basis compared to all sources of heat but have the additional advantages of being able to create high grade heat (i.e. 6 to 10 Barg steam) required for rendering operations and for creating sterilisation water and are not limited in scale (such as for waste heat recovery).

The cost of fuel routinely contributes to 85 to 95% of the operating costs of a boiler over its life, hence selecting a low fuel is paramount for generating low cost thermal energy.

Table 9: Comparison between different sources of thermal energy on a $ / GJ Lower Heating Value (LHV) basis, 2022 east coast Australia data.

Fuel Type	Fuel	Lower Heating Value (LHV)		kg CO_2-e/GJ (Scope 1)	Emissions indexed to fuel oil	Fuel unit price		Energy based cost	
Solid Fuels	Black coal	25.9	GJ/t	88.4	1.21	137.86	$/t	4.56	$/GJ
	Recycled wood (recycled, chipped)	13.5	GJ/t	1.3	0.02	50	$/t	3.7	$/GJ
	Air dried hardwood chip; 7.7% moisture.	17.5	GJ/t	1.3	0.02	55	$/t	3.14	$/GJ
	Wood - mill chip; 16.4% moisture	15.1	GJ/t	1.3	0.02	58	$/t	3.84	$/GJ
	Green hardwood (managed plantations)	10.7	GJ/t	1.3	0.02	95	$/t	8.89	$/GJ
	Paunch at 56.3% moisture	4.9 to 6.2	GJ/t	1.3	0.02	40	$/t haulage savings	-7.21	$/GJ
	Paunch at 77.1% moisture	2.4	GJ/t	1.3	0.02	40	$/t haulage savings	-16.67	$/GJ
	Paunch at 80.1% moisture	1.7	GJ/t	1.3	0.02	40	$/t haulage savings	-23.53	$/GJ
	Industrial materials and tyres	26.3	GJ/t	80.12	0.91			3.31	$/GJ
	Energy poly-pellet	26.3	GJ/t	80.12	1.1	50	$/t	1.9	$/GJ
Liquid fuels	Tallow (B grade)	40	GJ/t	0	0	720	$/t	18	$/GJ
	Diesel	35.58	GJ/kL	71.5	0.98	1.12	$/L	31.48	$/GJ
	Fuel oil – refined	38.19	GJ/kL	73.1	1	0.53	$/L	13.88	$/GJ
	Bunker fuel	34.67	GJ/kL	73.1	1	0.41	$/L	11.82	$/GJ
	LPG	23.07	GJ/kL	59.9	0.82			30	$/GJ
Gases	Biogas (89; 56; 32 TJ pa from waste)	22.3	GJ/m^3	0	0			8; 10; 17	$/GJ
	Nat gas	0.0393	GJ/m^3	51.3	0.7			12 [8 – 24]	$/GJ
	CNG	0.0393	GJ/m^3	51.3	0.7			19	$/GJ
	LNG	20.72	GJ/kL	51.3	0.7			16.57	$/GJ
	Hydrogen	142	GJ/t	0	0	21	$/kg	147.89	$/GJ
Solar	Solar thermal hot water to 80 DegC (20 yrs; boiler makeup pre-heat via vacuum tubes)			0	0			3.2	$/GJ
	Solar thermal steam via concentrator			0	0			10.45	$/GJ
Heat recovery	Waste heat recovery from flue gas (via heat exchanger)			0	0			0.70	$/GJ
Electricity	Electricity @ $0.20 / kWh i.e. grid power			0	0	0.20	$/kWh	55.56	$/GJ
	Electricity @ $0.03 / kWh i.e. solar array			0	0	0.03	$/kWh	8.33	$/G

8 Appendix

8.1 Biomass Fuel Data

Presented in the following tables is composition and fuel specification data from previous sampling events considering the possible boiler fuels generated at an RMP and also other fuels available to RMPs (i.e. manure and biomass). Gross Dry Calorific Value is the energy released upon complete combustion assuming that there is no moisture in the fuel. The Gross Wet Calorific Value for the paunch samples averages 19.33 GJ/tonne (n=3), which is analogous to the more commonly titled Higher Heating Value (HHV) which assumes that all of the heat of combustion is recovered (i.e. the energy of the latent heat of vaporisation of water can be recovered, which is considered unrealistic is a condensing heat recovery unit is not employed). The Net Wet Calorific Value is analogous to the Lower Heating Value (LHV) which is the parameter routinely used for solid fuels as it represents the practical usable thermal energy that is released by burning a sample 'as received' and includes the energy associated with vaporising the water content of the fuel (which has no calorific value). HHV is equal to the LHV plus the latent heat associated with vaporising any water present (thus HHV is always greater than LHV).

The results for the fuels blended with woodchip at the NSW pilot:

Clients sample Description	Riverina Walnut Shells 0 Weeks	Riverina Paunch 6 Weeks
Total Moisture		
Moisture, % (ar)	7.5	37.6
Ash Yield (550°C)		
Ash Yield, % (db)	1.0	11.1
Calorific Value (CV)		
Gross Dry Calorific Value, MJ/kg (db)	22.0	20.8
Gross Wet Calorific Value, MJ/kg (ar)	20.4	13.0
Net Wet Calorific Value, MJ/kg (ar)	19.0	11.3
Total Halides (S & Cl)		
S, % (db)	0.03	0.19
Cl, % (db)	0.06	0.06
Br, % (db)	<0.01	<0.01
I, % (db)	0.03	0.07
F, % (db)	<0.01	<0.01
Volatile Matter		
Volatile Matter, % (db)	81.8	76.8
Fixed Carbon, % (db)	17.2	12.1
CHN		
Carbon, % (db)	53.3	48.7
Hydrogen, % (db)	6.5	6.6
Nitrogen, % (db)	0.24	0.80
AFT (Reducing)		
SST, (°C)	1235	1155
DT, (°C)	1255	1200
HT, (°C)	1305	1230
FT, (°C)	1400	1365

This fuel was NOT used in this project, but analysed for theoretical utilisation into the future: Refuse Derived Fuel (biomass component of non-regulated waste otherwise sent to landfill)

Clients sample Description	1 Week
Total Moisture	
Moisture, % (ar)	37.3
Ash Yield (550°C)	
Ash Yield, % (db)	15.0
Calorific Value (CV)	
Gross Dry Calorific Value, MJ/kg (db)	16.8
Gross Wet Calorific Value, MJ/kg (ar)	10.5
Net Wet Calorific Value, MJ/kg (ar)	9.0
Total Halides (S & Cl)	
S, % (db)	0.14
CHN	
Hydrogen, % (db)	5.4

Composition of potential boiler fuels available to a RMP (2017).

	70 day dried cattle manure	Hardwood chip	Hardwood Chip Project 2	Paunch
	170521-2	170521-3	170521-4	170521-5
Ash Yield				
Ash Yield	46.9 % (db)	1.0 % (db)	0.9 % (db)	7.7 % (db)
CHN				
Carbon	28.1 % (db)	50.6 % (db)	50.7 % (db)	48.3 % (db)
Hydrogen	3.8 % (db)	6.4 % (db)	6.2 % (db)	5.9 % (db)
Nitrogen	0.68 % (db)	0.08 % (db)	0.08 % (db)	0.53 % (db)
Total Moisture				
Total Moisture	57.6 % (ar)	16.4 % (ar)	7.7 % (ar)	80.1 % (ar)
Volatile Matter				
Fixed Carbon	7.0 % (db)	14.7 % (db)	17.2 % (db)	20.2 % (db)
Volatile Matter	46.1 % (db)	84.3 % (db)	81.9 % (db)	72.1 % (db)
Calorific Value (CV)				
Gross Dry Calorific Value	10.6 MJ/kg (db)	19.9 MJ/kg (db)	20.4 MJ/kg (db)	18.9 MJ/kg (db)
Gross Wet Calorific Value	4.5 MJ/kg (ar)	16.6 MJ/kg (ar)	18.8 MJ/kg (ar)	3.8 MJ/kg (ar)
Net Wet Calorific Value	2.8 MJ/kg (ar)	15.1 MJ/kg (ar)	17.5 MJ/kg (ar)	1.7 MJ/kg (ar)
S, Cl, F, Br, I				
S	0.50 % (db)	0.01 % (db)	0.01 % (db)	0.50 % (db)
Cl	1.0 % (db)	0.02 % (db)	0.03 % (db)	0.11 % (db)
F	82 mg/kg (db)	51 mg/kg (db)	48 mg/kg (db)	152 mg/kg (db)
Br	34 mg/kg (db)	<10 mg/kg (db)	<10 mg/kg (db)	13 mg/kg (db)
I	25 mg/kg (db)	<10 mg/kg (db)	<10 mg/kg (db)	35 mg/kg (db)
AFT (Reducing)				
SST (°C)	1160	1320	1440	1000
DT (°C)	1190	1340	1520	1180
HT (°C)	1220	1380	1530	1300
FT (°C)	1320	1440	1540	1390

Composition of potential boiler fuels generated at a RMP (2017).

	Paunch 1	Paunch 2	DAF	Plastic	Tallow Oil
Ash Yield					
Ash Yield, % (db)	8.0	9.2	9.8	5.9	19.3
Total Moisture					
Moisture, % (ar)	77.1	77.8	59.1	7.1	90.3
CHN					
Carbon, % (db)	46.5	46.3	53.8	74.2	82.0
Hydrogen, % (db)	6.6	6.3	7.6	11.3	2.3
Nitrogen, % (db)	0.5	0.5	2.0	1.0	5.1
Sulphur & Chlorine					
S, % (db)	0.15	0.14	0.49	0.01	0.33
Cl, % (db)	0.07	0.09	<0.05	<0.05	0.13
Calorific Value (CV)					
Gross Dry Calorific Value, MJ/kg (db)	19.4	19.7	25.1	39.2	37.8
Gross Wet Calorific Value, MJ/kg (ar)	4.5	4.4	10.3	36.4	3.7
Net Wet Calorific Value, MJ/kg (ar)	2.4	2.3	8.3	34.1	1.5
Bulk Density					
Bulk Density, kg/m^3 (db)	45	53	---	---	---
Volatile Matter					
Volatile Matter, % (db)	76.9	77.6	---	---	---
Fixed Carbon, % (db)	15.1	13.2	---	---	---
Ash Fusion Temperature (Reducing)					
SST (°C)	1340	1160	---	---	---
DT (°C)	1380	1280	---	---	---
HT (°C)	1400	1330	---	---	---
FT (°C)	1500	1440	---	---	---

Previous Results Pelletising Paunch and DAF & paunch.

The tables below summarise the NATA lab results of pellets of paunch and DAF sludge & paunch with additives to enable pelletising.

Paunch and sludge/paunch pellet fuel analysis

Clients sample Description	Abattoir Sludge/Paunch Pellets
Ash Yield	
Ash Yield	19.0 % (db)
Total Moisture	
Moisture (ar)	12.0 % (ar)
Calorific Value (CV)	
Gross Dry Calorific Value	18.0 MJ/kg (db)
Gross Wet Calorific Value	15.8 MJ/kg (ar)
Net Wet Calorific Value	14.6 MJ/kg (ar)

Clients sample Description	VCT Paunch
Ash Yield	
Ash Yield	14.6 % (db)
Total Moisture	
Moisture (ar)	14.7 % (ar)
CHN	
Carbon	44.7 % (db)
Hydrogen	6.0 % (db)
Nitrogen	2.06 % (db)
S, Cl, F, Br, I	
S	0.20 % (db)
Cl	0.38 % (db)
F	35 mg/kg (db)
Br	39 mg/kg (db)
I	90 mg/kg (db)
Calorific Value (CV)	
Gross Dry Calorific Value	17.9 MJ/kg (db)
Gross Wet Calorific Value	15.2 MJ/kg (ar)
Net Wet Calorific Value	13.8 MJ/kg (ar)
Volatile Matter	
Volatile Matter	68.9 % (db)
Fixed Carbon	16.5 % (db)

TABLE 2 – Ash Analysis

hrl: Sample Description	180307
Clients sample Description	VCT Paunch
Major Elements (% In Sample (db))	
Si	3.8
Al	0.16
Fe	0.29
Ti	0.02
K	0.41
Mg	0.10
Na	1.8
Ca	0.74
S	0.09
P	0.60
Ba	0.01
Sr	0.01
Cu	<0.01
Mn	0.02
Cr	<0.01
Zn	0.01
V	<0.01

Clients sample Description	VCT Paunch
Ash Fusion Temperature (Reducing)	
Start Shrinking Temp ◦C	1030
Deformation Temp ◦C	1080
Hemispherical Temp ◦C	1140
Flow Temp ◦C	1240

8.2 Existing and Previous Australian Biomass Boiler Projects

Company	Location	State	Fuel	Scale
Fletcher International Exports Pty Limited	Albany	WA	Locally sourced clean woodchips	~15 MW
JBS Swift Australia Pty Limited	Longford	TAS	Sawdust	6 MW
Nippon Meat Packers Aust Pty Limited	Wingham	NSW	Sawdust	~6 MW
Frew Group	Stawell	VIC	Plantation timber sawdust	3 MW
Northern Co-Operative Meat Co Limited (NCMC)	Casino	NSW	Sawdust and macadamia shells sources externally	~10 MW
H. W. Greenham & Sons Pty Limited. Planned: 10MW woodchip boiler.	Smithton	TAS	Local pyrethrum briquettes and paunch waste (4,584t in FY17)	10 MW
Kilcoy Pastoral Company	Kilcoy	QLD	Locally sourced pine plantation woodchip by-product	~8 MW (TBC)
Nestle	Gympie	QLD	TBC (macadamia nut shells; coffee production by-product)	1.5 MW pinhole grate
Wagin Sheep and Cattle Pellet Facility	Wagin	WA	Oat husk; Wood residue	3.43 MW
Nut processor		NSW	Nut shells, 150 kg/hour	1 MW
Albany Council	Albany	WA	Locally available biomass	0.523 MW
MSM Milling	Manildra	NSW	Locally sourced timber residue	5 MW
Australian Tartaric Products	Colignan	VIC	Grape marc	8 MW
Family Fresh Farms	Peats Ridge	NSW	Externally sourced sawmill waste (wood chips)	5 MW
Unigrain	Geelong	VIC	Internally sourced oat hulls	3 MW
Meredith Dairy	Meredith	VIC	Wood chips (Timber construction waste) on-site	240 kW
Rocky Point Sugar Mill	Woongoolba	QLD	Bagasse and wood waste	30 MW grate boiler

Company	Location	State	Fuel	Scale
Harwood Sugar Mill	Harwood	NSW	Bagasse and wood waste	4.5 MW
Stanwell Power Station	Rockhampton	Qld	Biomass for steam to power trial	~300 MW
South32 Alumina Refinery	Allanson	WA	30% biomass in Boilers 5 and 6	2 x 103.4 MW
Wilmar Sugar Mills (8 in total (eg. Invicta, Pioneer, Victoria)	Various		Bagasse	199 MW
Capital Dynamics (sugar mills (e.g Condong and Broadwater)	Various		Bagasse	68 MW
Smart Recycling	Dandenong	VIC	C&D wastes	2 MW
JSA Jackson & Son Pty Limited	Armidale	NSW	TBC	TBC
G & B Gathercole (Vic) Pty Limited	Carrum	VIC	TBC	TBC
V & V Walsh Pty Limited	Davenport	WA	TBC	TBC

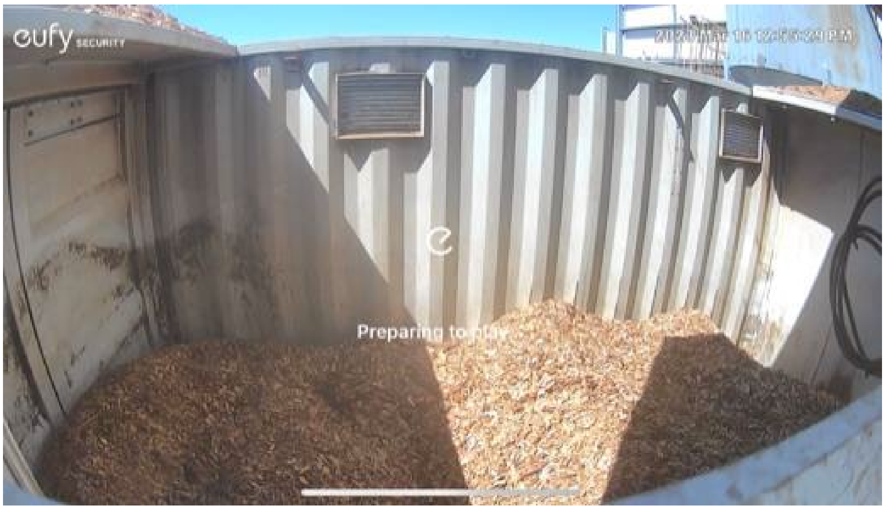
8.3 Lessons Learnt on Biomass Boiler Operation

8.3.1 Auger Rock Damage

A large rock damaged the fuel feeding auger during the NSW pilot. The rock was present in a pad "clean up pile" containing soil, rocks, walnuts, woodchip and paunch which was not intended for use in the pilot.

Summary of incident: A large rock was loaded into the 20' hopper, most likely between 10:13am to 10:20am on the 2nd April 2023. The images of these loads shown below in the first two images show material akin to the pad clean up pile which contained rocks, soil, paunch along with some walnut shells and woodchip. The third images shows the clean woodchip which is visibility very different to the pad clean up pile: lighter, homogenous, absence of large chunks / rocks.

Security camera images of 10:13am to 10:20am on the 2nd April 2023 showing material akin to the pad clean up pile which contained rocks, soil, paunch along with some walnut shells and woodchip.



Sample image of clean woodchip in the hopper of 16th March 2023.

On the 3rd April, the rock was able to travel along the flight until it became stuck at the walking floor exit of the container. It then became wedged causing the safety application to kick in whereby the auger reversed and forwarded 3 times before it tripped the fuel blockage sensor / motor overheat. It was reset and began to start the unblockage routine again. We can only surmise that at this point the rock was broken and at the same time caused the walking floor auger to be pushed through its bearing housing giving enough room between the 2 floating augers to travel up the 45% auger and again become trapped.

Prevention of rocks in the system has been mentioned on numerous occasions and has been the main fault of an otherwise excellent trial. There are a number of additional safety measures that can be employed including having the main auger motor fitted with a VSD or a “grizzly” for material loaded into the hopper. All these have a cost attached and would not be required for any fuel that is screened to remove over sized foreign objects.

As can be seen from the Alarm Log, the “Maximum number of attempts to reverse the fuel hopper extraction motor” alarm occurred at 10:35:25pm, with the “Fuel hopper extraction motor over-heat” alarm at 10:35:19pm. The system attempted to recover itself again with a similar outcome of at 10:51:57pm “Maximum number of attempts to reverse the fuel hopper extraction motor” alarm, with the “Fuel hopper extraction motor over-heat” alarm at 10:51:51pm.

Time column	Time Alarm On	Description Alarm
4/18/2023 6:40:57 PM	0,00:00:00	All9 - 009: Main emergency stop
4/18/2023 6:40:57 PM	0,00:00:00	All6 - 006: Safety Differential Pressure Switch Water Circuit
4/18/2023 6:40:57 PM	0,00:00:00	All0 - 000: Boiler emergency pushbutton
4/18/2023 6:40:56 PM	0,00:00:00	All165 - 165: Feeding material jam extraction silo
4/6/2023 8:32:45 PM	0,00:00:00	All6 - 006: Safety Differential Pressure Switch Water Circuit
4/6/2023 8:32:45 PM	0,00:00:00	All0 - 000: Boiler emergency pushbutton
4/5/2023 2:45:22 AM	0,00:00:00	All21 - 021: Lighter unit lit too long time
4/5/2023 12:42:34 AM	0,00:00:00	All148 - 148: Fire extinguish during phase 2
4/4/2023 9:51:09 AM	0,00:00:00	All145 - 145: Boiler max time in phase 2
4/3/2023 10:51:51 PM	0,00:00:00	All197 - 197: Termico motore estrazione silos
4/3/2023 10:51:57 PM	0,00:00:00	All52 - 052: Massimo numero tentativi inversione motore estrazione silos
4/3/2023 10:35:19 PM	0,00:00:00	All197 - 197: Termico motore estrazione silos
4/3/2023 10:35:25 PM	0,00:00:00	All52 - 052: Massimo numero tentativi inversione motore estrazione silos
4/3/2023 4:58:10 PM	0,00:00:00	All145 - 145: Boiler max time in phase 2
4/2/2023 11:21:32 AM	0,00:00:00	All6 - 006: Safety Differential Pressure Switch Water Circuit
4/2/2023 11:21:32 AM	0,00:00:00	All0 - 000: Boiler emergency pushbutton
4/1/2023 7:11:20 PM	0,00:00:00	[illegible]oiler max time in phase 2
3/30/2023 10:47:59 PM	0,00:00:00	[illegible]hter unit lit too long time
4/1/2023 7:11:21 PM	0,00:00:00	[illegible]ntial Pressure Switch Water Circuit
4/1/2023 7:11:21 PM	0,00:00:00	[illegible]oiler safety thermostat
4/1/2023 7:11:21 PM	0,00:00:00	[illegible]er emergency pushbutton
3/30/2023 1:27:56 PM	0,00:00:00	[illegible]oiler max time in phase 2
3/29/2023 9:16:53 AM	0,00:00:00	[illegible]l material zone in emergency
3/28/2023 4:28:27 PM	0,00:00:00	[illegible]e extinguish during phase 2
3/30/2023 8:32:17 AM	0,00:00:00	[illegible]oiler max time in phase 2
3/28/2023 5:14:02 PM	0,00:00:00	All21 - 021: Lighter unit lit too long time
3/30/2023 4:05:28 AM	0,00:00:00	All145 - 145: Boiler max time in phase 2
3/29/2023 3:52:09 PM	0,00:00:00	All145 - 145: Boiler max time in phase 2
3/29/2023 8:55:52 AM	0,00:00:00	All145 - 145: Boiler max time in phase 2
3/29/2023 4:09:28 AM	0,00:00:00	All163 - 163: Load material zone in emergency
3/28/2023 4:28:27 PM	0,00:00:00	All163 - 163: Load material zone in emergency
3/28/2023 4:28:27 PM	0,00:00:00	All145 - 145: Boiler max time in phase 2
3/28/2023 4:28:27 PM	0,00:00:00	All21 - 021: Lighter unit lit too long time
3/27/2023 7:07:07 AM	0,00:00:00	All172 - 172: Material transport alarm
3/27/2023 7:09:56 AM	0,00:00:00	All165 - 165: Feeding material jam extraction silo
3/28/2023 2:58:29 PM	0,00:00:00	All163 - 163: Load material zone in emergency

Session timeout!

Your TeamViewer session has timed out and will be closed.

More info OK

The damage was agreed to be rectified by site as follows: auger and trough removed and a new trough fabricated; auger checked for damage/straightness; geared motor mounting frame straightened and new bearing and housing is being fitted; mounting bolt holes have been retapped and checked for remounting; small amount of wood chips (only) run from hopper to ash bin to make sure everything is fine prior to decommissioning.

Images of the offending rock and damage are shown below.

8.3.2 Fuel That Is too Moist

The vendor recommended a maximum moisture content of 35%. Whilst fuel moisture higher than this was utilised (~45%) and appears to be a reasonable fuel once the system is up to high temperatures, trying to use fuel at this moisture level makes starting the boiler particularly difficult in winter periods. During the final winter, some woodchip stockpile samples showed up to 65.4% moisture, which proved to be very difficult to start the boiler with.

Further, the visual amenity of steam and smouldering / lower temperature combustion whilst the system gets up to temperature (i.e. larger particles in flue gas due to incomplete combustion) is undesirable. The main solution is to run the system hot and keep it hot; however high moisture is a particular challenge during start-up, hence a detailed cold start method was developed for when fuel is moist (refer section 8.3.3 below).

Not only is moisture present in the delivered fuel and absorbed whilst in the stockpile, during the final demobilisation the image below shows that there can be water ingress / pooling within the augers. Future installations should minimise water ingress and/or consider options to drain water at low points of the system (e.g. manual ball valve drain and screen).

Photo of final demobilisation showing water draining out of auger connecting the 20’ fuel storage with the 40’ mani boiler container.

8.3.3 Cold Start Method

Cold Start Method with Wet Biomass.

(1) Clear all alarms push reset. If there is a fuel loading alarm push the reset in the 20’ container control room.

(2) Remove inspection plate at the rear of the infeed auger and fill with wood shavings from bulka bag and dry wood chips from the top of the bunded wood chip pile. Replace inspection plate.

(3) Take kiln dried wood shavings from a bulka bag, place in a bucket and mix with cooking oil. Use the long handle shovel to spread at the back of the furnace (near where fuel is fed in by the auger). Refer example image:

(4) Light pile of shavings in the furnace with oil soaked rags.

(5) Then turn on **smoke aspirator fan** and start the four (4) x fuel feed system buttons:

a. Walking floor,

b. Extraction silo,

c. Load material and

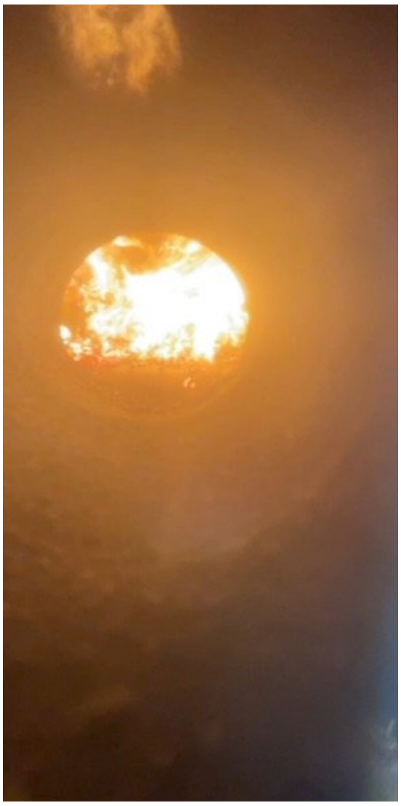
d. Back fire damper.

(6) Allow enough fuel to be fed into the furnace chamber (mix of wood chips and shavings) and allow the pile to take light. Refer example image:

(7) Build up the fire by having the boiler in maintenance mode and continue to build up the fire temperature until it reaches at least 180 Deg C.

(8) Then put boiler into automatic mode and it should cycle into the 300 seconds purge (this is required to remove gases from the system) and then after shifting to automatic mode ("AUT") the pilot will operate under its own control. PLC screen will look like this when completing safety purge to enter into auto mode:

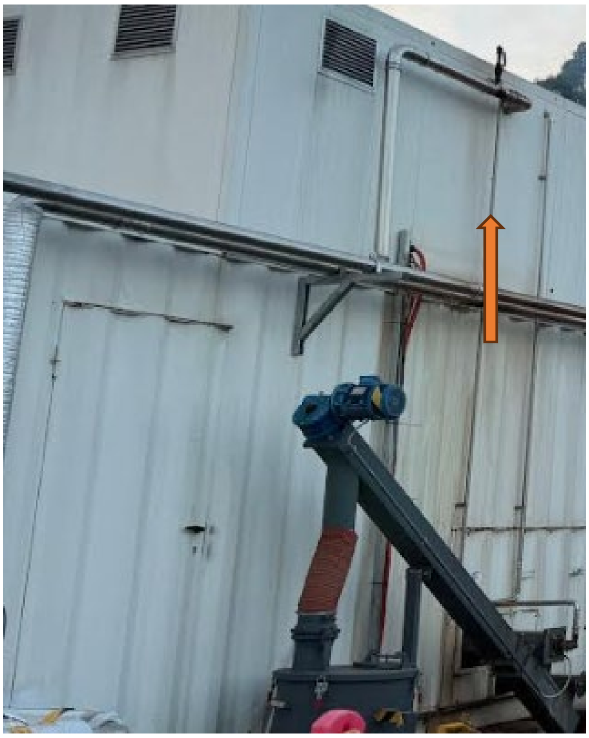
Note: if the pilot does not purge then go into automatic mode, put the pilot back into manual and run the temperature up to 250 DegC and repeat the process. Repeat until boiler running in automatic mode ("AUT").



Check #1: Keep a check on the water temperatures in and out of the boiler: it should not have a temperature difference (delta T) above 20 Deg C.

Check #2: Check the ABB pump drive in the switch cabinet is operating above 50 and up to 80 torque ("Motor torque %), lower values (below 25) indicate air needs to be bled from the boiler water as the pump is not pumping. To view the pump drive you will need to open the pump cabinet as these values are not on the HMI (see below).

The release air from the closed loop boiler water system by opening the ball value above the main boiler door (refer image below). **One recommendation is to install a ball valve at the base of the line with the orange arrow OUTSIDE OF THE CONTAINER to avoid the need for using a ladder to access the ball valve inside the container.**



Follow the line with the orange arrow back into the container to locate all valve.

Ball valve to degas water line is above the main boiler door, above the green arrow shown in the image above.

Boiler Shut down procedure (for weekends, etc):

(1) Switch boiler in to Maintenance mode.

(2) Stop fuel being added via the augers by turning off:

a. the walking floor,

b. extraction silo, and

c. load material.

(3) **Turn off** the back fire damper once no more fuel is coming into the combustion chamber.

(4) **Leave on** / running:

a. Pumps,

b. Primary/secondary fans running and

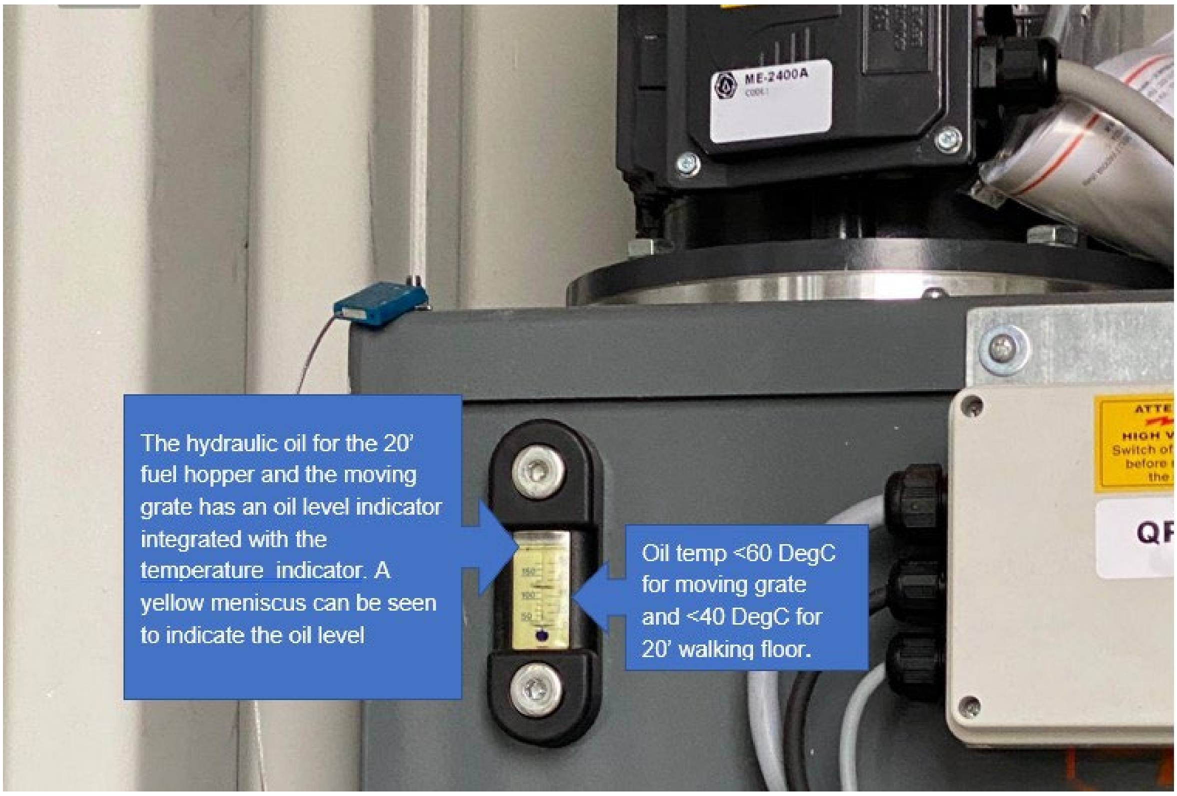
c. the smoke aspirator ID fan (as this will dissipate the heat within the boiler once the fuel has been turned off. Leaving the pumps and fans turned on will not cause any issues and is recommended for short periods (i.e. over the weekend).

(5) If the shut down is going to be longer than a couple of days, switch the balance of the plant off after 24 hours (as by this time there will be no over heating problems).

(6) When ready to restart the boiler clear any faults that are shown on the panel. Put the boiler into Maintenance mode and restart as per the instructions provided for “Cold Start Method with Wet Biomass”.

8.3.4 Hydraulic Oil Information

Hydraulic oil is used for the augers, hence the hydraulic oil levels and temperatures must be periodically checked.



8.3.5 Instructions for Moisture Analyser

Before putting in a sample of if the unit is unable to "Tare" (calibrate back to 0.00), then remove holder, base plate and support then clean thoroughly with pneumatic air to remove all particles / dust.