UK Government

Guidelines on Best Available Technologies for Thermal Energy Efficiency of Boilers in Malaysia

Featuring best practices from the Food and Beverage sector

November, 2022

INTRODUCTION

Reducing energy use makes perfect business sense; it saves money, enhances corporate reputation and helps everyone in the fight against climate change.

This document provides simple, effective advice to help businesses take action to reduce carbon emissions, and the simplest way to do this is to use energy more efficiently. We introduce the main energy savings opportunities for steam and high temperature hot water boilers, and demonstrate how simple actions save energy, cut costs and increase profit margins.

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Who we are

We are a trusted, expert guide to Net Zero, bringing purpose led, vital expertise from the climate change frontline. We have been pioneering decarbonisation for more than 20 years for businesses, governments and organisations around the world.

We draw on the experience of over 300 experts internationally, accelerating progress and providing solutions to this existential crisis. We have supported over 3,000 organisations in 50 countries with their climate action planning, collaborating with 150+ partners in setting science-based targets, and supporting cities across 5 continents on the journey to Net Zero.

CARBON TRUST

The Carbon Trust's mission is to accelerate the move to a decarbonised future.

Contents

Introduction 1

1. Objectives of the Guidelines 4

1.1. Purpose of the Guidelines 5
1.2. Scope of the guidelines: why boilers? 5
1.3. Intended use of the guidelines 6
1.4. Limitations of the guidelines 6

2. Characteristics of Boilers 7

2.1. Steam boilers 8
2.2. Hot water boilers 8
2.3. Sector relevance of boilers 9
2.4. Types of fuel used in boilers 9
2.5. Low(er) carbon alternatives 10

3. International best practice for boilers and heat generation processes 15

3.1. Boiler replacement 16
3.2. Optimisation measures for boiler efficiency 17
3.3. Boiler efficiency benchmarks 19
3.4. Energy savings opportunities in boilers and heat distribution 20

4. Best Available Energy Saving Technologies 23

4.1. Technology Assessment Methodology 24
4.2. BATs in Heat Generation Process 24

4.2.1. Heat Recovery Economiser 24
4.2.2. Air Preheater 26
4.2.3. Automated Blowdown Control System 27
4.2.4. Oxygen Trim Control System 29
4.2.5. Deaerator for Feedwater 30

4.3. Heat Use Process 31

4.3.1. Condensate Recovery 31
4.3.2. Insulation of Flanges or Valves 32
4.3.3. Management of Steam Leak 34
4.3.4. Management of Steam Trap 35
4.3.5. Flash Steam Recovery 38

4.4. Transformative low carbon solutions 39

4.4.1. Solar Thermal System 41
4.4.2. Electric Boiler 41

5. Recommendations 43

Abbreviations

BAT	Best available technologies
COP	Coefficient of performance
CHP	Combined heat and power
EECA	Energy Efficiency and Conservation Act
F&B	Food and beverage
NG	Natural gas
PPB	Part per billion
PPM	Part per million
TDS	Total Dissolved Solids

SECTION 1

Objectives of the Guidelines

1.1. Purpose of the Guidelines

As Malaysia seeks to regulate thermal energy consumption in industrial facilities through the Energy Efficiency and Conservation Act (EECA), it is vital that companies begin to adopt best available technologies that reduce their energy consumption and improve process efficiencies.

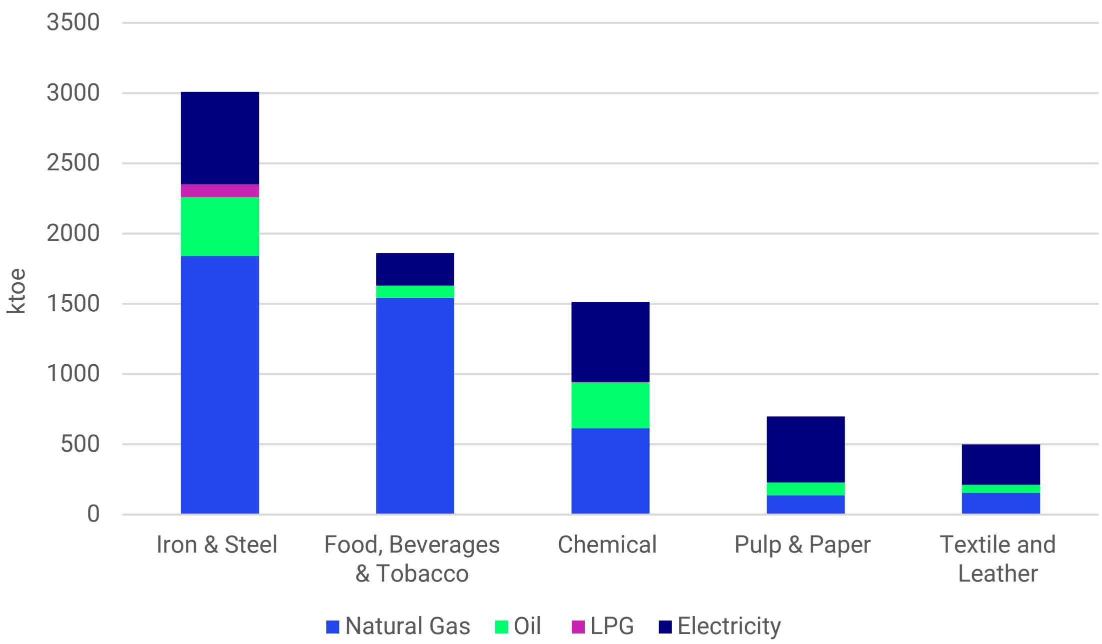
Boiler use is a significant contributor to total thermal energy consumption as they are commonly used in industrial sectors where there is a continual demand for steam or hot water. Many boilers and their distribution systems have been in place for years, even decades in facilities. Developments in modern steam boiler technology mean that efficiencies are now significantly improved when compared to older technologies.

This document seeks to support industrial facility managers to identify best practices in thermal energy efficiency, specifically focusing on boilers, so that they are well-placed to adapt to changing energy regulations in Malaysia.

1.2. Scope of the guidelines: why boilers?

Fossil fuel constituted 64.3% (12,173 ktoe) of Malaysia's total energy consumption in 2019, while electricity comprised 35.7% (6,748 ktoe). Figure 1 also illustrates the industry sector's reliance on fossil fuels to support production compared to electricity use. Realising the significance of thermal energy management to national energy reduction and decarbonization initiatives, Malaysia is drafting the Energy Efficiency and Conservation Act (EECA) to regulate energy users who consume 21,600 GJ/year and above of combined electrical and thermal energy.

Figure 1: Final Energy Use in Industrial Sub-Sectors, 2016



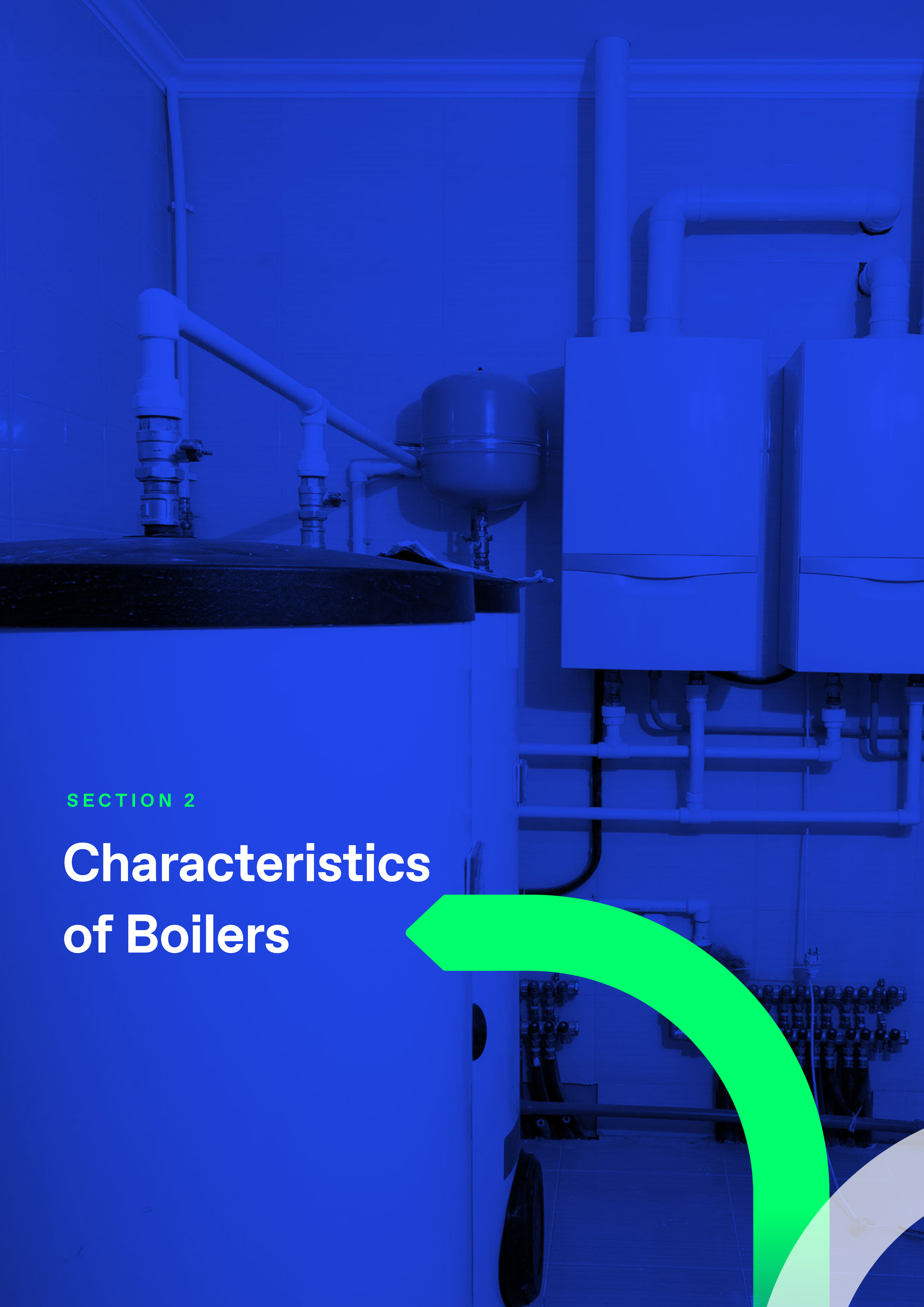
Boilers are a focus of this document as they represent a substantial amount of thermal energy consumption in industry, and there is significant room to improve the average efficiency levels of boilers currently in use. For example, energy audit data from a sample of 9 energy-intensive F&B facilities in 2021-2022 noted that boiler efficiency ranges between 55% to 70%, which is the typical efficiency of the industry without adoption of best available technologies (BAT).

1.3. Intended use of the guidelines

The guidelines have been prepared for energy managers and sustainability professionals at industrial facilities, specifically those in the F&B industry, to use as a basis to identify the best available technologies available for boilers and heat distribution systems that are well-placed to decarbonise production, while providing energy and cost savings. It is intended that the recommendations and best practices on thermal energy efficiency are adopted by industrial facilities so that they are better positioned to meet the regulatory requirements of the upcoming EECA.

1.4. Limitations of the guidelines

The guidelines are based on findings from energy audits completed in 2021-2022 across 9 energy-intensive facilities in the F&B sector, complemented with international best practices on industrial thermal energy efficiency. It is important to note that metrics used to calculate the efficiency improvement potential from adopting BATs is taken from the energy audit data collected from energy-intensive F&B facilities only. Therefore, while the exact improvement potential from the adoption of BATs is expected to vary for non-F&B sectors, the efficiencies of the BATs identified in the document should be a useful gauge for facilities in any sector to use to inform energy efficiency related CAPEX decisions.



SECTION 2

Characteristics of Boilers

2.1. Steam boilers

There are many different types of boiler design and construction, but all boilers are derivatives of two main types:

Shell type

Where the hot combustion gases pass down a tube and into subsequent bundles of tubes immersed below water level. The heat from these gases is then transferred to heat the water to produce steam. Most industrial steam and hot water boilers only require saturated steam for their process heating, and are derivatives of the shell type, which are also referred to as 'fire tube' boilers. These shell type boilers are popular in the food and beverage sector.

Water tube type

Where the water is contained in tubes and the hot combustion gases pass around them to heat the water to produce steam. In either case, the heat must transfer across the surface of the tubes containing the water or combustion gases.

Therefore, these tubes are made of materials with good heat-transfer properties. After use, the combustion gases exit the boiler via a chimney known as flue. The output steam will be fed out of the boiler into a steam header before distributing to various distribution system and finally to the point of use. Pipes and fittings are well insulated to ensure personal safety and maintain efficiency. There are two types of water tube boiler, one with higher pressure and steaming capacity steam used in large palm oil mills while the other with lower pressure and small steaming capacity such as "once through water tube boiler" are used in food industry.

Overall thermal efficiency will vary according to system configuration and the nature of the heat using processes, however a combustion efficiency of ~84% is typically deemed good for a natural-gas fuelled boiler.

2.2. Hot water boilers

There are three main types of hot water boiler: conventional, high-efficiency and condensing. These can be used separately or combined together within systems.

Conventional

These are often cast iron and larger than other hot water boilers. Most use atmospheric burners, where the air required for combustion is drawn from around the boiler through natural convection. **Seasonal energy efficiency levels are generally poor at <70%.**

High-efficiency

These boilers have a low water content, a large heat exchanger surface area and increased insulation to the boiler shell. They tend to be smaller than conventional hot water boilers and operate at **efficiency levels of up to ~82%**.

Condensing

Even in modern high-efficiency hot water boilers, waste heat in the exhaust gases is lost to the atmosphere via the boiler flue. Water vapour makes up some of these exhaust gases. In condensing boilers, a second heat exchanger is used to extract much of the waste heat and return it to the system **allowing efficiencies of up to ~90%** to be achieved for some low temperature systems.

The controls on hot water boilers set the required flow temperature of the water. If the return water is at a lower temperature than required, the boiler must 'fire' to produce heat, i.e. it must burn fuel. The hot combustion gases pass over the heat exchanger to heat the circulating water within and the resultant hot water is distributed to the heating system via a circulating pump with the exhaust gases discharged to the atmosphere via a flue.

2.3. Sector relevance of boilers

The sector and end-use relevance of steam and hot water boilers are illustrated in Table 1 and Table 2[1]. Hot water boilers are not as widely used as steam boilers as noted below.

Table 1: Sector relevance for steam and hot water boilers

Boiler Type	Temperature	Food, beverages and tobacco	Commodity production	Cement and non-metallic mineral	Chemical	Metals, machinery & electronics
Steam boiler	Medium	✓	✓	✓	✓	✓
	High	✓	✓	✓	✓	✓
Hot water boiler	Medium	✓	✓	✓	✓	✓
	High	X	X	X	X	X

Table 2: End-use relevance for steam and hot water boilers

	Heating / Boiling	Drying	Evaporation	Distillation	Firing / Sintering	Melting / Casting	Other processes < 150C	Other processes >150C
Steam boiler	✓	✓	✓	✓	X	X	✓	✓
Hot water boiler	✓	✓	X	✓	X	X	✓	X

Hot water boilers are seldom applicable for evaporation processes as this often utilizes properties of steam, e.g. pressure control in injector. Hot water boilers will only be able to cover an insignificant share of Other processes > 150 °C and is therefore not included as end-use relevancy.

2.4. Types of fuel used in boilers

There are a wide range of fuels used. Boilers commonly burn standard hydrocarbon fuels, such as natural-gas, LPG, oil and coal, but some burn tallow or waste materials. Some boilers, known as dual-fuel boilers,

[1] https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_industrial_process_heat.pdf

can burn gas or oil which is useful in instances where an interruptible gas supply contract is held. Coal burners can be a variety of designs mainly centring on how the coal is fed to the boiler and burnt.

Biomass boilers are becoming more popular. Biomass is any solid non-fossil-based organic fuel and includes wood (either grown specifically as a fuel or as waste material), straw, types of grass and many other organic by-products. The mechanisms for handling and burning fuel differ markedly for solid, liquid and gaseous fuels, and the design of a boiler depends on the intended fuel type(s). However, as many of the general principles for saving energy are the same, this guide does not distinguish between fuel types.

2.5. Low(er) carbon alternatives

In response to rising fuel costs and environmental concerns, an increasing number of companies are seeking to incorporate and integrate a range of low and zero carbon technologies into their facilities in order to reduce the thermal load and fuel usage by their boilers including those outlined below.

Solar thermal

Solar thermal systems use solar collectors to absorb energy from the sun and transfer it, using heat exchangers, to heat water. For industrial process heating applications, solar thermal systems can be used to provide hot water at temperatures of between 30°C and 300°C. Although a relatively mature technology with enormous technical potential, it is massively under-exploited.

There are two main types of solar heating collector that are particularly suited to the 30°- 150°C hot water temperatures commonly demanded in industry:

- **Flat-plate collectors**: These are relatively low cost and low maintenance and are suitable for delivering thermal energy at between 30°C to 80°C. Construction typically comprises absorber plates, insulation layers, recuperating tubes filled with a heat transfer medium, such as water or water/glycol mixture, encased with glazing covers. The operation of the flat plate collector is simple: when the solar irradiation hit the surface of the collector, the radiation passes through the transparent glazing cover and reaches the absorber plate. The radiation is then absorbed by the plate and converted into thermal energy which is then transferred to the heat transfer fluid. Thermal efficiency of flat-plate collectors range from 50-60%[2].

- **Evacuated tube collectors:** This is the predominant solar thermal collector technology worldwide with a market share >65 % chiefly due to their largescale manufacture and deployment in China which accounts for more than 70% of global installed solar thermal capacity. Evacuated tube collectors are designed to operate at higher temperature than flat plate collector commonly ranging from 50°C to 130°C. The manufacturing process, mechanical complexity and material selection of evacuated tube collectors make them more expensive than for flat plate collectors. For example, the design of collectors' housing is made of a vacuum glass tubes to reduce and eliminate convection and conduction thermal losses. However, evacuated tubes are more efficient at around 60-75%[3],

[2] Solar Keymark

[3] Solar Keymark

Solar thermal systems can displace fossil fuel use by, for example, heating or pre-heating steam boiler feedwater or make-up water and/or increasing the return temperature of closed loop hot water systems serving drying, washing or heat treatment processes.

Combined heat and power (CHP)

Also referred to as co-generation, CHP systems capture usable waste heat that is produced in the process of generating electricity. By doing so, CHP plants can achieve higher system energy **efficiency levels in excess of 80%** through waste heat recovery from the exhaust of the primer movers or production waste heat , reducing carbon emissions and energy costs. As most industries have significant simultaneous demands for electricity and thermal energy (heating and cooling), CHP is commonly deployed.

CHP systems can use either gas turbines or reciprocating engines, according to power demands and heat-to- power ratios, with reciprocating engine-based prime movers generally best suited to applications below 5MW of electricity generation capacity.

How it works

Typically, the engine directly drives a generator to produce electrical power and heat is recovered from the engine jacket, the oil cooler and the exhaust gases and, if the heat required is at low enough temperature, from the intercooler. This type of CHP was developed in the 1980s and is usually supplied as a fully packaged unit. Turbines have higher capital cost and have lower electrical efficiency, but have a smaller physical footprint, can provide higher temperature heat and can have greater reliability.

A CHP unit typically operates in parallel with the public supply with additional electricity imported as required. The heat output is commonly supplemented with boiler plant to ensure delivery of required service temperatures and at times of peak demand. A thermal store can be included to smoothen the heat demand, reduce the need for peak boiler use and maximise electricity production at times of higher electricity prices. It is also possible to use heat from a CHP system to generate cooling via absorption chillers to deliver a tri-generation solution i.e. electricity, heating and cooling.

For facilities with limited year- round heat requirements but with large year-round cooling needs, this option would lower the site's electrical load by displacing the electrical demand of conventional chiller plants.

An innovative energy solution that adds further benefits to the traditional CHP process is called **quad-generation** which is increasingly used by the F&B sector to deliver heat, power, cooling and carbon dioxide capture via one process. Through this process, carbon dioxide is recovered from the plant exhaust gas and scrubbed so that it can be used in the industrial process by manufacturers (e.g. for carbonated drinks, keeping packaged food fresh, supporting the brewing fermentation process etc).

It is important that other energy savings measures are fully considered before the viability of a CHP scheme is evaluated. Failure to do so may result in the benefit of the CHP scheme being undermined by the later application of other energy efficiency measures.

As an energy generation process, CHP is 'fuel neutral'. This means that a CHP process can be applied to both renewables like biomass and biogas and fossil fuels like natural gas and oil. For example, in certain

F&B sub-sectors, where there is a significant quantity of unavoidable organic 'waste' co-product, such as fruit and vegetable peelings, the deployment of an anaerobic digester to breakdown the organic matter into a methane-rich biogas, can provide a sustainable, low carbon fuel supply to the CHP system (and/or boilers).

Heat pumps

A heat pump may be thought of as a refrigerator designed to work in reverse i.e. to effectively upgrade a low temperature waste heat stream to a useful high temperature heat stream. The mechanical heat pump is the most widely used in industry and has just four main components: evaporator, compressor, condenser and expansion device.

The refrigerant is the working fluid that passes through all these components in a closed circuit. In the evaporator heat is extracted from a waste heat source e.g. the humid waste air stream from a dryer, causing the refrigerant to evaporate from a liquid state to a gas. Following compression to a higher temperature and pressure, the recovered heat along with the electrical energy input to the compressor can be exchanged in the condenser and delivered to the consumer. Giving up its energy causes the refrigerant to condense. By passing through an expansion device the refrigerant changes back to a low-pressure liquid state then circulates to the evaporator allowing the cycle to repeat.

The efficiency of the heat pump is denoted by its coefficient of performance (COP), defined as the ratio of total heat delivered by the heat pump to the amount of electricity needed to drive the heat pump. Heat pumps operating in the F&B sector routinely achieve COPs of >5 i.e. every one unit of electricity used by the compressor delivers >5 kWh of useful heat. Potential waste heat streams include condenser heat from refrigeration systems, dryers and waste water streams.

As for solar thermal and CHP systems, heat pumps can be integrated with existing systems and services to operate in series or parallel to provide part of the thermal loads with boiler (or other systems) providing the remainder.

Community Boilers

A community boiler for steam generation is a concept common in developed industrialised economies. In this model, large sized boiler is located strategically and supplies steam through pipeline to the surrounding industrial facilities eliminating the need to install small industrial boilers. Presently, most small boilers are operating at low efficiency to meet steam demand of the respective industry. Community boilers can operate above 82% efficiency and reduce fuel consumption compared to the cumulative fuel used across several industries. Further, power can also be generated from the flow of steam through back pressure steam turbine without burning additional fuel. This model, if adopted also has the potential to eliminate industrial air pollution.

Use cases from similar models tested in India show reduction fuel consumption (coal) by 16%, air pollutants like PM, SO_2, NOx by 70-80%, wastewater generation by 40%, space saving of 18% and cost of steam production by 33%. An ideal approach to pilot / demonstrate this model would be identify industrial clusters which has a potential of more than 10 boilers and conduct feasibility studies on the design of this system. However, given the limited the use cases of such systems there are inherent challenges such reticulation of pipes, leakage in the return line buried underground or above ground, higher capex due to technology and infrastructure costs that needs to be evaluated prior to implementation.

Industrial Waste Heat Recovery

Heat recovery is a method of reducing the overall energy consumption of your site and therefore reducing the running costs. Recovered heat can help you reduce energy consumption or provide useful heat for other purposes. Waste heat is a by-product of a process or operation which is not captured or recovered and is therefore not re-used in a secondary system.

Sources of waste heat

The following common sources of waste heat often present opportunities for cost-effective heat recovery:

- Ventilation system extracts
- Boiler flue gases
- Boiler blowdown
- Air compressors
- Refrigeration plant
- High temperature exhaust gas streams from furnaces, kilns, ovens and dryers
- Hot liquid effluents
- Power generation plant
- Process plant cooling systems

Uses for recovered heat

The most cost-effective use of waste heat is to improve the energy efficiency of the heat generating process itself. Common uses for recovered heat include:

- Pre-heating of combustion air for boilers, ovens, furnaces
- Pre-heating fresh air used to ventilate the building
- Hot water generation, including pre-heating of boiler feed water
- Space heating
- Drying
- Other industrial process heating/pre-heating
- Power generation

Heat recovery applications

Installing boiler heat recovery systems is a good way to reduce energy costs and carbon emissions. Key things you should look at before you implement heat recovery are:

- **Controls:** Make sure the boiler controls are set correctly. Running the boiler when it isn't needed or heating to overly high temperatures are common problems leading to inefficiency.
- **Insulate:** Make sure the boiler, pipework and any storage vessels are properly insulated as this can be a major source of wasted heat.
- **Maintain:** Ensure you have a regular and thorough maintenance programme. If your equipment is running optimally, this will always help increase efficiency.

Other energy saving techniques, such as the use of variable speed pumps, should also be investigated alongside heat recovery techniques.

Thermal Oil Boilers

In today's industry, there are several processes where direct heat input is not possible and requires thermal oil heating systems. This is the case when the material to be heated is flammable, causes decomposition or requires uniform heating at a high temperature. Oil is an ideal heat carrier which can meet these requirements as it has a good thermal stability, low volatility, good heat transfer properties, low freezing point amongst others. It is possible for this system to operate with very low pressure and up to a temperature range of 350ºC.

Although oil is a fossil fuel, these systems are designed as a closed circuit with 90% of the fuel consumed in the heating process with minimal leaks and thus offering up to 20% fuel savings compared to steam boilers. Additional energy savings is possible by integrating variable frequency drive to adjust the speed of the motor as this is the major energy consuming component in a thermal oil system. Further, digital modulating burners which can regulate fuel and air for combustion could also provide additional 2% efficiency improvement.

SECTION 3

International best practice for boilers and heat generation processes

3.1. Boiler replacement

If a boiler is more than 15 years old, it is likely to be a conventional type of standard boiler, designed to operate with an average water temperature of 60 to 70°C. These often have a cast iron heat exchanger and atmospheric burners, which draw the air required for combustion from around the boiler by natural convection. They produce water or steam at high temperatures. Standard boilers which do not meet minimum efficiency requirements as noted in Table 3, should be replaced by high-efficiency boilers.

Table 3: Typical Boiler Efficiency

Boiler type	Typical Efficiency	Energy input rate required to meet 100kW heating demand
Standard, old, poor condition	45%	222kW
Standard, good condition	70%	143kW
High-efficiency	82%	122kW

High efficiency boilers: These boilers have lower water contents, larger heat exchanger surface areas and greater insulation of the boiler shell compared to conventional designs. High efficiency boilers can work with all types of heating systems. They are particularly suited to applications where a higher water temperature is required, such as space heating systems using radiators designed to operate at typical flow temperatures of 70-80°C or some process heating applications.

Electric boilers: As the name implies, steam is generated by electricity instead of through the conventional combustion technology. Electricity can be procured from renewable energy sources to power these boilers to experience the greatest benefits of decarbonisation. The benefits of electric boilers are essentially centred on increased efficiency and better environmental sustainability in the context of the absence of flue gases from combustion including carbon monoxide. However, the extent of the benefits depend on the grid emissions unless electricity is generated from a renewable source. It also provides better control over steam generation.

Boiler replacement process

Where boilers are coming up for major refurbishment or replacement, it is worth undertaking a detailed appraisal of current and planned thermal requirements to ensure replacement boilers are properly sized and to consider the merits of incorporating low and zero carbon technologies into the design e.g. solar thermal, CHP and heat pumps.

Condensing boilers are more expensive than non-condensing designs and if you have a number of boilers, it can often be more cost-effective to install just one or two condensing boilers to act as the lead boilers. The rest can be non-condensing types for back-up and peak load top-up.

All steam boilers and hot water boilers over 500 kW should be professionally commissioned by the manufacturer or their approved agent. They should:

- Confirm steam/water flow rates
- Measure combustion efficiency across the full range of firing and give you a copy of the results
- Give you the commissioning certificate and warranty forms
- Provide training to the facilities staff during handover.

In installations with more than one boiler, it's also important to commission the sequence or step controls to make sure the number of boilers operating match the heat load. This is particularly important when one or more is a condensing boiler. In these cases, the sequence controller needs to make sure the condensing boiler always operates as the lead.

3.2. Optimisation measures for boiler efficiency[4]

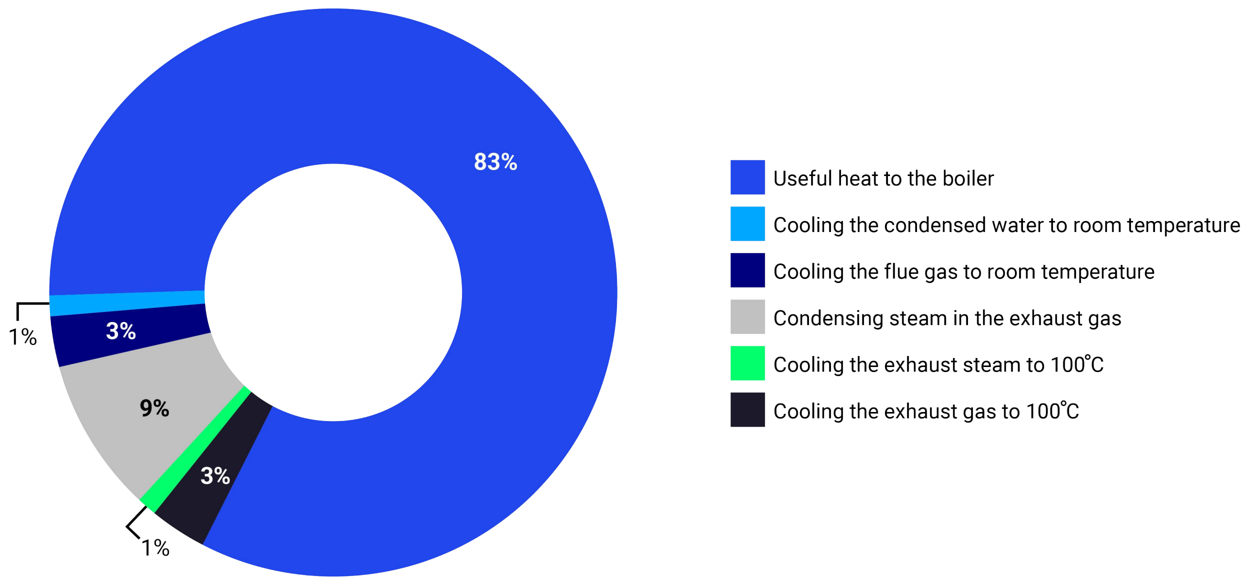
The key issues for energy efficiency relate to the optimisation of boiler efficiency and the control of heat delivery systems as noted below.

Figure 2: Best practices to optimise boiler use

	Best Practice
Fuel preparation	Fuel preparation is particularly important for coal and oil, less so for gas. For coal, choice of fuel is critical since grates are often designed for quite a narrow selection. Characteristics such as size range, ash content, dryness and therefore fuel storage are important. For oil, viscosity is the key characteristic to be controlled. Check on the correct temperature needed to optimise oil atomisation with oil supply companies and monitor the burner oil temperature on a regular basis. Clean oil filters each shift.
Fuel combustion	Fuel combustion is dependent on both fuel and air provision, and contributes significantly to system efficiency. Keeping an even spread of coal on the grate, ash removal, under and over-bed combustion, air pressure and coal height are all critical for optimising coal combustion air pre-heat systems. For heavier oils, cleanliness of the rotary cup, pressure jets etc. is essential. The pressure of fuel and air is critical, particularly at low turndowns when mixing is poor. Poorly maintained burner systems require higher excess air levels giving lower efficiencies. For fluid systems, oxygen trim systems have wide application, although maintenance is an important cost factor. Ask the manufacturers of any burner equipment about the optimum appearance of the flame.
Heat Exchanger	Heat exchanger performance requires a check on flue gas exit temperature. For steam or hot water boilers a good figure is one which is 30 - 55°C above the highest steam/water temperature with the boiler at full load. As the thermal load reduces, this temperature difference should decrease since the heat exchange surface area remains unchanged. If this temperature is seen to increase, this indicates that air flow rates are too high and the heat exchanger is operating too far outside its design parameters. Both fireside and waterside heat transfer surfaces must be kept clean. Fireside with gas firing does not usually present a problem, but oil and coal-fired boilers may need their tubes cleaned on a 12-week and 6-week schedule respectively. In particular, tube cleaning should be carried out when the flue gas working fluid temperature difference increases to 750°C due to fouling. For oil-fired boilers, water injection may help to keep the fireside tubes significantly cleaner. Gas-fired boilers tend to scale on the waterside, but the timing of cleaning will still be governed by the degree of efficiency loss and its value compared with the cost of de-scaling.

[4] Energy Efficiency Best Practice Programme, UK. Good Practice Guide – Practical tips for energy saving in the rubber processing industry.

Steam generation	For steam generation, steam and hot water lines should be insulated and steam leakage should be minimised. Lost condensate and flash steam are responsible for significant energy losses. Isolate heat supplies that are no longer needed with automatic valves, and also sections where significant losses occur when there is no demand. Checking that steam traps are operating correctly should be part of your regular maintenance schedule. As required, failed or mechanical type traps should be changed to modern thermodynamic/orifice plate type traps. Steam should be generated at the pressure necessary to meet the maximum required by the equipment in the system. Control process and space heating systems to optimum operating times and temperatures. For hot water generation systems, minimise supply temperatures and match pump operation to demand. Distribute steam at a pressure higher than that required by any user to ensure that the final required pressure is provided. The steam pipe should be sized against permissible velocity and the allowable pressure loss. Losses are due to heat emission from pipework and leakage. Heat loss from the boiler casing represents between 2 - 5% of boiler steam output in well-designed and operated systems.
Condensate Return	Condensed steam under pressure flashes when reduced to atmospheric pressure conditions in collection tanks. This flash is usually lost and accounts for 43% of the heat in the condensate. As a condensate at 7 bar pressure carries 26% of the heat in the delivered steam, then the flash represents 11.2% of this figure. If the condensate (now at atmospheric pressure) is lost to drain, this is another 14.8% of input steam heat content lost. Therefore, in sites where all flash steam is lost and only 50% of condensate returned, the overall loss is 18.6%. Heat is also lost from condensate lines. As such, condensate return should be maximised as it is usually always cost effective to do so.
Flue Gas Heat Recovery	Even in larger well-controlled gas boilers ~17% or more of the energy in the fuel can be wasted (see chart below for the breakdown of losses). The largest component of that wasted energy is the heat of the water vapour present in the exhaust gas. Condensing boilers and economisers can often be configured to recover that energy be it as an addition to a new build or a retrofit.



3.3. Boiler efficiency benchmarks

Facilities should make consistent and regular efforts to reduce the air ratio for boilers as per Table 4.

Table 4: Air ratios for boilers[5]

Parameter	Boiler capacity (tph)	Load factor (%)	Air Ratio[6]					
			Coal			Biomass fuel	Liquid fuel	Gas fuel
			Pulverised fuel	Fluidized bed	Others			
Standard[7]	> 100	50-100	1.16-1.20	1.15 –1.18	-	-	-	-
	51 – 100	50-100	-	1.15 – 1.18	1.20-1.25	-	-	-
	11-50	50-100	-	1.18 – 1.24	1.24-1.30	1.47-1.55	1.18 - 1.25	1.12-1.15
	Up to 10	50-100	-	1.20 – 1.25	1.35-1.40	1.49-1.56	1.26 - 1.33	1.15-1.18
Target[8]	> 100	50-100	1.12-1.17	1.10 – 1.16	-	-	-	-
	51 – 100	50-100	-	1.12 – 1.17	1.17-1.20	-	-	-
	11-50	50-100	-	1.14 – 1.18	1.22 -1.26	1.32-1.39	1.13-1.18	1.10-1.14
	Up to 10	50-100	-	1.15 – 1.20	1.32-1.38	1.32-1.39	1.18-1.24	1.12-1.15

Source: Bureau of Energy Efficiency, Ministry of Power, Government of India (2018). Energy Conservation Guidelines for Industries

The flue gas temperature of the boiler should be reduced by recovering sensible heat in the exhaust gases by considering reference value noted in Table 5.

Table 5: Flue gas temperature of boilers

Parameter	Boiler capacity (tph)	Load factor (%)	Flue gas temperature [9]					
			Coal			Biomass fuel	Liquid fuel	Gas fuel
			Pulverised fuel	Fluidized bed	Others			
Standard[10]	> 100	50-100	140	140	-	-	-	-
	51 – 100	50-100	-	140	140	-	-	-
	11-50	50-100	-	140	140	180	190	140
	Up to 10	50-100	-	220	220	220	220	220
Target[11]	> 100	50-100	130	130	-	-	-	-
	51 – 100	50-100	-	130	130	-	-	-
	11-50	50-100	-	130	130	160	180	130
	Up to 10	50-100	-	200	200	200	200	180

[5] Bureau of Energy Efficiency, Ministry of Power, Government of India (2018). *Energy Conservation Guidelines for Industries.* https://www.beeindia.gov.in/sites/default/files/Energy%20conservation%20guidelines%20for%20industries.pdf
[6] Air ratio= 21/(21-% oxygen in flue gases)

[7] Standards are optimum performance values achieved by an energy consuming equipment in daily operation.
[8] Targets are equal to the best achievable values of an energy consuming equipment in daily operation.

[9] Average temperature at the outlet of the final stage of heat recovery from flue gas or chimney base.
[10] Standards are optimum performance values achieved by an energy consuming equipment in daily operation.
[11] Targets are equal to the best achievable values of an energy consuming equipment in daily operation.

Source: Bureau of Energy Efficiency, Ministry of Power, Government of India (2018). Energy Conservation Guidelines for Industries

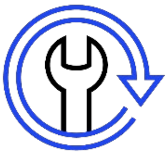
3.4. Energy savings opportunities in boilers and heat distribution

By ensuring efficient steam generation and distribution, energy costs can be reduced by up to 50%. It may not be cost-effective to replace boilers that are relatively new. However, there are still opportunities to make substantial savings through improvements to other items of the boiler plant. Many of these measures will need specialist help. If in doubt, always consult a thermal energy expert or boiler manufacturer.

Inspect and maintain boilers

A poorly maintained industrial boiler can consume 10% more energy than one that has been well maintained.

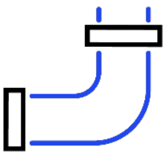
- Make sure that boilers are formally checked at least weekly between services. Common signs of boiler inefficiency are warning lights, pressure drops, and damage, such as burn marks and increased noise levels. Every time a warning sign is ignored, energy is being wasted.
- Gas leaks are a serious safety issue and should be reported immediately.
- Boilers should be serviced at least once a year by a qualified technician. If in heavy use then servicing should be carried out more often, for example, boilers used to provide a base heat load on a continuous basis.



Match boiler outputs to process and/or site requirements

A 2% reduction in flue gas level will give a fuel saving of 1.2%

- Before product changeover or scheduled stoppage, make sure that the boiler operatives know about the step changes in output capacity of steam or hot water. Matching supply to demands will help to save boiler fuel.
- The engineer should replace worn parts and clean the burners and any heat exchangers to remove the build-up of deposits. The service should also include a combustion and/or flue gas test and an adjustment to the fuel/air mix so that the boiler burns fuel efficiently.



Fit insulation and inspect it regularly

Around 10% of the heat produced in steam boilers can be lost through insufficient or ineffective insulation on the distribution system.

- Make sure that all distribution networks (such as pipes, valves, flanges, manhole openings) are suitably insulated and that the insulation is in good condition. Extra inspection to be carried out in areas that have been serviced previously. Reducing heat loss will cut running costs.

Do not lose heat on standby

Installing an isolation damper can eliminate this heat loss and fuel savings of up to 12% are possible.

- When a boiler is on standby, the heat loss through the flue can be significant. An isolation damper can also reduce harmful emissions.

Look at water quality

An automatic water treatment system can save 2% of the fuel requirement.

- Poor water quality can lead to scale, deposition and corrosion, which all reduce heat transfer and eventually lowers boiler efficiency. Consider using automatic water treatment and analysis. Generally treatment consists of adding chemicals to the water.

Investigate the potential for recovering waste heat

These measures can save between 2 and 5% of fuel in sectors like F&B.

- Waste heat from boiler flue gases can be used to preheat the combustion air for boilers or the boiler feedwater, therefore reducing the overall amount of energy required in the process.

Investigate installing automatic controls and use isolation procedures

Boilers are at their most efficient at the maximum firing rate.

- If a site needs varying rates of heat for different processes, it might be worth considering having several smaller boilers to cover the site load and utilising sequencing controls to ensure the varying requirements are met using the most efficient configuration.

Checklist for efficient operation of steam thermal systems

This checklist summarises the key criteria and characteristics of energy efficient steam thermal systems. If the current system cannot meet any of the criteria, it is likely that the efficiency of the system could be improved, resulting in emissions reduction and cost savings.

Best practice criteria	Impact
Do burners operate with trim control to keep excess O_2 levels <3% across combustion air pre-heat firing range?	Retrofitting modern, modulating burners with exhaust gas trim control typically reduces fuel consumption by 10-15% and burner electricity consumption by >30%. Simple payback commonly achieved in <2 years.
Is the boiler water level controlled by a modulating feedwater control system?	'On/off' control systems can lead to unstable boiler operation as pressures can quickly fall and rapidly recover during periods of light-loading. The installation of full feedwater modulation control can reduce short cycling and improve efficiency. Fuel savings >5% and paybacks of ~3-years are common.
Are boilers fitted with automatic TDS controls?	Installing closed-loop automatic controls can provide closer control of TDS levels at reduced blowdown rates. Fuel savings of >1% and paybacks <3-years are common.
Are flue gas discharge temperatures <200°C?	If flue gas temperatures are >200°C, an economiser can be fitted to extract energy from the hot flue gases and use it to preheat boiler feedwater. Fuel savings of 4-6% are commonly achieved with a payback of ~4-years.
Are boilers operated at their design pressure (as opposed to a lesser required system pressure)?	If not, the diminished 'store' of energy within the boiler water risks short cycling which can reduce effective boiler efficiency levels to below 50%. With no CAPEX necessary, 'payback' is instant!
Is the flash steam from TDS blowdown being recovered to the feedwater tank via a deaerator head?	Doing so can recover 10-15% of blowdown water (saving water and chemical costs) and >40% of blowdown energy content. Simple payback commonly achieved in <3-years.
Is energy recovered from residual blowdown effluent?	Using a plate heat exchanger to pre-heat cold boiler make-up water can extract a further 40-50% of total available blowdown energy. Simple payback commonly achieved in <3-years.
Is the feedwater tank maintained at a temperature >85°C?	Supplying water to a boiler at a high temperature of >85°C not only reduces thermal stresses on the boiler and helps maintain its output it also significantly reduces the amount of oxygen scavenging chemicals required.
Is at least 85% of condensate being recovered and returned to the feedwater tank?	A well design and operated steam and condensate system should enable >85% of condensate to be returned to the feedwater tank, thereby saving on water, chemicals and fuel costs. Each 6°C rise in feedwater temperature achieved from improved condensate return rates will deliver a 1% improvement in system efficiency. Simple payback commonly achieved in <1-year.
Are all sections of steam and condensate pipework, valves, vessels and fittings effectively insulated?	Ensuring that all hot surfaces are properly insulated to keep surface temperatures below 40°C is highly cost effective. Fitting flexible, removable covers to valves typically paybacks in under 2-years.

SECTION 4

Best Available Energy Saving Technologies

4.1. Technology Assessment Methodology

The BATs in heat generation and heat-use processes were identified based on their typical potential impact on energy and carbon efficiency in engineering units of GJ_{NG}/GJ_{S} and $kgCO_2/GJ_S$ respectively. The data was extracted from the energy saving measures identified during the audits of energy-intensive F&B facilities. Where data was not available primarily due to absence of steam flow meters, some numbers were extrapolated from the existing metrics of similar operating parameters. It is to be noted that the operating parameters of most boilers such as the operating pressure, temperature, boiler efficiency, operating hours and conditions differ from each other, making it challenging to present BAT metrics for all boilers and heat use processes.

Two sets of BAT metrics were compiled for operating pressure and temperature of 10 bar, 180 ^{o}C and 15 bar, 200 ^{o}C respectively. These operating parameters are more common among all heat generators and they can best represent the typical performance of the boilers and heat-use processes. Considerable care was taken to validate the energy and carbon efficiency data in GJ_{NG}/GJ_S and $kgCO_2$/ GJ_S to support the benchmarking of BATs.

The energy efficiency and carbon efficiency improvement related to BATs were calculated using the following baseline parameters. Unless stated otherwise, the following parameters are extracted from outputs of data analysis from one audited factory:

a. Boiler Plant efficiency is 72.7% (main operating boiler)
b. Weighted average price of Natural Gas is MYR 34.52 per GJ at Q4 2021
c. Energy content of annual natural gas consumption of 4,322 GJ/month or 51,864 GJ/year
d. Energy content of generated steam is 3,142 GJ/month or 37,704 GJ/year
e. Carbon emission factor of Natural Gas is 56 kgCO2 per GJ (source: MGTC)
f. Annual operating hours of boiler plant taken as 4,320 hours/year

4.2. BATs in Heat Generation Process

This section describes the energy efficiency improvement potential of best available technologies and energy saving techniques that can be applied to the installation and operation of technologies in heat generation processes.

4.2.1. Heat Recovery Economiser

Description

This BAT involves installing a flue gas economiser with the objective of recovering waste heat from the flue gas for pre-heating of feedwater temperature prior to entering the boiler. It is a heat exchanger mechanism which reduces boiler fuel consumption by transferring heat from the hot flue gas to the incoming feed water.

The adoption of an economiser is very common and a standard solution due to its substantial energy saving potential. There are two types of economisers: standard and condensing. A standard economiser captures the heat from the hot flue gas heat above the condensation temperature of the vapour (sensible heat), whereas a condensing economiser extracts heat from hot flue gas below the condensation temperature of the vapour (recovering the latent heat). This condensed vapour mixes with sulphur and NOX from the combustion and it becomes acidic and thus corrosive. As such condensing economisers are less in demand despite the ability to recover higher energy as it is more expensive due to the requirement of acid-proof materials such as stainless steel.

Efficiency Benefits

This BAT improves efficiency by between 4-7% . The associated energy and carbon savings are as outlined in the table below.

Table 6: Heat Recovery Economiser Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	*6.0*	1.307	73.2	10 bar, 180°C
1.470	82.3	*5.0*	1.397	78.2	15 bar, 200°C

Economic Considerations

The BAT considers the use of a high efficiency plate-to-shell economiser, as opposed to the conventional shell-and-tube type. The proposed location of installation would be at the boiler flue gas exhaust before the exhaust stack.

In calculating the savings, the following parameters are used:

i. Boiler operating load is 4 tons per hour
ii. Feedwater temperatures before and after the economiser is respectively 45°C and 85°C.

The boiler being audited operates at 80% of the annual operation hours of 4,230 hours and that equates to 3,384 hours. The computation of energy and carbon efficiency improvements is as tabulated below.

Table 7: Analysis of Savings - Heat Recovery Economiser

No.	Parameter	Unit	Value
1	Boiler Operating Load	ton/hour	4
2	Boiler 2 efficiency	%	73.3%
3	Feedwater before economiser	°C	45
4	Feedwater after economiser	°C	85
5	Specific Heat of Water	kJ/kg°C	4.19
6	Annual Operation Hour	hours/year	3,384
7	Heat transfer	kJ/hr	670,400
8	Annual Energy Saving	MJ	2,268,634
		GJ	2,269
9	Annual Energy Saving Input (NG)	GJ	3,095
10	Cost of NG	MYR/GJ	34.52
11	Annual NG Cost Saving	MYR	106,839
12	CAPEX	MYR	450,000
13	Simple Payback Period	Years	4.21

Among the heat recovery technologies, an economiser which can recover an average of 4 to 7% of input energy was not well adopted by the factories being audited. There were only 10 out of the 23 boilers installed with economisers, or 43% of the total. Based on detailed analysis of the existing plant efficiency, operating hours, boiler operating load level and flue temperature, it is confirmed that input energy can be saved between 3.5% to 6% when an economiser is being installed.

4.2.2. Air Preheater

Description

An air preheater heats the air used by the burner of a boiler. A higher air temperature improves combustion efficiency resulting in increased plant efficiency.

Efficiency Benefits

This BAT improves efficiency by an average of 1-2%. The corresponding metrics on energy and carbon efficiency before and after adoption of the BAT are as shown in the table below.

Table 8: Air Preheater Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	1.0	1.376	77.0	10 bar, 180°C
1.470	82.3	1.0	1.455	81.5	15 bar, 200°C

Economic Considerations

As a rule of thumb, every 30 °C increase in intake air temperature will result in a 1% improvement in boiler efficiency. This is used as the basis for calculation of savings potential for this BAT. The installation of an air preheater is in general cost effective for a new boiler. Based on audits of a typical boiler plant, the energy and carbon efficiency improvements are outlined below.

The energy saving of this BAT ranges between 1% to 2% based on the assumption that the air temperature is raised from 30 °C to 60 °C. The long-term impact of this BAT on financial savings is significant when the price of NG increases.

Table 9: Analysis of Savings - Air Preheater

No.	Parameter	Unit	Value
1	Average monthly Natural Gas Input Energy	GJ	6,026
2	Average monthly Steam Output Energy	GJ	3,309
3	Average Boiler Efficiency	%	54.8
4	Supply Air Before	°C	30
5	Supply Air After	°C	60
6	Boiler efficiency after	%	0.558
7	Input Energy after 1% increase	GJ	5,930
8	Saving NG per month	GJ	96
9	Annual NG Saving	GJ	1,151
10	Cost of NG	MYR/GJ	22.1
11	Annual NG Cost Saving	MYR	25,430
12	CAPEX	MYR	75,000
13	Simple Payback Period	Year	2.95

4.2.3. Automated Blowdown Control System

Description

In order to reduce the levels of suspended and total dissolved solids (TDS) in a boiler, water is periodically discharged or blown down. High dissolved solids concentrations can lead to foaming and carryover of boiler water into the steam. This could lead to the occurrence of water hammer which may damage piping, steam traps, or process equipment. Surface blowdown removes dissolved solids that accumulate near the boiler liquid surface, and is often a continuous process. Suspended and dissolved solids can also form sludge. Sludge must therefore be removed as it reduces the heat transfer capabilities of the boiler, resulting in poor fuel-to-steam efficiency and possible pressure vessel damage. Sludge is removed by mid blowdown.

In order to reduce heat loss caused by frequent blow-down due to the poor quality of feed-water, all audited factories have religiously implemented chemical treatment to control the level of total dissolved and undissolved solids. Manual blowdown is the norm when TDS reaches the range of 2000 to 2500ppm. Due to good water quality, manual blowdown was infrequent and most of the boilermen carried out manual blowdown either once or twice per day.

In the event that a fixed rate of blowdown regime is being implemented, operators will not know the changes in makeup and feedwater conditions, or variations in steam demand or condensate return. An automatic blowdown-control system optimizes surface-blowdown rates by regulating the volume of water discharged from the boiler in relation to the concentration of dissolved solids present. Automatic surface-blowdown control systems maintain water chemistry within acceptable limits, while minimizing blowdown and reducing energy losses. Cost savings come from the significant reduction in the consumption, disposal, treatment, and heating of water.

While all steam boilers need to be blown down to control the level of total dissolved solids (TDS) in the boiler water, energy and water treatment efficiency can be significantly improved by recovering flash steam and the residual heat from this boiler blowdown. A blowdown heat recovery system is made up from a flash vessel and a heat exchanger. The flash vessel lowers the high-pressure blowdown stream to atmospheric pressure, generating flash steam and a flow of 100°C water. The flash steam is collected and used to provide heating typically by injecting it into the hotwell. The hot water is discharged to the heat exchanger from where its heat can be transferred to process, e.g. boiler makeup water.

Efficiency Benefits

This BAT improves efficiency by an average of 0.1%. The associated energy and carbon savings are as outlined in the table below.

Table 10: Automated Blowdown Control System Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	0.1	1.388	77.7	10 bar, 180°C
1.470	82.3	0.1	1.468	82.2	15 bar, 200°C

Economic Considerations

This investment measure involves installing an automatic blowdown system for 2 boilers of a factory being audited. Current practice of the boilerman (or boiler operator) is to conduct manual blowdown hourly regardless of the value of Total Dissolved Solids (TDS) in water of the boiler even though the TDS setpoint is 2,500ppm. The automatic blowdown system will perform blowdown when the setpoint of 2,500ppm is triggered. It is estimated that the automatic blowdown system can conservatively, reduce the frequency of blowdown from being hourly to once in every 3 hours.

In calculating the savings, the following additional parameters are used:

i) Blowdown pipe flow rate at 2.5kg/s at a pressure of 15 bar.

ii) Annual operation day of boiler plant is 284 days (based on 6,816 hours).

Based on a typical audit of a boiler plant, the computation of energy and carbon efficiency improvements is as tabulated below.

Table 11: Analysis of Savings - Automated Blowdown Control System

No.	Parameter	Unit	Value
1	Blowdown flow	kg/s	2.5
2	Blowdown frequency before	nos/day	24
3	Blowdown frequency after	nos/day	8
4	Blowdown duration	s	60
5	Boiler plant efficiency	%	75.0%
6	Steam Enthalpy @ 15bar, hf	kJ/kg	844
7	Feedwater Enthalpy @ 100C, hf	kJ/kg	419.2
8	Annual Operation Day	day	284
9	Heat transfer, $Q = mCp\Delta T$	kJ	289,543,680
	Annual Energy Saving	MJ	289,544

10		GJ	290
		mmBTU	274
11	Annual Energy Saving Input (NG)	GJ	386
12	Cost of NG	MYR/GJ	34.52
13	Annual NG Cost Saving	MYR	13,327
14	Total Annual Cost Saving	MYR	13,327
15	CAPEX	MYR	50,000.00
16	Simple Payback Period	Year	3.75

Significant savings in energy, chemicals, feed-water and cooling can be achieved from this BAT. The investment cost of the automatic blowdown system is dependent upon the system operating pressure and the design and performance options specified. An automatic blowdown-control system can cost from RM 50,000.

This BAT will reduce 386 GJ/year of energy even if the blowdown is assumed to happen at 8 cycles per day instead of 2 being the norm. Financially, the saving is RM 13,327 per annum and the corresponding carbon emission reduction is 22 tCO_2/year.

4.2.4. Oxygen Trim Control System

Description

While some degree of excess air is needed for complete combustion excessive air results in heat losses and drop in efficiency. Therefore, it is crucial to know if the excess air is at an optimal level by measuring the amount of oxygen or CO_2 at the exhaust using a combustion analyser.

Excess air can be minimised by adjusting the air flowrate in proportion to the fuel flowrate. This is greatly assisted by automating the measurement of oxygen content in the flue-gases. For safety reasons, there should always be some excess air present (typically 1 – 2 % for gas and 10 % for liquid fuels).

Efficiency Benefits

This BAT improves efficiency by an average of 1.5-3%. The associated energy and carbon savings are as outlined in the table below.

Table 12: Oxygen Trim Control System Efficiency Benefits

Without BAT		BAT potential efficiency improvement	**With BAT**		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	1.5	1.369	76.7	10 bar, 180°C
1.470	82.3	1.5	1.448	81.1	15 bar, 200°C

Economic Considerations

Assumptions made for computation of potential impact of this BAT is that for every 5% reduction in excess air, boiler efficiency increases by 1%. It is further assumed that 20% to 30% of excess air (1.20 to 1.30) is a norm in most factories that do not practise thermal energy management.

Base air ratio of a NG-fuelled boiler having a capacity between 10 to less than 30 tons/hr is 1.15 to 1.30. When the base air is optimised to 1.15 operation-wise, a maximum reduction of 15% of excess air is attained which will improve boiler efficiency by 3%. For the calculation of efficiency benefits of the above table, only 1.5% improvement was considered after taking safety into account.

4.2.5. Deaerator for Feedwater

Description

The presence of oxygen in the boiler water can be a significant problem due to the corrosion that can occur at high temperatures. To overcome this, a deaerator is used. Deaerators use heat, typically steam to reduce the oxygen content in water and they are typically pressurized tanks that raise the water temperature to the point of saturation. They also break the feed water into fine droplets to facilitate the removal of oxygen and other non-condensable gases. Depending on the design, the feedwater oxygen content can be reduced to levels ranging from 7 to 40 parts per billion (ppb).

Atmospheric deaerators are typically found in smaller, lower-pressure boiler systems. They operate at atmospheric pressure and the maximum operating temperature is 100 °C. However, most of the deaerators operate at temperatures lower than this. Atmospheric deaerators normally cannot achieve the same level of oxygen removal as that of pressurised deaerators when typically water with oxygen levels of 5 to 10 part per million (ppm) is supplied. In applications that require lower oxygen levels than achievable with a pressurised deaerator, oxygen scavenger can be used to remove most residual oxygen. In most systems, an oxygen scavenger is part of the system's water treatment program.

Efficiency Benefits

This BAT improves water quality by virtually eliminating the amount of dissolved oxygen and carbon dioxide in the feed water. Efficiency is typically around 0.5%. The associated savings are outlined in the table below.

Table 13: Feedwater Deaerator Efficiency Benefits

Without BAT		BAT potential efficiency improvement	**With BAT**		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	0.5	1.383	77.5	10 bar, 180°C
1.470	82.3	0.5	1.463	81.9	15 bar, 200°C

Economic Considerations

This BAT helps lower operating costs and improve steam quality. Indirectly, it lowers the frequency of blowdown besides saving cost to repair and /or replacement of the boiler water tubes.

4.3. Heat Use Process

This section describes the energy efficiency improvement potential associated with the application of best available technologies and the energy saving techniques that can be applied to the installation and operation of technologies in heat use processes.

4.3.1. Condensate Recovery

Description

Condensate recovery is a very effective heat recovery mechanism and also a common energy saving measure. Condensate maintains a substantial thermal energy. The amount of energy in a condensate varies from 18% at 1 barg to 30% at 14 barg. Therefore it is crucial that the condensate is recovered either back to the boiler system or in some cases, recovered via heat exchanger for other requirements. Condensate that returns to the boiler will reduce the fuel consumed for the combustion in the boiler. It is estimated that every 60ºC rise in feedwater temperature will save 1% of fuel for boiler and other associated steam raising costs

Any unrecovered hot condensate will be replaced with cold makeup water. This will incur additional cost of water treatment and fuel to raise the temperature of water at colder temperatures, and hence reduce the steaming rate.

Efficiency Benefits

This BAT improves efficiency by an average of 9.0%. The associated energy and carbon savings are as outlined in the table below.

Table 14: Condensate Recovery Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	9.0	1.265	70.8	10 bar, 180°C
1.470	82.3	9.0	1.338	74.9	15 bar, 200°C

Economic Considerations

Reusing hot condensate can lead to significant savings in terms of energy, carbon savings and water resources, as well as improving working conditions.

The following actions will help release the maximise the associated energy savings and financial benefits:

- Regularly monitor and repair any leaks in the steam distribution and condensate return system.
- Insulate condensate return system piping to prevent heat loss and protect personnel against burns

As outlined above maximising condensate recovery can offer significant savings,

In calculating the savings, the following additional data has been used:

i. Condensate recovery rate is 3.36 m^3/hour (based on 70% recovery rate)
ii. City water and recovered condensate water temperatures are respectively 30°C and 80°C
iii. Water tariff rate of RM2.28 per cubic meter in the Klang Valley region

Typical energy and carbon efficiency improvement based on site audit data is outlined below.

Table 15: Analysis of Savings: Condensate Recovery

No.	Parameter	Unit	Value
1	Condensate Recovery	m^3/h	3.36
2	Density of water at 80°C	kg/m^3	971.76
3	Boiler efficiency	%	76.3%
4	Feedwater Temperature	°C	30
5	Condensate Water Temperature	°C	80
6	Specific Heat of Water	kJ/kg°C	4.19
7	Annual Operation Hour	hr	8,160
8	Heat transfer, $Q = mCp\Delta T$	kJ/hr	684,041
9	Annual Energy Saving	MJ	5,581,777
		GJ	5,582
10	Annual Energy Saving Input (NG)	GJ	7,316
11	Annual Water Saving	m^3	27,418
12	Cost of NG	MYR/GJ	22.1
13	Cost of Water in Klang Valley	MYR/m^3	2.28
14	Annual NG Cost Saving	MYR	161,674
15	Annual Water Cost Saving	MYR	62,512
16	Total Annual Cost Saving	MYR	224,186
17	CAPEX	MYR	150,000
18	Simple Payback Period	Year	0.67

4.3.2. Insulation of Flanges or Valves

Description

Steam pipes, condensate return pipes, flanges and valves that are not insulated are a constant source of heat loss through radiation which is easy to remedy. Insulating all heat surfaces is, in most cases, an easy measure to implement and it is a low-cost measure. In addition, localised damage to insulation can be readily repaired. It is quite a common sight to find insulation which has been removed or not being replaced during operation, maintenance or repairs.

Any wet or hardened insulation needs to be replaced. The cause of wet insulation can often be found in leaking pipes or tubes. The leaks should be repaired before the insulation is replaced. The table below shows heat losses from uninsulated steam lines at different steam pressures.

Table 16: Approximate heat loss per 30 m of uninsulated steam line

Distribution Line Diameter (mm)	Approximate Heat Loss Per 30 m of Uninsulated Steam Line (GJ/yr)			
	Steam Pressure (barg)			
	1	10	20	40
25	148	301	396	522
50	248	506	665	886
100	438	897	1,182	1,583
200	781	1,625	2,142	2,875
300	1,113	2,321	3,070	4,136

Efficiency Benefits

This BAT improves efficiency by an average of 0.1%.

The associated energy and carbon savings are as outlined in the table below.

Table 17: Insulation of Flanges or Valves Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	0.1	1.389	77.8	10 bar, 180°C
1.470	82.3	0.1	1.469	82.2	15 bar, 200°C

As a baseline, all piping operating at temperatures above ambient temperature should be insulated to prevent heat loss and safety risk. This is especially the case for steam above 180 °C where it needs to be distributed it in pipes of diameters of more than 200 mm. Insulation must be checked periodically to ensure it is always in good condition. Infra-thermography is a very effective measure to check the integrity of insulation.

Infra-thermography taken during site audits have demonstrated that surface temperature of flanges and valves were as high as 100°C. When compared to the ambient temperature of around 30°C, this equates to a convective heat loss with temperature differential of 70°C.

Economic Considerations

In calculating the savings, the following additional basis for calculation were used:

i. Flanges and/or valves are assumed to be cylindrical in shape and having a surface area of ("Pi" x Pipe Diameter x Length of section)
ii. Pipe Diameter and Section length are taken as 6" (150mm) and 600mm respectively

A total of five (5) flanges and valves are observed to be uninsulated.

The associated energy and carbon savings are as outlined in the table below.

Table 18: Analysis of Savings: Insulation of Flanges or Valves

No.	Parameter	Unit	Value
1	Ambient Temperature	°C	30
2	Steam Pipe Temperature	°C	100
3	Temperature Difference	°C	70
4	Boiler efficiency	%	54.8
5	Heat Loss rate @ delta 70C	kJ/m^{2}h	3,298
6	Flanges/Valves area	m^2	0.283
7	Quantity of Flanges/Valves Uninsulated	nos	5
8	Annual Operation Hour	hr	7,920
9	Heat transfer	kJ/hr	4,662
10	Annual Energy Saving	MJ	36,925
		GJ	37
11	Annual Energy Saving Input (NG)	GJ	67
12	Cost of NG	MYR/GJ	22.1
13	Annual NG Cost Saving	MYR	1,489
14	CAPEX	MYR	4,000
15	Simple Payback Period	Year	2.69

4.3.3. Management of Steam Leak

Description

Steam leaks are inevitable as the entire steam distribution is subject to thermal stress which causes joints to be loosened or fracture. Steam leak at valves, bends and tees is commonly visible and should be rectified quickly to limit energy and water loss. The rate of energy loss increases exponentially with the diameter of the hole.

Efficiency Benefits

This BAT improves efficiency by an average of 0.4%.

The associated energy and carbon savings are as outlined in the table below.

Table 19: Management of Steam Leak Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	0.4	1.384	77.5	10 bar, 180°C
1.470	82.3	0.4	1.464	82.0	15 bar, 200°C

Economic Considerations

The potential savings outlined are calculated using the following parameters:

i) Nominal leak diameter of 3mm
ii) Steam leakage rate is approximately 15 kg/hr at the given leak diameter and steam pressure

The associated energy and carbon savings are as outlined in the table below.

Table 20: Analysis of Savings: Management of Steam Leak

No.	Parameter	Unit	Value
1	Steam Pipe Leak Diameter	mm	3
2	Steam Pressure	bar	6
3	Steam Leakage rate	kg/hr	15
4	Boiler efficiency	%	54.8
5	Steam Enthalpy @ 6bar	kJ/kg	2,652.9
6	Feedwater Enthalpy @ 102C	kJ/kg	420
7	Annual Operation Hour	hr	7,920
8	Heat transfer	kJ/hr	33,494
9	Annual Energy Saving	MJ	265,269
		GJ	265
10	Annual Energy Saving Input (NG)	GJ	484
11	Cost of NG	MYR/GJ	22.1
12	Annual NG Cost Saving	MYR	10,697
13	CAPEX	MYR	1,000
14	Simple Payback Period	Years	0.09

4.3.4. Management of Steam Trap

Description

Steam traps are used to remove water, air and non-condensable gases from the steam distribution pipe work to help maintain system efficiency. The primary functions of steam traps are to discharge the condensate without allowing steam to escape. Condensate usually contains around 25% of the usable energy of the live steam. As previous outlined every effort should be made to recover condensate to maximise system efficiency.

Condensate removed from the steam system and returned to the feed tank also reduces the need for boiler blowdown, which is used to regulate the concentration of dissolved solids in the boiler. This therefore reduces the energy lost from the boiler during the blowdown process.

Removing the unwanted condensate from the system ensures there is less chance of damage from issues like water hammer and corrosion. Steam traps remove the condensate as it forms, keeping better quality steam in the system and protecting pipework and equipment from erosion and corrosion.

There are a few types of steam traps and in general, they are: 1) the thermostatic traps which is operated by changes in fluid temperature, e.g. bellows, bimetallic; 2) the thermodynamics traps which is operated by changes in fluid dynamics, e.g. disc; 3) the mechanical traps which is operated by changes in fluid density, e.g. ball float, inverted bucket, float & thermostatic.

Steam trap failure allows live steam to escape resulting in considerable energy loss. . Steam traps can fail to function when they cannot open or close or are partially leaking or partially closed. The condition of steam traps can be checked via visual inspection, and conventional acoustic methods where sound is transmitted through screwdriver, stethoscope and other acoustic devices. The most accurate method is by thermography camera which is now a common place and accessible technology.

Proper Good maintenance practice can reduce these losses in a cost-efficient manner. In steam systems where the steam traps have not been inspected in the last three to five years, up to about 30 % of them may have failed. In systems with a regularly scheduled maintenance programme, less than 5 % of the total number of traps should be leaking.

There are many different types of steam traps and each type has its own characteristics and preconditions. Checks for escaping steam are based on acoustic, visual, electrical conductivity or thermal checks.

The table below shows the approximate steam losses caused by leaks of several diameters.

Table 21: Leaking steam trap discharge rate

Approximate trap orifice diameter (mm)	Approximate steam loss (kg/h)			
	Approximate steam pressure (barg)			
	1	7	10	20
1	0.4	1.5	2.1	-
2	1.5	6.0	8.6	16.4
3	6.2	24.0	34.4	65.8
4	13.9	54.0	77.0	148.0
6	24.8	96.0	137.0	263.0
8	55.8	215.0	309.0	591.0

Efficiency Benefits

This BAT improves efficiency between 0.4% and 1.0%.

The associated energy and carbon savings are as outlined in the table below.

Table 22: Management of Steam Trap Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	

1.390	77.8	0.4	1.384	77.5	10 bar, 180°C
1.470	82.3	1.0	1.455	81.5	15 bar, 200°C

Many problems with steam traps are caused by poor installation. As such drain points should be installed in such a manner that condensate can be easily channelled into the steam trap. As best practice, in a 150mm steam distribution main, a drain pot of 100mm diameter should be provided at the lowest part of the pipe

1. Pipe should be adequately sized particularly for pipe leading to and away from steam trap. Avoid having valves, bends and tees too close to the trap as these may cause excessive back pressure.
2. Selection of group trapping or individual trapping: group trapping is considered when there is a need to counter water logging and loss of output while individual steam trap for each process connected to a common condensate return piping is a more satisfactory arrangement.
3. Provision of strainers before the steam traps and a sight glass after the trap to observe proper functionality of traps is also best practice.
4. Regular scheduled testing and maintenance are crucial to the effective working of steam traps and thus preventing any unnecessary energy loss

Recommended Steam Trap Testing Intervals

- High-Pressure (150 psig and above): Weekly to Monthly
- Medium-Pressure (30 to 150 psig): Monthly to Quarterly
- Low-Pressure (below 30 psig): Annually

Economic considerations

Assuming a malfunctioned steam trap leaks steam, this BAT will result in 488 GJ/year of energy savings and financial saving of RM 14,261 per year. Carbon emission reduction is 27 tCO_2/year.

Table 23: Analysis of Savings: Management of Steam Trap

No.	Parameter	Unit	Value
1	Steam Trap Leakage rate	kg/hr	36
2	Boiler efficiency	%	75.0%
3	Steam Enthalpy @ 15bar	kJ/kg	2,790.0
4	Feedwater Enthalpy @ 102C	kJ/kg	420
5	Annual Operation Hour	hr	4,290
6	Heat transfer Q = mΔh	kJ/hr	85,320
7	Annual Energy Saving	MJ	366,023
		GJ	366
8	Annual Energy Saving Input (NG)	GJ	488
9	Cost of NG	MYR/GJ	29.22
10	Annual NG Cost Saving	MYR	14,261
11	CAPEX	MYR	10,000
12	Simple Payback Period	Year	0.70
13	NG CO2 emission rate	tCO2/GJ	0.056
14	Annual CO2 Emission Reduction	tCO2/year	27

4.3.5. Flash Steam Recovery

Description

Flash steam is formed when condensate at high pressure is discharged to a lower pressure source and the steam can be used for heating at a lower pressure. The reduction of pressure is achieved by a pressure reducing valve or as an example, exiting through a steam trap.

Energy recovery can be achieved through heat exchange with boiler make-up water. If the blowdown water is brought to a lower pressure in a flash tank beforehand, then steam will be formed at a lower pressure. This flash steam can be moved directly to the degasser and can thus be mixed with the fresh make-up water. The flash steam does not contain any dissolved salts and the steam represents a large portion of the energy in the blowdown.

Flash steam does, however, occupy a much larger volume than condensate. The return pipes must be able to deal with this without pressure increases. Otherwise, the resulting backpressure may hamper the proper functioning of steam traps and other components upstream.

In the boiler plant, the flash steam, like the condensate, can be used to heat the feed-water in the degasser. Other possibilities include the use of the flash steam for air heating. Besides the boiler plant, flash steam can be used to heat products up to 100 °C. Where steam uses are at a pressure of 1 barg The flash steam can be directly injected into these pipes.

Heat-use processes at low pressure are usually met by throttling high pressure steam. But a portion of the process requirements can be achieved at low cost by flashing high pressure condensate.

Efficiency Benefits

This BAT improves efficiency by an average of 1.0%.

The associated energy and carbon savings are as outlined in the table below.

Table 24: Flash Steam Recovery Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.470	82.3	1.0	1.455	81.5	15 bar, 200°C

This BAT is applicable when the factory has steam distribution with pressures lower than the pressure at which steam is generated. Re-use of flash steam is more efficient than utilising the heat in the blowdown via a heat exchanger.

In theory, any energy use at a lower temperature can be a possible use for flash steam instead of fresh steam although implementation is not always easy. It is widely used in the petrochemical industry. The BAT potential saving from flash steam recovery is about 1.0 to 2.0% for steam pressure of 15 bar at 200°C and the metrics before and after adoption of BAT are tabulated above.

Economic considerations

The recovery of flash steam can provide greater energy savings than from condensate return. Flashing is particularly attractive when it is not economically feasible to return the high-pressure condensate to the boiler. This BAT will save 1,915 GJ/year of energy and a financial saving of RM 59,328 per year. Carbon emission reduction is 107.4 tCO_2/year

Table 25: Analysis of Savings: Flash Steam Recovery

No.	Parameter	Unit	Value
1	City Water make up flow rate	m3/h	2.0
2	Density of water at 50oC	kg/m3	988
3	Boiler plant efficiency	%	71.6%
4	City water Temperature	°C	30
5	Preheated City Water Temperature by Flash Steam Recovery	°C	50
6	Specific Heat of Water	kJ/kg°C	4.19
7	Annual Operation Hour	hr	8,280
8	Heat transfer, Q = mCpΔT	kJ/hr	165,589
9	Annual Energy Saving	MJ	1,371,075
		GJ	1,371
10	Annual Energy Saving Input (NG)	GJ	1,915
11	Cost of NG	MYR/GJ	30.98
12	Annual NG Cost Saving	MYR	59,324
13	CAPEX	MYR	150,000
14	Simple Payback Period	Year	2.53
15	NG CO2 Emission Rate	tCO2/GJ	0.056
16	Annual CO2 Emission Reduction	tCO2/year	107

4.4. Transformative low carbon solutions

4.4.1. Solar Thermal System

Description

Solar thermal systems use solar collectors to absorb energy from the sun and thereafter transfer the heat energy using heat exchangers to heat water.

Figure 3: Present boiler make-up water tank configuration

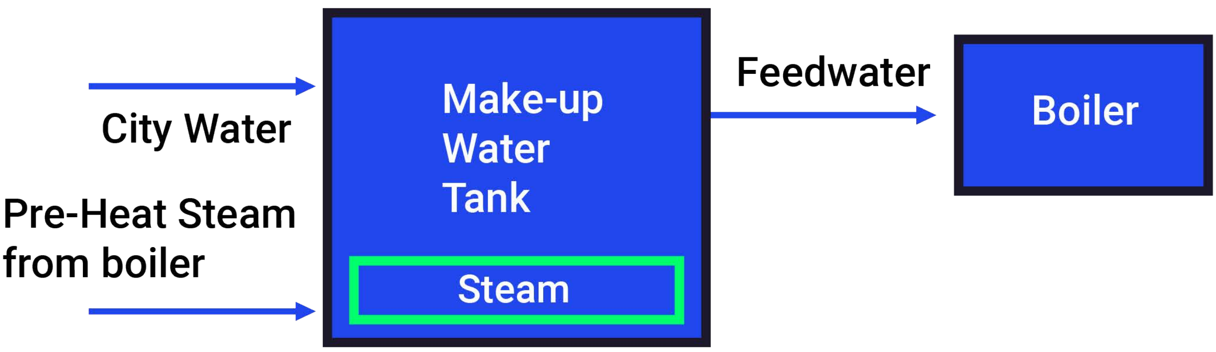
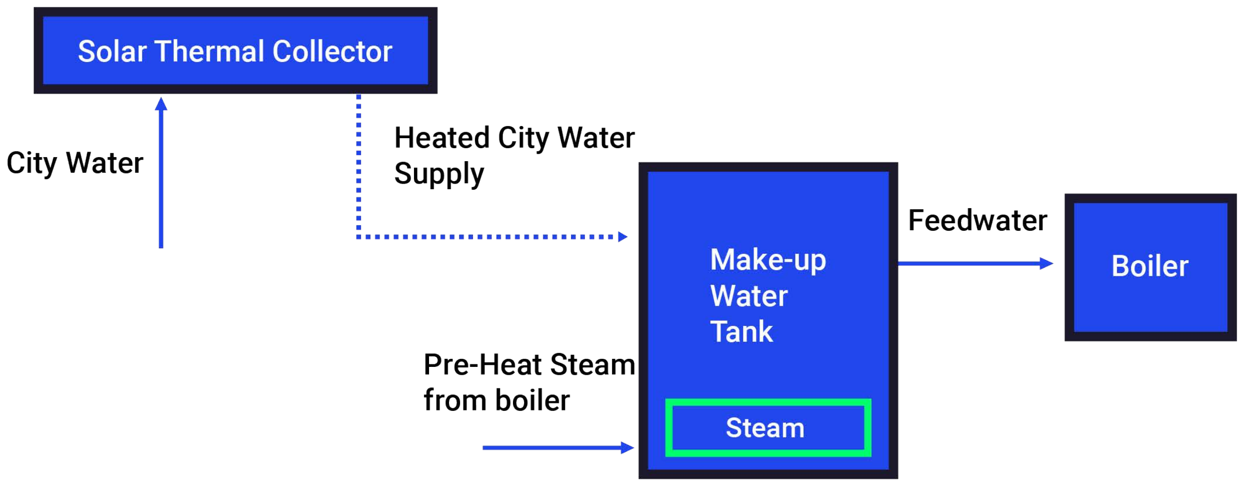


Figure 4: Proposed boiler make-up water tank configuration



Technology Maturity and Commercial Readiness

Solar thermal is a mature technology however the need for a large footprint restricts its wider adoption. It is ideally installed on rooftop if space is not a limitation but structural integrity needs to be to be taken into account.

Efficiency Benefits

Solar thermal systems can improve boiler thermal efficiency by an average of 0.7% and is restricted by short operating hours of the system. - The associated energy and carbon savings are as outlined in the table below.

Table 26: Solar Thermal System Efficiency Benefits

Without BAT		BAT potential efficiency improvement	With BAT		Remarks
Typical energy efficiency	Typical carbon efficiency		BAT energy efficiency	BAT carbon efficiency	
GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	%	GJ_{NG}/GJ_S	$kgCO_2/GJ_{NG}$	
1.390	77.8	0.7	1.380	77.3	10 bar, 180°C
1.470	82.3	0.7	1.460	81.7	15 bar, 200°C

Economic Considerations

In analysing the savings, the following additional data was used:

i) City water flowrate of 1 m^3/hour (estimation based on solar thermal capacity of 1 m^3/hr)
ii) Annual operation hours of the Solar Thermal System taken as 2,190 hours per year. The low hours quoted accounts for the fact that the solar heat recovery is only effective between 10am and 4pm in the day. Before and after day light hours, the recovery is considered negligible
iii) Price estimate of flat plate solar collector

Table 27: Analysis of Savings: Solar Thermal System

No.	Parameter	Unit	Value
1	Water Flow Rate	m3/hr	1
2	Density of water at 80°C	kg/m3	971.76
3	Water Mass Flow Rate	kg/hr	971.76
4	Boiler efficiency	%	76.3%
5	City Water Temperature	°C	30
6	After Solar Thermal Temperature	°C	80
7	Specific Heat of Water	kJ/kg°C	4.19
8	Annual Operation Hour	hr	2,190
9	Heat transfer, $Q = mCp\Delta T$	kJ/hr	203,584
10	Annual Energy Saving	MJ	445,848
		GJ	446
11	Annual Energy Saving Input (NG)	GJ	584
12	Cost of NG	MYR/GJ	22.1
13	Annual NG Cost Saving	MYR	12,914
14	CAPEX	MYR	60,000
15	Simple Payback Period	Year	4.65

4.4.2. Electric Boiler

As the name implies, steam is generated by electricity instead of through the conventional combustion technology. Electricity can be procured from renewable energy sources which is made available by TNB in 2022 under the Green Electricity Tariff. The benefits of electric boilers are essentially centred on increased efficiency and better environmental sustainability in the context of the absence of flue gases from combustion including carbon monoxide. However, the extent of the benefits depend on the grid emissions unless electricity is generated from a renewable source. It also provides better control over steam generation.

If renewable energy is not available throughout the entire process of steam generation, the benefits of electric boilers being a low carbon technology is highly debatable. It is to be noted that the fuel mix for electricity generation in Malaysia is highly dependable on fossil fuel, the resultant CO_2 emission factor of electricity is 192.78 $kgCO_2/GJ$. This is 3.4 times more than the emission factor of NG which is at 56.1 $kgCO_2/GJ$. Even if electric boilers use renewable energy for 50% of steam generation and the remaining electricity from the power plants, it does not qualify as a low carbon system.

SECTION 5

Recommendations

5. Recommendations

Technology will drive a successful transition to secure, more affordable energy and reduced emissions. Deploying the appropriate technology when and where it is needed will allow Malaysian industry to capture new opportunities from increasing global demand for reducing emissions across products and services. The solutions identified for thermal energy management require implementation through demonstration across industries before being recommended for wider adoption across sectors. While there is no perfect way to implement this, some processes could be adopted through collaboration with stakeholders. A summary of the key steps that could be taken are provided below:

Bridging the gap

The gap between government and investments in fundamental research (concentrated at new technologies with low readiness) and private sector investments in commercialisation (concentrated at technologies with high readiness) needs to be bridged. KeTSA could consider establishing ‘Clean Manufacturing Innovation Institutes’ to demonstrate advanced technologies and processes, leading to commercialisation. These centres could be a part of a strategy that addresses the gap in funding which will be critical to the maturity of new technologies.

Increased research & development on deployment

This is important to push some technologies into the mainstream and the emphasis on deployment will help industries in Malaysia gain a competitive advantage through low emissions operations. Additionally, working in close partnership with industry to deploy technologies would give researchers and solution providers a sense of the practical challenges and opportunities within the industry, which could improve the research in the future. An example of this approach is the Malaysian Green Technology and Climate Change Corporation (MGTC) which is tasked with the objective of promoting green growth by providing access to technology, financing and creating advocacy for scaling up energy efficiency and renewable energy across sectors. Another example could be to replicate the demand side management plan developed on the premise of the study conducted for the F&B sector to other energy-intensive sectors. A final example would be support for joint industry-academic technology demonstrations.

International collaboration

Collaborate internationally on research & development in some of these technologies. Certain technologies identified show large potential to improve energy efficiency and are being increasingly deployed globally. For such technologies collaborative research efforts should be developed to advance these mutually beneficial goals. One example of an area of important international focus would be community boilers demonstration in the F&B sector. Given the scale of the global F&B industry, Malaysia should align its programmes with international efforts.

Invest in best available technologies

Despite the energy savings opportunity available for industry, the lack of investment into best available technologies is a key barrier limiting the amount of energy and carbon efficiency that can be achieved, and the subsequent cost savings being realised. Some barriers can be easily overcome with minimal capital expenditure but require commitment, awareness, and willingness of the top management to implement energy saving measures. There is a strong business case to be made for adopting best available technologies since the return on investment is significant and is especially attractive when energy prices are high.

Further, the uptake of these technologies could be fuelled through a structured demand-side management plan by setting targets and implementing robust activities through a structured process. Such a plan may also help the government in budgeting for energy saving opportunities upfront and could become a long-term strategy for the transformation of the energy-intensive industries in Malaysia.

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