Final Report on Heating Systems (for Industry)

KBR | ENERGY SOLUTIONS | CONSULTING

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Contents

Abbreviations

AEC	Annual Energy Consumption
Avg_{eff}	Average Thermal Efficiency
$Avg_{Stack\ O2}$	Average Stack Oxygen Content
$Avg_{Stack\ T}$	Average Stack Temperature
BAT	Best Available Technique
BFW	Boiler Feed Water
BP_{eff}	Best Practice Thermal Efficiency
$BP_{Stack\ O2}$	Best Practice Stack Oxygen Content
$BP_{Stack\ T}$	Best Practice Stack Temperature
CAPEX	Capital Expenditure
CDU	Crude Distillation Unit
DCS	Distributed Control System
EDB	Economic Development Board
GTG	Gas Turbine Generator
HRSG	Heat Recovery Steam Generator
KBR	Kellogg Brown & Root Asia Pacific Pte Ltd
LP	Low Pressure
M&V	Measurement and Verification
MP	Medium Pressure
NDA	Non-Disclosure Agreement (in figure)
NEA	National Environment Agency
NG	Natural Gas
P&ID	Piping and Instrumentation Diagram
PFD	Process Flow Diagram
SGD	Singapore Dollars
TO	Thermal Oxidiser (in figures)
VSD	Variable Speed Drive

1 Executive Summary

National Environment Agency (NEA) has commissioned a study into the heating systems in the oil refining, petrochemical and chemical industry. This study focuses on 4 main heating systems which are the predominant energy consumers in these industries. The heating systems are namely, boilers, furnaces, hot oil heaters and cogeneration systems.

KBR and the NEA team has worked closely on the development of the Assessment Framework on Heating Systems. Details on the assessment methodology, key metrics and measurement & verification plans were documented. The assessment methodology was then applied onto the study with the participating plants.

The study with each participating plant typically involves the following key milestones:

- Data collection
- Kick-off meeting / Process Flow Diagram (PFD) reviews
- Review meetings
- Close out meeting and issuance of Customised Reports

Plant-specific findings were summarised in the Customised Reports that were issued to the participating plants at the close-out of the study. The Customised Reports contains information on the heating system performances of the participating plant and also details on the shortlisted opportunities.

All key findings and observations from the entire study were summarised in the Final Report to NEA. A Best Practice Guide was also developed to document the best energy practices in Heating Systems in relation to what was observed during the study. Generalised findings on heating systems were also presented to all participating plants through the Results Sharing Workshop.

This study was conducted from August 2019 to June 2021 and it was executed in 2 key phases. All participating plants have given full support and commitment towards this study. The energy managers / representatives of each participating plant have played a leading role in collecting plant-specific information and arranging for the right resources to support this study. The top management of some participating plants have even expressed interest in the scope, progress and results of this study.

After much discussion with all participating plants, 40 opportunities have been shortlisted for implementation considerations. Table 1 below shows a summary of the shortlisted opportunities, sorted by heating systems.

Table 1: Summary of Shortlisted Opportunities by Heating Systems

Heating System	No. of Shortlisted Opportunities	Total CAPEX [k SGD]	Energy Reduction [TJ/yr]	Estimated AEC [TJ/yr]	Energy Improvement [% of AEC]	CO_2 Abatement [ktpa]	Annual Cost Savings [k SGD/yr]	Payback [yr]
Boiler	6	21 950	182	20 840	0.9%	17	3297	6.7
Furnace	14	48 750	919	66 617	1.4%	54	12 961	3.8
Hot Oil Heater	11	17 160	324	8080	4.0%	20	4495	3.8
Cogeneration	9	19 860	631	24 256	2.6%	37	6538	3.0
Total	**40**	**107 720**	**2056**	**119 793**	**1.7%**	**127**	**27 291**	**3.9 (average)**

These 40 shortlisted opportunities are potentially worth 2056 TJ/yr of energy reduction, equivalent to approximately 127 ktpa of carbon abatement. To realise these figures, participating plants will need to undertake more detailed feasibility studies, involving more accurate Capital Expenditure (CAPEX) estimates, involvement of technology / equipment vendors and developing strong business cases for investment decision by the plant managements. All participating plants are fully aware of the grant support schemes that are available to them through the NEA and / or Singapore Economic Development Board (EDB).

While this study has provided rich insights to the energy performance of the oil refining, petrochemical and chemical sectors of Singapore, KBR has observed that there is untapped carbon abatement potential in some plants. Due to the nature of each plant's processes, the available heat sources and sinks within each plant are unlikely to change significantly over time. This has presented huge challenges in incentivising waste heat recovery, particularly for plants with a significant excess of waste heat but without significant heat sinks. An integrated study of heat source / sink profiles of plants that are situated in close proximity can bring about new perspectives on improving heat integration and waste heat recovery. Fundamentally, waste heat is a useful resource that should be exploited and monetised by plants. Industrial plants need to work collaboratively to explore synergies that help to achieve a win-win situation in minimising energy costs.

2 General Project Information

Energy efficiency is a focal point for governments and society. In addition to reducing operating cost and increasing margin for the industrial sector, energy efficiency improvement represents an important opportunity for Singapore to reduce emissions and improve industrial competitiveness.

Oil refining, petrochemical and chemical plants account for the bulk of energy use in the industrial sector in Singapore. According to the NEA, heating systems alone account for about 95.7% of the energy consumption for these plants. The breakdown of the energy consumption shows that greater emphasis should be placed on direct and indirect heating systems and cogeneration.

NEA has commissioned a Heating System Study that endeavours to improve the energy efficiency of heating systems in the refining, petrochemical and chemical sub-sectors. The key objectives of this study are:

- Investigate the energy performance of energy-intensive Heating Systems in at least ten (10) plants from the oil refining, petrochemical and chemical sub-sectors in Singapore;
- Assess and quantify the energy performance gaps that exist; and
- Identify effective measures to improve energy performance of Heating Systems, taking into account technical feasibility and economic considerations.

KBR has conducted this study for 11 participating plants, in accordance with the Assessment Framework that was developed as part of this project. Details of the calculation methodologies used in this study can be found in the Assessment Framework [Ref. 1].

The entire course of study has spanned over a period of 22 months from August 2019 to June 2021. KBR has completed the following deliverables to various stakeholders in this study:

- Assessment Framework – comprising Measurement and Verification (M&V) methodology of each Heating System
- Customised Reports for 11 participating plants
- Final Report
- Best Practice Guide
- Result Sharing Session

The above deliverables, except Customised Reports, are publicly available on the NEA website.

3 Study Approach

The approach and methodology adopted in this study have been developed through the completion of numerous successful projects by KBR previously. Figure 1 below shows the workflow of key activities in this study. This section elaborates on the following:

- Conduct of key meetings
- Data collection and processing
- Opportunity generation
- Opportunity assessment and evaluation
- Detailed opportunity evaluation / shortlisting
- Development of implementation roadmap
- Customised report development

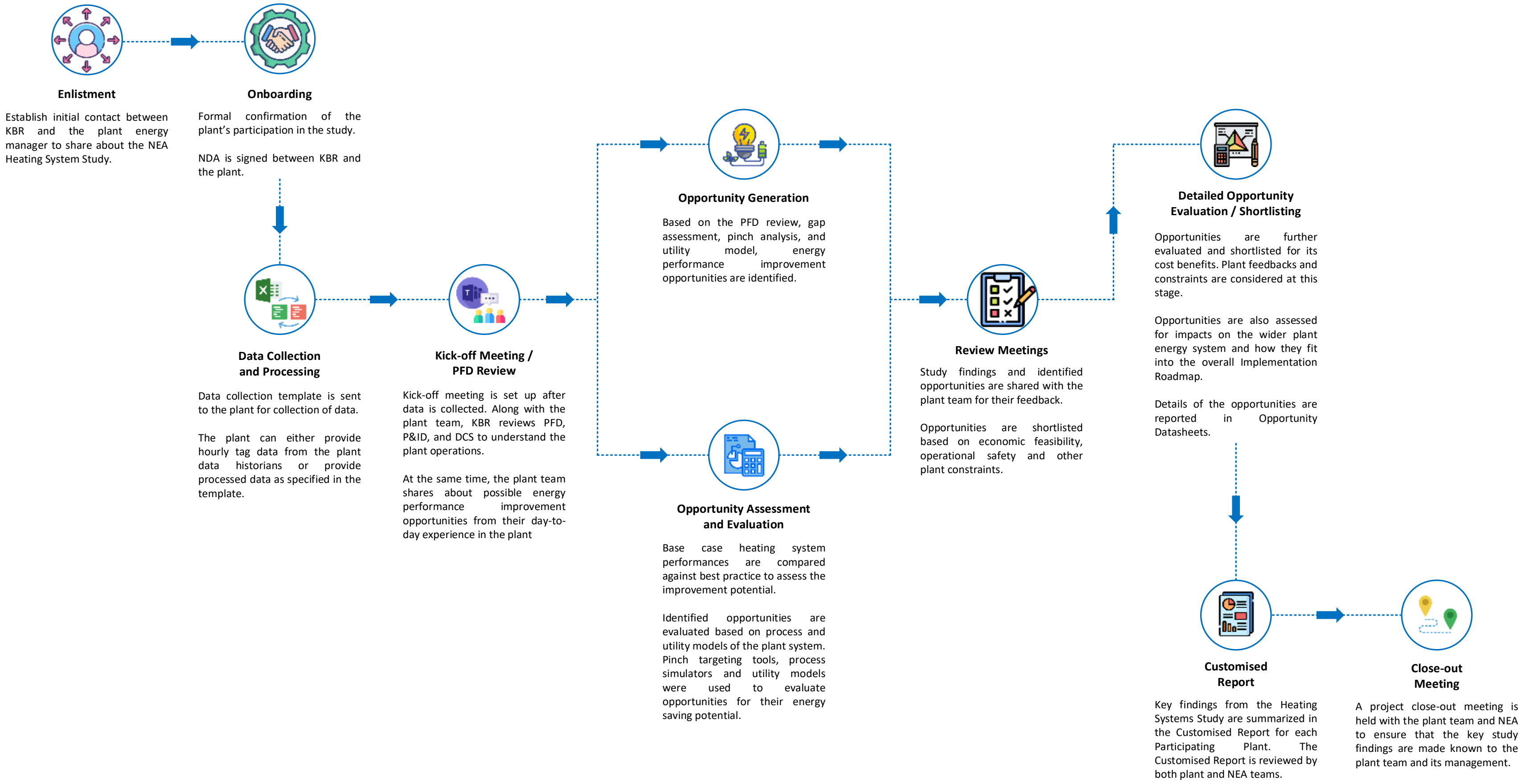

Figure 1: Study Workflow

3.1 Key Meetings

The following key meetings were held throughout the course of the study for each participating plant:

- Kick-off meeting / PFD reviews
- Review meetings
- Close-out meeting

In all key meetings above, the participants involved were:

- From participating plant
    - Energy manager (or team)
    - Process plant specialists
    - Plant management (mainly for kick-off and close-out meetings only)
- KBR project team (energy specialists)
- NEA representatives

Kick-off Meeting / PFD Review

The kick-off meeting marked the official commencement of the study with the participating plant. At the kick-off meeting, the agenda was typically as follow:

- KBR communicated to plant on project overview, scope, deliverables and timeline; and
- Plant provided feedback on the above.

For most participating plants, the kick-off meeting was attended by a management representative.

Following the kick-off meeting, the PFD review meeting commenced. The plant team gave an introduction of the plant operation, along with the review of Distributed Control System (DCS) / PFDs / Piping and Instrumentation Diagrams (P&IDs) of all key process units to the KBR team. Aside from familiarising the KBR project team with the plant heating systems and its operation, the main purpose of this meeting was to identify potential performance improvement opportunities based on the plant team day-to-day experience in the plant.

Review Meetings

After processing the data collected and evaluating the performance improvement opportunities, findings from the initial evaluation were shared with the participating plant and NEA during the review meeting. Technical details were made available to the plant team for their internal reviews and discussions. The KBR team then followed up with the respective plants for feedback on each opportunity to determine which opportunities would be evaluated in more detail.

Depending on the scope of the study and number of opportunities identified, multiple review meetings were held to go through all findings in detail.

Close-out Meeting

The close-out meeting was held towards the completion of the study for each plant. It was aimed at sharing results of the study with the plant management so as to ensure that they were aware of the shortlisted and rejected opportunities. In all cases, the plant management had already been briefed by their respective energy manager on the study results internally.

3.2 Data Collection and Processing

Data Collection

To assess the energy performance of the heating systems (defined as boiler, furnace, hot oil and cogeneration systems) in a plant, the following workflow for data and information collection was adopted in this study:

- Distribution of spreadsheet template to the participating plants via e-mail; and
- Briefings about data collection requirements through virtual meetings.

Key information captured in the data collection spreadsheet included but was not limited to:

- Economic information (e.g. fuel / utility price, fuel lower heating value);
- Baseline period;
- Annual operating hours;
- Key parameters of heating systems (e.g. stack oxygen content / temperature, fuel flows, useful energy output etc.); and
- Heat exchanger information (heat exchanger duty, process stream information, temperature profiles).

Data collected came in the form of either processed information based on measured data, or raw hourly tag measurements.

Where data was not available due to the absence of instrumentation, faulty or a poorly calibrated sensor, KBR adopted the following alternative methods to derive missing information:

- Data extraction from any energy use monitoring files / simulation files maintained by the plant team;
- Usage of process simulation software, such as Aspen HYSYS, to estimate the required missing data based on other available information;
- Estimation of required missing data with the available information based on theoretical equations and established database (e.g. estimation of steam heater duty based on steam flow and enthalpy change);
- Extraction of design data from equipment datasheet, PFD or P&ID; and
- Deployment of temporary field instruments to perform data logging of required parameters over a period of 2 weeks (e.g. diesel flow meter fitted to determine the amount of fuel used by a fired heater).

Prior to the data collection process, KBR emphasised to each participating plant on the importance of baseline period selection. The following guidelines were provided to each plant to guide them in baseline period selection. Baseline period should be representative of:

- A stable, normal plant operation; and
- The plant's future operations.

Upon initial processing of the data collected and evaluation of the opportunities identified, subsequent rounds of data collection were initiated by KBR where additional information was required.

Data Processing

Arithmetic mean of the hourly tag data provided by the plant was calculated for the computation of the performance metrics. To ensure that the calculated average value was representative of the regular plant operation in the baseline period, time series charts were plotted to detect any large fluctuation in the value of the measured variable.

For information that was processed by the plant based on the historian data, this was validated by comparing against the corresponding design data, P&ID / PFD, or DCS information.

3.3 Opportunity Generation

In the study with all participating plants, lists of opportunities were generated for evaluation and consideration by the plant team. The opportunities were generated via the following process.

PFD Review

This involved technical discussions between KBR and the plant team on the plant design, operations and constraints. Opportunities were captured based on the KBR team experiences in similar energy studies. Opportunities that were evaluated by the plant in the past were also noted down by KBR team. These opportunities will be evaluated if KBR sees economic value in them.

Gap Assessment

Existing energy performances of heating systems were compared to best practice to identify areas for improvement. These were flagged as new opportunities to be discussed with the plants.

Pinch Analysis

The effectiveness of heat integration was assessed using pinch analysis. Available heat sources and heat sinks were identified as potential projects that could be implemented.

Utility Model Development

For complex steam systems, KBR developed steam system models. These models were used to evaluate projects, work around constraints and determine the fuel savings from steam related projects.

All opportunities were initially evaluated by KBR. During the initial evaluation, the technical and economic feasibility of each opportunity was assessed on a standalone basis. Only opportunities that showed economic benefits were presented to the plants during the Review Meeting.

3.4 Opportunity Assessment and Evaluation

At the initial stage, the opportunities were evaluated based on:

- Marginal utility values used for the economics of process units;
- Relevant models (process or utilities) used to determine utility savings and any effects over the process; and
- High level cost estimation (e.g. heat exchanger area).

Simulations of the process units (e.g. preheat trains) as well as the utility system were carried out to evaluate the economic benefits of various identified opportunities. Pinch analysis was performed using the KBR in-house pinch targeting tool as well as Aspen Energy Analyser software. For opportunities involving new technologies such as HeatMatrix or QPinch, the KBR team worked with the technology licensors on detailed opportunity evaluations where applicable.

Where needed, opportunities were also assessed by KBR process specialists and the plant team to ensure that opportunities did not lead to undesirable impacts on plant production.

CAPEX Estimation Methodology

The CAPEX estimation (+ / - 50%) of opportunities was carried out by KBR cost estimation specialists. The cost estimation approach took into consideration the following factors:

- Major equipment needed;
- Existing process design;
- Plot plan / equipment configuration;
- Piping, electrical, structural modifications (if needed); and
- Other factors as advised by the cost estimation specialist.

Appropriate allowances, factors and ratios were applied in the estimate to account for freight, construction, and other miscellaneous costs. Relevant past projects in Singapore and South East Asia were used as reference to ensure reasonable accuracy in the cost estimates.

3.5 Detailed Opportunity Evaluation / Shortlisting

In the long list of opportunities presented to the plants during the Review Meeting, there could have been some conflicting opportunities, or opportunities that relied on the same heat source / sink. Upon receiving feedback from the plants, the shortlisted opportunities were put through detailed evaluation for a more representative cost – benefit analysis.

The opportunities were then checked for:

- Mutual exclusivity, where 2 potential opportunities cannot be implemented together. Both opportunities may be using the same heat source, heat sink or involving the same equipment.
- Dynamic interactions of each opportunity idea on the wider cogeneration system and all other shortlisted opportunities. For example, steam saving projects may lead to a larger steam vent, or the saving of steam will necessitate gas turbines to be off-loaded, leading to unfavourable cost implications.

The final shortlisted opportunities were then assessed for their appropriate implementation timeframes.

All rejected opportunities and their corresponding reasons are documented for records purposes.

3.6 Implementation Roadmap

Specifically for plants having multiple shortlisted opportunities with complex, dynamic interactions with the wider steam and power system, the utility model was used to develop the Implementation Roadmap (Figure 1).

The Implementation Roadmap displays all shortlisted opportunities and its expected implementation timeframe. The Implementation Roadmap was developed considering the following:

- Shortlisted opportunities were simulated one after another on the utility model to understand the marginal benefits of each opportunity implementation.
- No and low-cost projects were simulated first, followed by investment opportunities in order of increasing investment required. The plant upcoming turnaround schedules were taken into consideration when lining up the list of shortlisted opportunities for implementation.
- Key metrics such as cost savings, CAPEX and payback periods are summarised on the Implementation Roadmap.
- Utility system constraints taken into account in the utility model. Any constraints which were likely to stop the implementation of further projects would be subject to review for workarounds.

3.7 Customised Report

Towards the end of the study for each participating plant, all study findings were summarised into a Customised Report (Figure 1).

The Customised Report was sent to the plant team for review. Usually, there were multiple rounds of reviews by multiple stakeholders within the plant. Examples of stakeholders are the energy manager, process subject matter experts and the plant management. All feedback and comments from the plant team were addressed by KBR. In some cases, clarification meetings were held to address queries from the plant.

Following the approval of the Customised Report by the plant, KBR then shared the report with NEA for 2 rounds of reviews. Once all comments from NEA were addressed, KBR then issued the report to the plant.

4 Summary of Heating System Performance – Boilers

The energy performance of the boiler systems investigated in this study is generally within expectations of efficiency systems, with thermal efficiencies ranging from 81% to 94%. The average thermal efficiency of the boiler systems is 89%, falling short from the best practice thermal efficiency of 92%. Out of the 15 boiler systems, 4 boilers systems are performing better than the best practice.

Stack temperature of the boiler systems varies from 93°C to 255°C. From Figure 2 and Figure 3, the inverse relationship between thermal efficiency and stack temperature is apparent, where thermal efficiency decreases with increasing stack temperature. Average stack temperature is 165°C, higher than the best practice stack temperature of 150°C.

Stack oxygen of boiler systems ranges from 2.9% to 8.5%, with an average figure of 4.5%. Opportunities to improve air flow control of boilers to achieve lower stack oxygen content have been considered in this study.

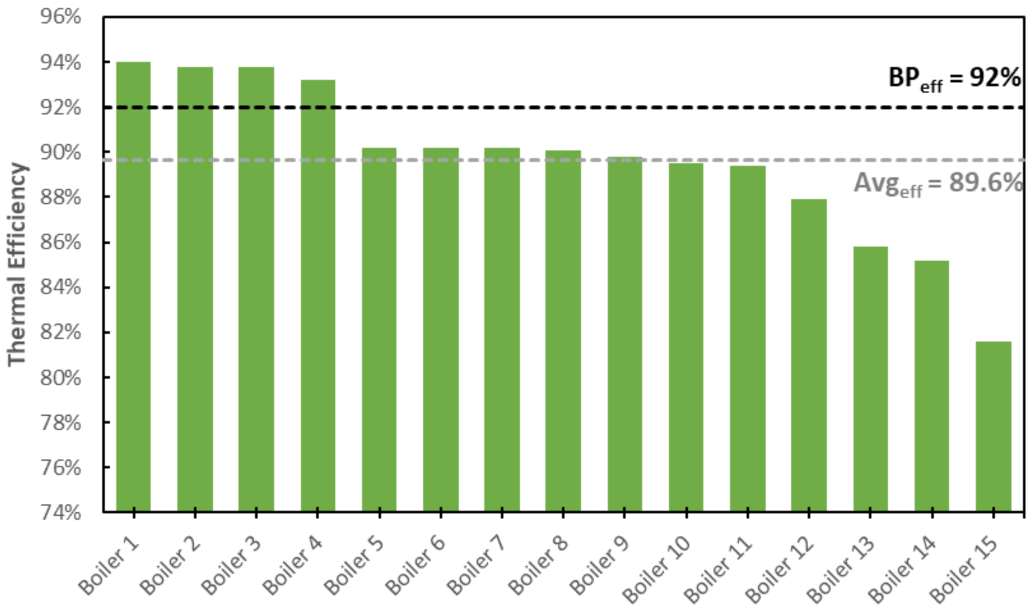

Figure 2: Summary of All Boiler Efficiencies of All Participating Plant

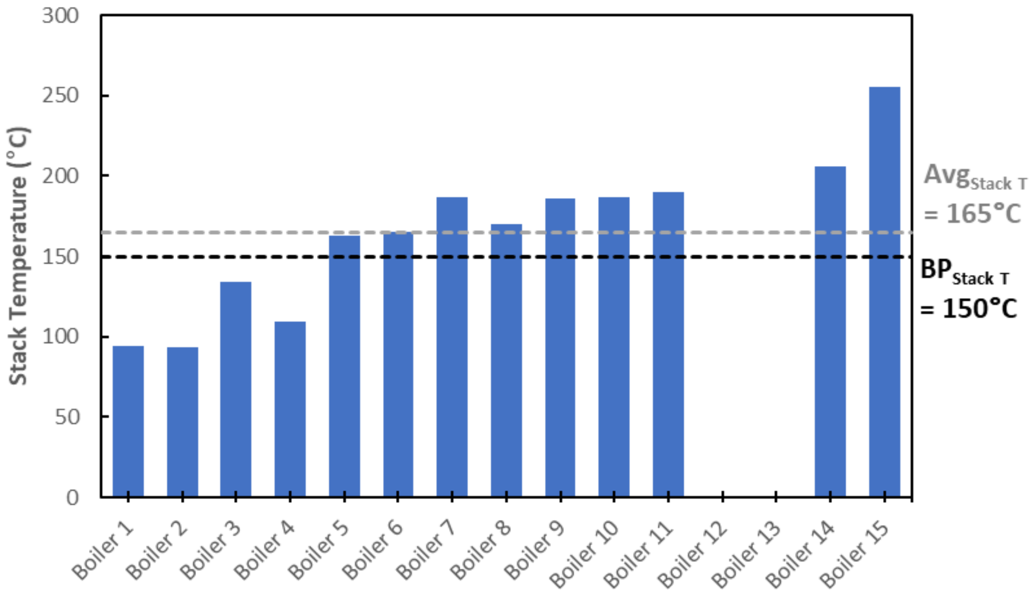

Figure 3: Summary of All Boiler Stack Temperatures of All Participating Plants

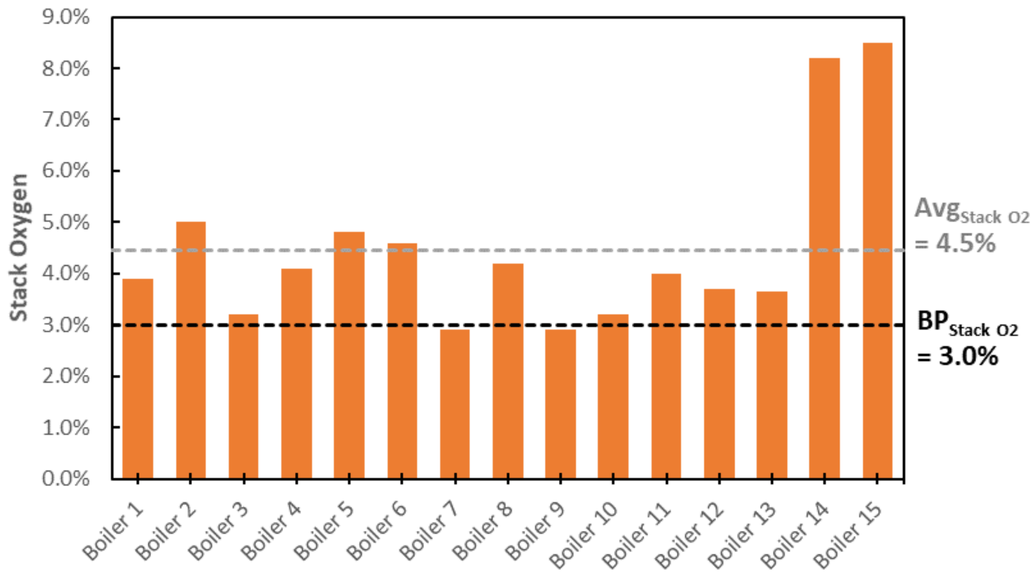

Figure 4: Summary of All Stack Oxygen Contents of All Participating Plants

It is observed that Boilers 1, 2, 3, 14 and 15 are operated at turndown conditions, where the boiler load is near its operating minimum. While it is largely expected that boilers operating at turndown conditions tend to be less efficient, the above trend has shown that this is not the case. Boiler 1, 2 and 3 are the best-in-class boilers in this study, despite operating at very low loads compared to their respective designs. Such desirable energy performance of these boilers can be largely attributed to their design, which recovers stack heat for combustion air or Boiler Feed Water (BFW) preheating. This can be seen from their stack temperatures, which are all lower than the best practice figure of 150°C.

On the other hand, Boilers 14 and 15 have high stack temperatures and high excess air levels, which is a primary cause for their relatively poorer efficiency.

4.1 Typical Performance Gaps and Opportunities

Table 2: Recommended Energy Performance Metrics for Boiler System

Energy System	Hierarchy	Metric	Best Practice
Boiler Equipment only	Energy Performance Indicator	Thermal Efficiency (%)	92.0
	Energy Performance Indicator	Energy Performance Gap (Gcal/h)	-
	Energy Influencing Variable	Stack Temperature (°C)	150
	Energy Influencing Variable	Stack Oxygen (%)	3.0
	Energy Influencing Variable	Steam Flow (t/h)	-
General Steam and Condensate System	Energy Performance Indicator	Overall Mass / Energy Balance of Steam System	-
	Energy Performance Indicator	BFW Pump Specific Energy Consumption (kW/unit throughput)	Dependent on its application, pump design, system pressure, fluid properties etc.
	Energy Influencing Variable	Condensate Recovery (%)	-
	Energy Influencing Variable	Deaerator Pressure	-

Table 2 shows a list of metrics and its corresponding best practice figures for a boiler system. The key energy performance metrics evaluated in this study are namely, thermal efficiency (%), stack temperature (°C), and stack oxygen (%), for the identification of operation / performance gaps and possible opportunities for performance improvement.

Operation / Performance Gaps

The computation of thermal efficiency of the boiler systems evaluated in this study is performed by using energy balance and empirical equation based on stack temperature and stack oxygen. The empirical equation is used when the calculated values from energy balance deviates significantly from expectations (e.g. greater than 100% or does not match the measured stack temperature and / or stack oxygen). This indicates that the instrumentations around the boiler may not be providing accurate measurements for the computation of the boiler thermal efficiency. It may be due to old or poorly calibrated instruments, or if the boiler is operating at a load significantly below its design capacity, it may result in inaccurate measurements.

As mentioned above, stack temperature serves as an indicator of the amount of heat available in the stack flue gas. Stack temperature is monitored for 13 out of the 15 boiler systems in this study, with only 2 boiler systems that do not have stack temperature measurement. It is advisable for plants to monitor the temperature of flue gas as it is a significant source of heat loss. The availability of this data may justify heat recovery projects on the boilers.

Typical Opportunity Areas

From the evaluation of the energy performance metrics of the boiler system, typical performance improvement opportunities have been identified in the study.

1. Heat Recovery from Stack Flue Gas

As shown in Figure 3, 11 boiler systems in this study have flue gas temperature higher than the best practice stack temperature of 150°C. This includes the 2 boiler systems that do not have stack temperature measurement, but are very likely to be discharging stack gas at >150°C. This indicates that there is potential to recover heat from the flue gas for BFW or combustion air heating, reducing the amount of fuel fired by the boilers. However, several of such opportunities were rejected in this study due to the nature of the boiler operation (e.g. fluctuating loads depending on overall steam supply and demand), acid or precipitate formation when stack temperature drops below the acid dew point / precipitation temperature, or if there are already ongoing projects.

2. Air Flow Control

From Figure 4, there are some boiler systems with stack oxygen content higher than the best practice 3% stack oxygen. Optimisation of the air flow through the boilers reduces the amount of heat loss through the flue gas. Nevertheless, some of these opportunities are not pursued further as they lead to small energy performance improvement that does not justify the economic investment. Some boilers are already operating at turndown condition where any further reduction in air flow may lead to incomplete combustion or tripping of the boiler. Unlike stack temperature, the impact of excess oxygen on the energy performance of the boilers is less significant. As shown in Figure 2 and Figure 4, Boiler 1 – 4 have relatively good energy performance despite having stack oxygen content higher than the best practice figure of 3%.

3. Installation of Variable Speed Drive (VSD) for BFW Pump

Opportunities for retrofitting BFW pumps with VSDs may be applicable for pumps that are oversized or systems where there are more BFW pumps in operation than needed. Retrofitting pumps with VSD will help achieve energy savings via a reduction in pump speed, which will also lead to a corresponding reduction in pump head. Care must be taken to ensure that the reduced pump head is sufficient to meet the system requirements.

A successful retrofitting of BFW pump with a VSD will lead to a step change in the specific energy consumption of the BFW pump system.

4. Steam Demand Reduction

Steam demand reduction can be achieved via heat recovery projects that backs off steam consumption. Heat recovery projects can be identified systematically via pinch analysis, where all process heating and cooling requirements are analysed. A reduced steam demand will lead to a lower boiler load, which leads to fuel savings.

However, in some steam systems, boilers could already be operating at minimum turndown conditions. Any further steam savings would not lead to boiler fuel savings, but a steam vent.

The methodology for quantifying the energy improvement before and after implementation of energy conservation measures relating to the boiler system is outlined in the Assessment Framework [Ref. 1].

4.2 Summary of Comprehensive M&V for High CAPEX Opportunities

Of the 6 opportunities identified to improve the energy performance of the boiler system, 2 opportunities require high CAPEX. These opportunities involve:

- The installation of polymer heat exchanger(s) for stack heat recovery; and
- The installation of a steam turbine for power generation.

Installation of Polymer Heat Exchanger(s) for Stack Heat Recovery

The M&V methodology of such a heat recovery project is targeted at quantifying the actual amount of heat that is absorbed by the combustion air going to the burners. This can be achieved by performing an energy balance of the combustion air, before and after the air preheater set up.

Note that waste heat from the stack can also be recovered into other heat sinks such as the BFW.

Installation of a Steam Turbine for Power Generation

Installation of a new steam turbine may be applicable for steam systems that are experiencing a significant let-down and / or an excess of steam. Note that the installation of condensing turbine capacity should only be considered as a last resort as it brings about poor steam cycle efficiency.

The M&V methodology of steam turbine projects requires a power meter that measures the amount of electricity generated. This will allow the plant to determine the amount of imported electricity that is backed off.

5 Summary of Heating System Performance – Furnace

By definition, a furnace heating system covers:

- All fuel-fired furnaces for process heating (such as furnaces in crude distillation units [CDUs] and ethylene cracking units);
- Thermal oxidisers (TO) and incinerators.

Having completed the analysis of all furnaces in this study, KBR observed a distinct difference in performance between furnaces for process heating and furnaces for waste treatment (thermal oxidisers / incinerators). Hence, results for these 2 types of furnaces are presented separately.

Furnaces – Process Heating Only

A total of 81 furnaces for process heating have been investigated in this study. Figure 5 below shows a histogram of thermal efficiencies of these furnaces. The histogram is classified into bins of 2% thermal efficiency, with the number of furnaces in each bin shown in the vertical bars. In general, thermal efficiency of furnaces ranges from 59% to 91%. The distribution of furnace thermal efficiency is skewed to the right, with a long tail to the left. This indicates that the majority of the furnaces are operating at high efficiencies > 86+%, albeit none of the furnaces has met or outperformed the best practice thermal efficiency of 92%.

The average stack temperature of furnaces in each bin is plotted in Figure 6. It can be observed that stack temperatures range from a low of 121°C to a high of 565°C. Figure 6 clearly shows the trend between stack temperature and furnace efficiency. Recovery of heat from furnace stack gas, leading to low stack temperature, is a pre-requisite to efficient furnace operation.

Stack oxygen of furnace systems ranges from 1.6% to 17.7%, with an average figure of 4.4%. Opportunities to improve air flow control of furnaces to achieve lower stack oxygen content have been considered in this study. Generally, the stack oxygen content is lower for furnace systems that are more efficient, as seen in Figure 7. However, this correlation is less pronounced as compared to the stack temperature variable.

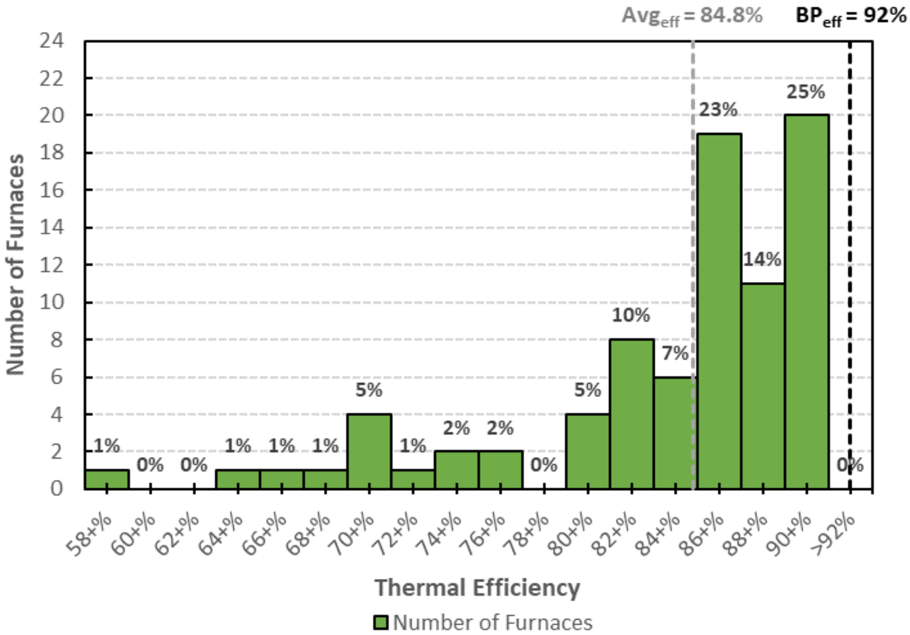

Figure 5: Summary of All Furnace Efficiencies of All Participating Plants

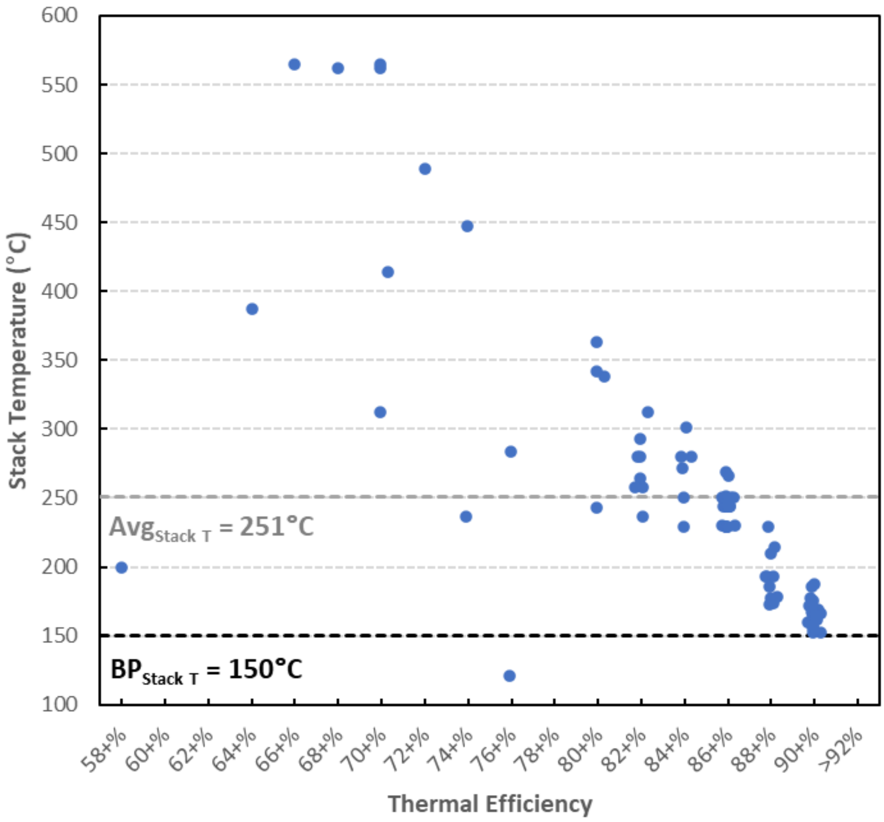

Figure 6: Summary of All Furnace Stack Temperatures of All Participating Plants

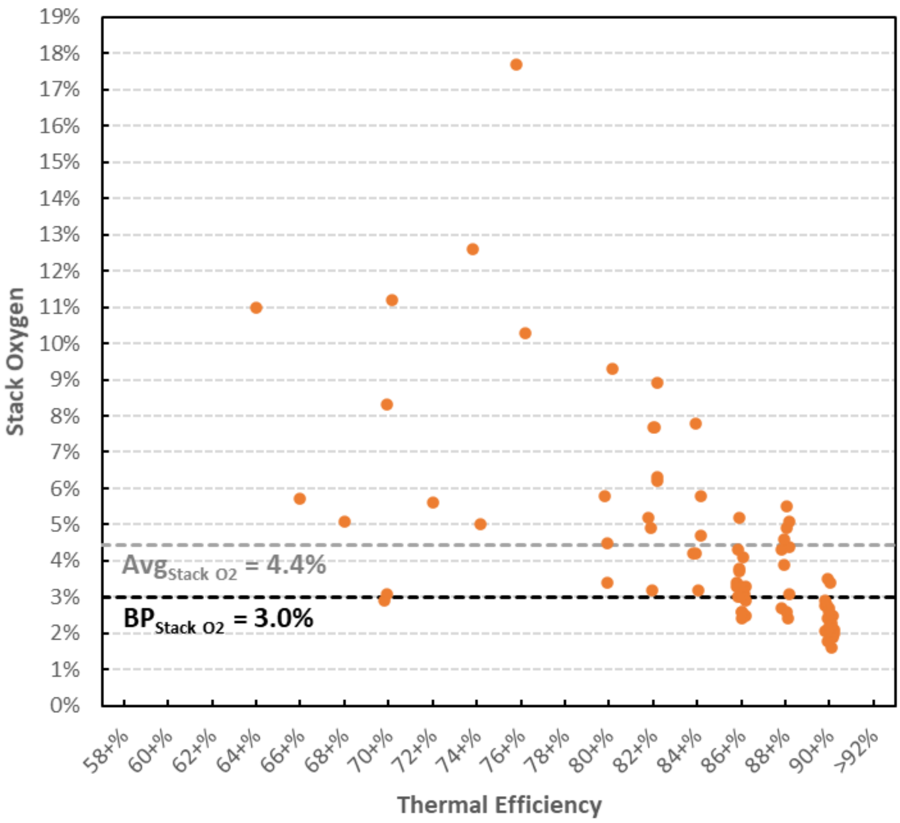

Figure 7: Summary of All Furnace Stack Oxygen Contents of All Participating Plants

Furnaces – Incinerators / Thermal Oxidisers Only

21 incinerators / thermal oxidisers have been evaluated in this study. These are furnace units designed for the combustion of waste streams, ensuring toxic chemicals and pollutants are effectively neutralised before discharge to the atmosphere.

The performances of these incinerators / thermal oxidisers are as follow:

- As seen in Figure 8, 11 incinerators / thermal oxidisers involve energy recovery in the form of steam generation or preheating of combustion air. Thermal efficiency of these units ranges from 64% to 89%.
- All other incinerators / thermal oxidisers operate with heat in the stack gas wasted to the atmosphere or through other means.
- Stack oxygen content ranges from 1.7% to 20.6%. Air flow for these units is controlled primarily to ensure stable operations and complete combustion of the waste streams. Note that the incinerators / thermal oxidisers with 20+% stack oxygen content applies to those that process waste air which already comprise 21% oxygen content.

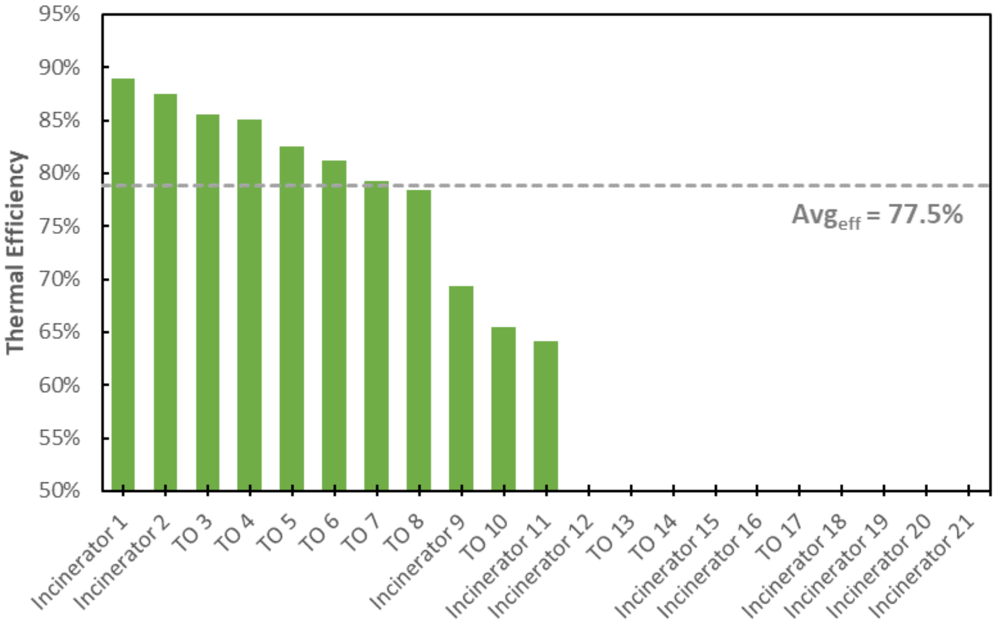

Figure 8: Summary of All Incinerator / Thermal Oxidiser Efficiencies of All Participating Plants

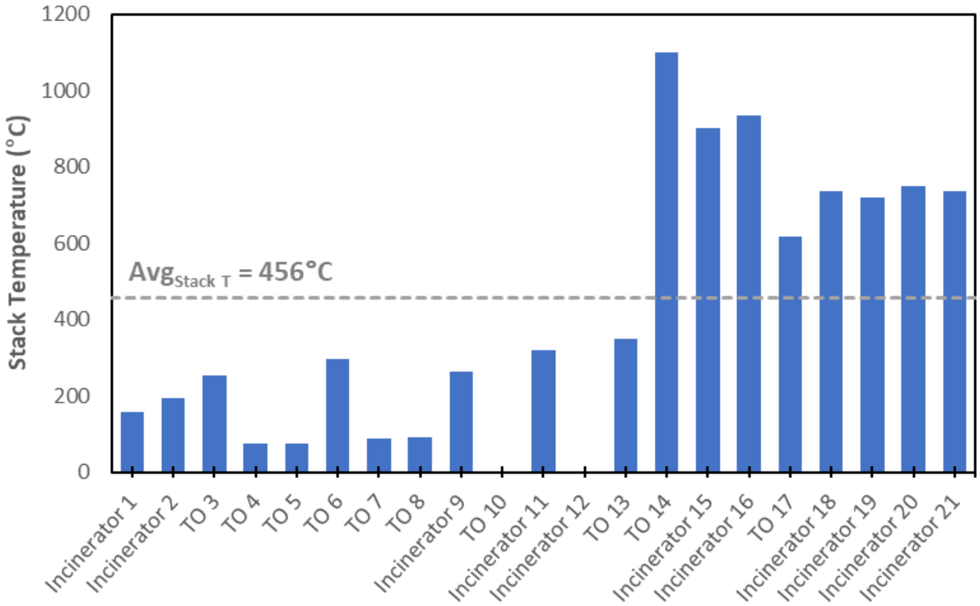

Figure 9: Summary of All Incinerator / Thermal Oxidiser Stack Temperatures of All Participating Plants

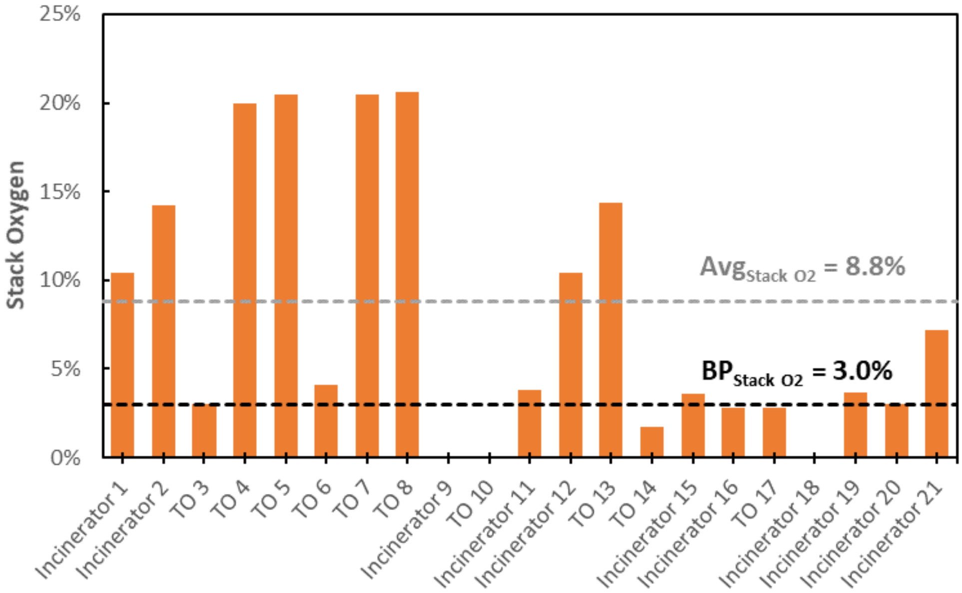

Figure 10: Summary of All Incinerators / Thermal Oxidisers Stack Oxygen Contents of All Participating Plants

5.1 Typical Performance Gaps and Opportunities

Table 3: Recommended Energy Performance Metrics for Furnace System

Energy System	Hierarchy	Metric	Best Practice
Furnace Equipment only	Energy Performance Indicator	Thermal Efficiency (%)	92.0 or 94.0 (for ethylene cracker furnaces)
	Energy Performance Indicator	Energy Performance Gap (Gcal/h)	-
	Energy Influencing Variable	Stack Temperature (°C)	150 or 110 (for ethylene cracker furnaces)
	Energy Influencing Variable	Stack Oxygen (%)	3.0 or 1.5 (for ethylene cracker furnaces)
	Energy Influencing Variable	Steam Flow (t/h)	-
Furnace Preheat Train	Energy Performance Indicator	Charge Pump Specific Energy Consumption (kW/unit throughput)	Dependent on its application, pump design, system pressure, fluid properties etc.
	Energy Influencing Variable	Coil Inlet Temperature (°C)	-

Table 3 shows a list of metrics and its corresponding best practice figures for a furnace system. The key energy performance metrics evaluated in this study are, thermal efficiency (%), stack temperature (°C), and stack oxygen (%), for the identification of operation / performance gaps and possible opportunities for performance improvement.

Specifically, for incinerators and thermal oxidisers, as such equipment serves to ensure environmental pollutants are effectively treated in the combustion process, it will not be reasonable to evaluate their stack temperature against a best practice figure of 150°C. The flue gas from incinerators and thermal oxidisers may contain significant solid content or acidic components, potentially inhibiting heat recovery. However, for stack oxygen content, a 3.0% best practice figure is realistically achievable. From Figure 10, it is observed that some incinerators and thermal oxidiser operate close to 3.0% stack oxygen content.

Operation / Performance Gaps

The computation of thermal efficiency of the furnace systems evaluated in this study is performed using energy balance and empirical equation based on stack temperature and stack oxygen. The empirical equation is used when the calculated values from energy balance deviates significantly from expectations (e.g. does not match the measured stack temperature and / or stack oxygen). This indicates that the instrumentations around the furnace may not be providing accurate measurements for the computation of the furnace thermal efficiency. It may be due to old or poorly calibrated instruments, resulting in inaccurate measurements.

Some furnaces are designed for natural draft operations, where combustion air flows into the furnace by difference in air density. Natural draft furnaces are less efficient as these tend to be designed with minimal heat recovery devices in the stack to minimise pressure drop and introduce air flow resistance. Retrofitting natural draft furnaces to recover stack heat will also involve more complex engineering work such as the installation of induced draft and / or forced draft fans etc.

For thermal oxidisers and incinerators, some plants have opted for one that does not recover stack heat for steam generation. This is especially so when plants do not have sufficient heat sinks available to utilise the steam that could be generated from thermal oxidiser / incinerator waste heat.

While the majority of the furnaces and incinerators / thermal oxidisers have their stack temperature and stack oxygen content monitored, there are some systems that do not have these instrumentations. It is advisable for plants to monitor the temperature and oxygen content of flue gas as it is a significant source of heat loss when flue gas leaves with high temperature or when excessive air flows through the furnace. The availability of this data may justify heat recovery projects on the furnaces and serves as operational indicators of the performance of the furnace systems.

Typical Opportunity Areas

From the evaluation of the energy performance metrics of the furnace system, typical performance improvement opportunities have been identified in the study.

1. Heat Recovery from Stack Flue Gas

As shown in Figure 6 and Figure 9, 93% of the units have flue gas temperatures higher than the best practice stack temperature of 150°C. This indicates that there is potential to recover heat from the flue gas for combustion air heating, reducing the amount of fuel fired by the units.

For furnaces, several of these opportunities were rejected due to the design of the furnace (e.g. natural draft furnace), already having existing waste heat recovery of flue gas for waste heat boilers before discharging to the atmosphere, or if there are already ongoing projects.

Heat recovery from flue gas of incinerators / thermal oxidisers can be difficult to implement as it will involve a more detailed study with the equipment vendor. Depending on the type of wastes processed, there may be concerns of acidic condensation, plugging of heat exchangers due to high solids contents or even introducing a backpressure effect on the combustion chamber of the equipment.

2. Air Flow Control

From Figure 7 and Figure 10, 63% of the units have stack oxygen content higher than the best practice 3% stack oxygen. Optimisation of the air flow through the units reduces the amount of heat loss through the flue gas.

Nevertheless, some of these opportunities are not pursued further as they lead to small energy performance improvement that does not justify the economic investment. The firing of fuel oil in some furnaces does not allow for excess air to be further trimmed to ensure complete combustion. Additionally, with some furnaces operating at turndown condition, any further reduction in air flow may lead to incomplete combustion or tripping of the furnace.

For some incinerators / thermal oxidisers, air flow cannot be an optimisation variable as it may lead to combustion problems or tripping of the equipment.

3. Preheat Train Optimisation

Preheat train optimisation can be achieved by recovering waste heat onto process streams. These projects can be identified systematically through pinch analysis, where all process heating and cooling requirements are analysed. The optimisation will result in an increase in the coil inlet temperature, which will reduce the furnace load and fuel consumption.

However, certain projects identified from the pinch analysis involve heat recovery for the process stream at the beginning of the preheat train. Thus, after taking into account the dynamic effects of the entire heat exchanger network, the eventual impact of the heat recovery does not impact the coil inlet temperature significantly. As such, the furnace fuel saving is small and may not justify the economic investment.

4. Installation of VSD for Charge Pumps

Although the VSD do not directly affect the furnace performance, this application can potentially reduce electricity consumption. In this study, opportunities for retrofitting charge pumps with VSDs may be applicable for pumps that are oversized or systems that operate with more charge pumps than needed. Retrofitting pumps with VSD will help achieve energy savings via a reduction in pump speed, which will also lead to a corresponding reduction in pump head. Care must be taken to ensure that the reduced pump head is sufficient to meet the system requirements.

A successful retrofitting of charge pump(s) with a VSD will lead to a step change in the specific energy consumption of the charge pump.

The methodology for quantifying the energy improvement before and after implementation of energy conservation measures relating to the furnace system is outlined in the Assessment Framework [Ref. 1].

5.2 Summary of Comprehensive M&V for High CAPEX Opportunities

Of the 14 opportunities identified to improve the energy performance of the furnace systems, 12 opportunities require high CAPEX. The opportunities involve:

- Heat recovery from stack flue gas;
- Improved heat integration in preheat trains; and
- Installation of VSD.

Heat Recovery from Stack Flue Gas

Such opportunities involve the recovery of heat from stack flue gases of furnaces for combustion air preheating.

The M&V methodology used is targeted at quantifying the actual amount of heat that is absorbed by the combustion air going to the burners. This can be achieved by performing an energy balance of the combustion air, before and after the air preheater set up.

Improved Heat Integration in Preheat Trains

Such projects typically involve the retrofit of preheat train heat exchangers, through the use of tube bundles that facilitates increased heat transfer or the installation of new heat exchangers.

The M&V methodology focuses on quantifying the actual amount of fuel that is backed off from improved heat recovery.

Energy savings from heat integration projects of crude units tend to be small relative to the scale of the furnace duty. Hence, the furnace coil inlet temperature should be monitored as a key metric to quantify the benefits from heat integration projects at the preheat train.

Installation of VSD

The M&V methodology for VSD projects involves the comparison of baseline versus post-implementation electrical consumption of the pump.

6 Summary of Heating System Performance – Hot Oil Heaters

Thermal efficiency of the hot oil heaters investigated in this study ranges from 46% to 85% as seen from Figure 11. With an average efficiency of 74.8%, hot oil heaters are generally less efficient than boilers and furnaces. The poor efficiencies can be mainly attributed to the high stack temperatures ranging from 247°C to 310°C shown in Figure 12. Many hot oil heaters are found not to have stack heat recovery devices large enough to enable extensive heat recovery. Opportunities to further recover heat from the flue gas have been considered in this study.

Stack oxygen of hot oil heaters ranges from 3.8% to 6.4%. With an average figure at 4.8%, it is similar to that of boilers and furnaces. Many hot oil heaters are small in duty. Hence, there is generally lesser focus in optimising air-fuel ratio of hot oil heater operations.

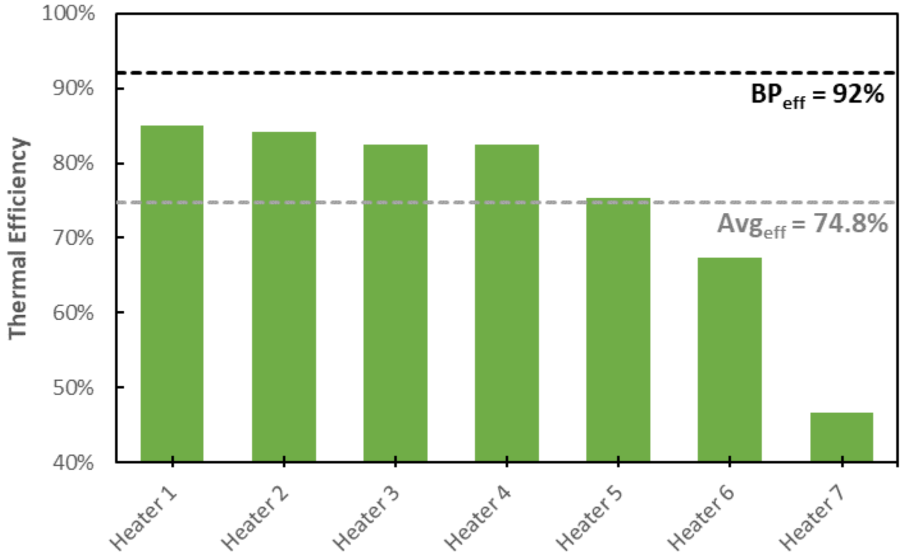

Figure 11: Summary of All Hot Oil Heater Efficiencies of All Participating Plants

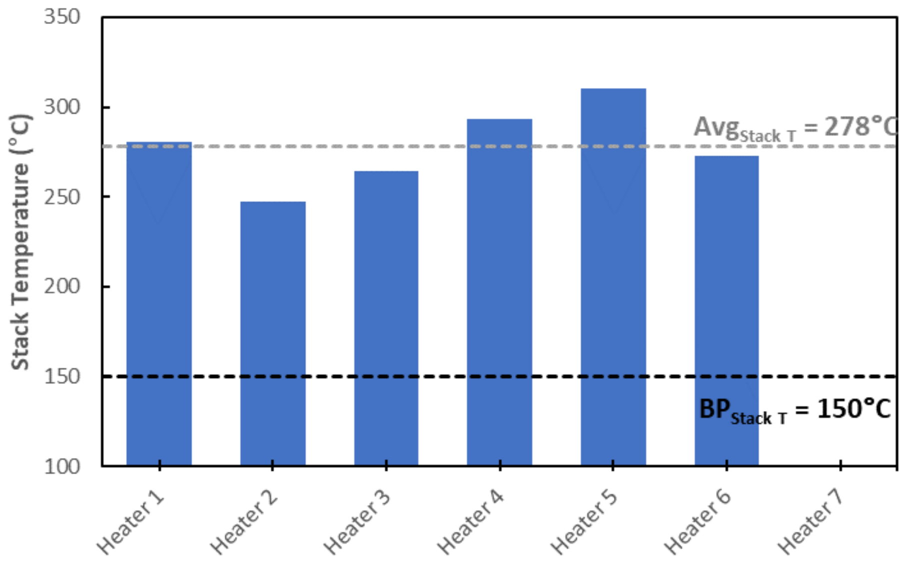

Figure 12: Summary of All Hot Oil Heater Stack Temperatures of All Participating Plants

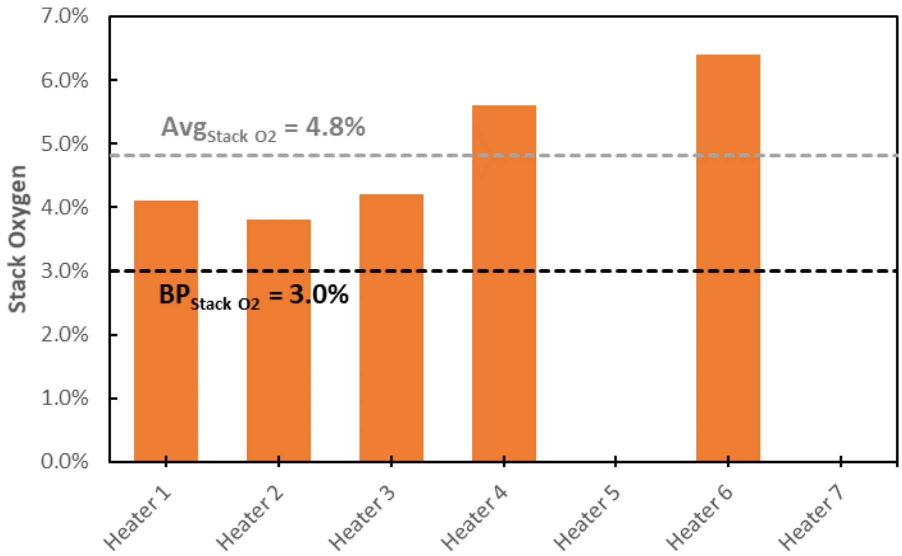

Figure 13: Summary of All Hot Oil Heater Stack Oxygen Contents of All Participating Plants

6.1 Typical Performance Gaps and Opportunities

Table 4: Recommended Energy Performance Metrics for Hot Oil Heater

Energy System	Hierarchy	Metric	Best Practice
Heater Equipment only	Energy Performance Indicator	Thermal Efficiency (%)	92.0
	Energy Performance Indicator	Energy Performance Gap (Gcal/h)	-
	Energy Influencing Variable	Stack Temperature (°C)	150
	Energy Influencing Variable	Stack Oxygen (%)	3.0
	Energy Influencing Variable	Hot Oil Supply Temperature (°C)	-
	Energy Influencing Variable	Hot Oil Return Temperature (°C)	-
Hot Oil System	Energy Performance Indicator	Overall Mass / Energy Balance of Hot Oil System	-
	Energy Performance Indicator	Hot Oil Pump Specific Energy Consumption (kW/unit throughput)	Dependent on its application, pump design, system pressure, fluid properties etc.

Table 4 shows a list of metrics and the corresponding best practice figures for a hot oil heater. The key energy performance metrics evaluated in this study are, thermal efficiency (%), stack temperature (°C), and stack oxygen (%), for the identification of operation / performance gaps and possible opportunities for performance improvement.

Operation / Performance Gaps

The computation of thermal efficiency of the hot oil heaters evaluated in this study is performed by using energy balance or empirical equation based on stack temperature and stack oxygen. The empirical equation is used when the calculated values from energy balance deviates significantly from expectations (e.g. greater than 100% or does not match the measured stack temperature and / or stack oxygen). This indicates that the instruments around the hot oil heaters may not be providing accurate measurements for the computation of the heater thermal efficiency. It may be due to old or poorly calibrated instruments, or the lack of permanent instruments leading to the use of temporary sensors, that results in inaccurate measurements.

Many hot oil heaters tend to be small in terms of fired duty. Correspondingly, ancillary systems such as the combustion air blower are small as well. The operating speed of the combustion air blowers and the dampers governing the air flow rates may not be centrally controlled in the plant control room. As a result, many of these air blowers operate at their rated speed regardless of their real-time load, usually delivering more air than required by the combustion process. Without centralised control of hot oil heaters, plant operators are unlikely to optimise air-fuel ratio in real-time by making frequent visits to the hot oil heater to manually adjust air registers or control valves.

While the majority of the heaters have their stack temperature and stack oxygen content monitored, there are some systems that do not have the required instrumentations It is advisable for plants to monitor the temperature and oxygen content of flue gas as it is a significant source of heat loss when flue gas leaves with high temperature or when excessive air flows through the heaters. The availability of this data may justify heat recovery projects on the hot oil heaters and serves as operational indicators of the performance of the heaters.

Typical Opportunity Areas

From the evaluation of the energy performance metrics of the hot oil heaters, typical performance improvement opportunities have been identified in the study.

1. Heat Recovery from Stack Flue Gas

As shown in Figure 12, all hot oil heaters have flue gas temperatures significantly higher than the best practice stack temperature of 150°C. This indicates that there is potential to recover heat from the flue gas for combustion air heating, reducing the amount of fuel fired by the units. While some heaters already have existing air preheaters, waste heat from the stack can also be recovered into other heat sinks such as the BFW.

2. Installation of VSD for Hot Oil Pumps

Opportunities for retrofitting hot oil pumps with VSDs may be applicable for pumps that are oversized or systems that are operating more hot oil pumps than needed. Retrofitting pumps with VSDs will help achieve energy savings via a reduction in pump speed, which will also lead to a corresponding reduction in pump head. Care must be taken to ensure that the reduced pump head is sufficient to meet the system requirements.

A successful retrofitting of hot oil pumps with VSD will lead to a step change in the specific energy consumption of the hot oil pump system.

3. Hot Oil Demand Reduction

Hot oil heater load reduction can be achieved via heat recovery projects that minimise the use of hot oil for process heating. Heat recovery projects can be identified systematically via pinch analysis, where all process heating and cooling requirements are analysed. A reduced hot oil demand will lead to a lower heater load, which leads to fuel savings.

The methodology for quantifying the energy improvement before and after implementation of energy conservation measures relating to the hot oil heater is outlined in the Assessment Framework [Ref. 1].

6.2 Summary of Comprehensive M&V for High CAPEX Opportunities

Of the 11 opportunities identified to improve the energy performance of the hot oil heaters, 4 opportunities require high CAPEX. The opportunities involve:

- Heat recovery from stack flue gas; and
- Process waste heat recovery.

Heat Recovery from Stack Flue Gas

The M&V methodology of such heat recovery project is targeted at quantifying the actual amount of heat that is absorbed by the combustion air going to the burners. This can be achieved by performing an energy balance of the combustion air, before and after the air preheater set up.

Note that waste heat from the stack can also be recovered into other heat sinks such as the BFW.

Process Waste Heat Recovery

The recovery of process waste heat to provide heating for a cold stream typically saves on hot utility usage (such as hot oil). As these utilities are usually metered, tracking the reduction in utility flow rates will help quantify the energy recovered. To quantify the fuel savings, reduction in hot oil use can be converted to fuel equivalent values by accounting for the hot oil heater efficiency.

7 Summary of Heating System Performance – Cogeneration

Of the 11 participating plants, there are 4 plants with heating systems comprising cogeneration systems (defined as a steam and power system with a gas turbine and associated heat recovery steam generator [HRSG]). The energy performance of the cogeneration systems investigated in this study shows efficiency gaps that range from 2% to 15% (Figure 14). The gaps are due to multiple reasons such as:

- Gas turbines operating at low load;
- Operating philosophy (for example, boilers running at minimum load while inhibiting HRSG from using supplementary firing.);
- HRSG efficiency;
- Power generated through a condensing power cycle, which lowers the overall cycle efficiency due to the intrinsic inefficiency of condensing cycles;
- Significant flow of steam going through let-down valves; and
- Steam venting.

How each of these elements affects the efficiency gap will depend on the configuration of each plant. The best configuration of a cogeneration system will depend on its steam to power requirements, which can vary significantly from plant to plant. It will not be a fair comparison to expect one cogeneration system to be as efficient as another cogeneration system, as both plants will have different steam to power requirements and different steam producing equipment.

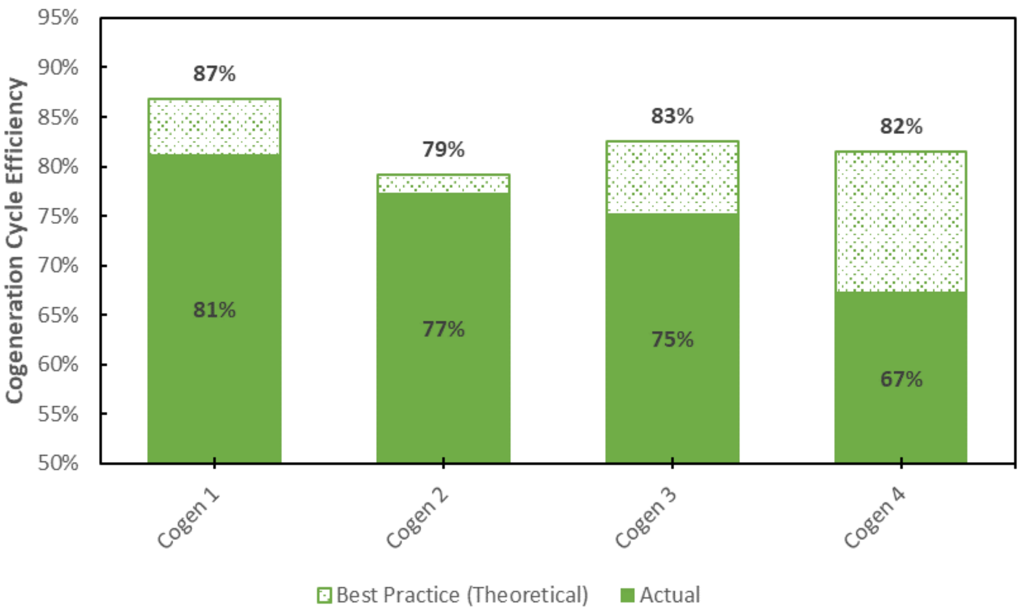

Figure 14: Summary of All Cogeneration System Efficiencies of All Participating Plants

7.1 Typical Performance Gaps and Opportunities

Table 5: Recommended Energy Performance Metrics for Cogeneration System

Energy System	Hierarchy	Metric
Entire Cogeneration System	Energy Performance Indicator	Thermal Efficiency (%)
	Energy Performance Indicator	Energy Performance Gap (%)
Gas Turbine only	Energy Performance Indicator	Thermal Efficiency (%)
HRSG only	Energy Performance Indicator	Thermal Efficiency (%)
	Energy Influencing Variable	HRSG Stack Temperature (°C)
Steam Turbine only	Energy Performance Indicator	Thermal Efficiency (%)
General Steam and Condensate System	Energy Performance Indicator	Overall Mass / Energy Balance of Steam System
	Energy Performance Indicator	Condensate Recovery (%)
	Energy Performance Indicator	BFW Pump Specific Energy Consumption (kW/unit throughput)
	Energy Influencing Variable	Deaerator Pressure

Table 5 shows a list of metrics for a cogeneration system.

The evaluation of the improvement potential of cogeneration systems involves the calculation of their baseline cycle efficiency. Step out cases towards best practices are then simulated to assess their improvement potential. Results from this approach are then cross-checked against the R-curve methodology to ensure consistency. It should be noted that there is no standard efficiency target as the target depends on the power and steam energy demand of each plant.

Refer to the Assessment Framework [Ref. 1] and Best Practice Guide [Ref. 2] for more details on the above methodology.

Typical Opportunity Areas

From the evaluation of the energy performance metrics of the cogeneration system, typical performance improvement opportunities have been identified in the study.

1. Increase Gas Turbine Load

Some gas turbines are not operating near their design capacity. This happens when gas turbines are oversized for the current power demand. There is no practical solution to this challenge as the cycle efficiency can only be improved by either a full reconfiguration of the system (too costly) or allowing power export (subject to regulatory hurdles or price economics).

2. Supplementary Firing HRSGs

Supplementary firing on an HRSG could be considered the most efficient way of generating steam as it is 100% efficient. While all HRSGs evaluated in this study are designed for supplementary firing, they are not fully utilised due to the plant's operating philosophy. For reliability purposes, plants tend to operate boilers at low loads, which takes away the opportunity to exploit the high steam generation efficiency of the firing of HRSG.

3. Steam Generation from Process Units

This refers to opportunities for improving waste heat recovery. Waste heat from process streams can be used to generate steam. If there is no suitable steam user within the process unit, then the steam may be exported to the main steam header to be distributed to steam users in other process units. Waste heat recovery for steam generation may potentially lead to a reduction in fuel demand from the overall steam and power system. Such scenarios need to be simulated on a utility model to ensure that benefits are translated to fuel savings at the boilers or gas turbines. Depending on the plant existing utility balances, some steam generation projects lead to increased steam venting, which brings no benefits.

4. Reduce Steam Demand

Such projects reduce steam demand by improving the overall energy efficiency of process units. For example, by improving the process-to-process heat integration within a unit. This will effectively use waste heat, which is currently rejected to air or cooling water coolers, to reduce the amount of fuel consumed by the plant.

It should be pointed out that, in some steam systems, the steam generation equipment operates at minimum turndown conditions. Hence, any further steam savings will not lead to fuel savings, but a steam vent.

The methodology for quantifying the energy improvement before and after implementation of energy conservation measures relating to the cogeneration system is outlined in the Assessment Framework [Ref. 1].

7.2 Summary of Comprehensive M&V for High CAPEX Opportunities

Most opportunities involving cogeneration systems fall into the following categories:

- Recovery of waste heat for steam generation or reduce steam consumption; and
- Improving performance of condensing turbine condenser(s).

Recovery of Waste Heat for Steam Generation or Reduce Steam Consumption

The M&V methodology of such a heat recovery project is targeted at quantifying:

- The actual quantity of steam generated from waste heat; or
- The actual reduction in steam consumption.

These steam generation or consumption figures should be simulated in a utility model to evaluate the fuel impacts at the boilers or gas turbine / HRSGs.

Improving Performance of Condensing Turbine Condenser(s)

Improving the vacuum quality of condensing turbine drives will allow a smaller steam flow to generate the same amount of output shaft work. The overall steam savings should be simulated in a utility model to evaluate the fuel impacts at the boilers or gas turbine / HRSGs.

8 Introduction of New Technologies

During the course of this study, KBR has identified 2 new technologies that may be applicable to the heating systems of the participating plants. The technologies are:

- HeatMatrix polymer heat exchangers for heat recovery from flue gas of fired heaters; and
- Qpinch proprietary technology to upgrade the temperature of low-grade heat.

These technologies have been introduced to the selected plants, where applicable, and evaluated for their technical and economic feasibility. The sections below provide a summary of the technology involved and general observations.

8.1 Use of Polymer Heat Exchangers for Heat Recovery from Flue Gas of Fired Heaters

Technology Introduction

The HeatMatrix Group has developed a polymer-based heat exchange technology that allows for the recovery of heat from corrosive or fouling flue gases. The HeatMatrix air preheater consists of multiple corrosion resistant polymer tube bundles mounted into a metal casing. Its geometric design creates a strong rigid matrix grid that can withstand high gas velocities and thermal shocks. It also improves heat transfer by up to 20% compared to cross flow type exchangers.

The HeatMatrix air preheater is also designed to cool flue gas down through the acid dew point. As a result, sulphuric acid condenses on the tube wall in the polymer heat exchanger, which eventually gathers at the bottom of the exchanger. The acidic condensate can then be disposed of separately.

The recovered heat can be used for the pre-heating of combustion air, which is typically fed at ambient temperature into fired heaters or heated up using LP steam followed by heat recovery from flue gas. These fired heaters, even for those designed for heat recovery, tend to discharge flue gas at >200°C due the need to keep temperature higher than the acid dew point temperature. There is potential for heat recovery, bringing flue gas temperature down to about 110°C.

The recovered heat may also be used for BFW heating, which is typically a significant heat sink in most plants.

Observations from Heating System Study

Given that this study involves the energy assessment of furnaces, hot oil heaters and boilers, KBR has actively looked for opportunities where the installation of polymer heat exchangers is possible. Some plants have even contacted HeatMatrix Group directly for technical clarifications, indicating some interest in exploring this technology.

However, it should be noted that retrofitting existing fired heaters to incorporate heat exchangers for stack heat recovery is a major engineering project. Minimally, it will likely involve the following works:

- Re-routing of flue gas, combustion air (or BFW) pipes; and
- Detailed engineering design.

Other related CAPEX items that may be needed are:

- Replacement or upgrade of existing forced draft / induced draft fans;
- New metal air preheater or additional area on existing metal air preheater; and
- Addition of bypass lines to ensure the polymer exchanger operates within a set temperature range.

The CAPEX of equipment such as fans and heat exchangers is much lower relative to the CAPEX for all other engineering works that come with it. Such projects tend to cost millions of dollars in investment, which plants may not invest unless there are strong economic justifications. Plants will also have to undertake detailed engineering studies internally before arriving at an investment decision.

8.2 Use of a Proprietary Technology to Upgrade the Temperature of Low-Grade Heat

Technology Introduction

Qpinch has developed an industrial chemical heat pump technology that can provide a temperature uplift to low-grade waste heat via a closed-loop reaction pathway. This technology can potentially utilise low-grade heat as low as 40°C and provide a temperature uplift of up to 100°C. The upgraded waste heat can go as high as 230°C, opening up more possibilities for direct heat recovery or steam generation.

For each unit of waste heat provided to the reactor system, approximately half of it can be made available at a higher temperature. This will come at an expense of about 2 – 4% electrical energy consumption based on useful output duty.

The applicability of such a technology has been evaluated for plants with significant amounts of waste heat. Unfortunately, there are challenges that prevent the implementation of such a solution.

- **Waste Heat has to be Available on a MW scale for Better Economics**

  Such a technology will be more suitable for large plants with significant amounts of waste heat. Generally speaking, larger scale implementation of this solution tends to provide better economics.

- **Plot Space and CAPEX Requirements**

  Implementation of this solution will be a major investment as CAPEX tends to be in the range of millions of Singapore dollars. It will also require the construction of a multi-storey structure to hold the reaction system and its ancillary equipment. Indicative plot space requirements are shown below:

  - For a 1 MW steam production facility, plot space required is 5 m x 6 m x 12 m.
  - For a 10 MW steam production facility, plot space required is 12 m x 15 m x 12 m.

- **Operational Risks**

  Plants may want to implement pilot projects on a much smaller scale, but that will likely come with unfavourable economics. Based on plant feedback, going straight into large-scale implementation of this solution may introduce risks which plants may not want to undertake.

- **Technical Challenges**

  Temperature of the upgraded waste heat is capped at about 230°C. While the direct heat recovery for process heating is preferred, the heat sink profile of the plant and physical location of the heat sink may not allow for this to happen.

  The upgraded waste heat allows for MP and / or LP steam generation. The generation of steam must fit the overall steam system. Plants that are facing an excess of steam in the LP steam headers will be unlikely to consider such a technology.

  In some cases, the upgraded waste heat is likely going to be below the pinch point of most process plants, where there is already an excess of waste heat that needs to be rejected to cold utilities.

  There is an opportunity to use this technology on a cluster level energy improvement roadmap as it would allow low grade waste heat from one plant to be exported to another plant via temperature uplift or steam generation.

9 Conclusion

With climate change as one of the major environmental challenges of our time, Singapore is fully committed to playing its part in reducing greenhouse gas emissions. The main contributor of greenhouse gas emission is CO_2, which is primarily produced from the firing of fossil fuels to meet the energy needs in the oil refining, petrochemical and chemical industries in Singapore. One of the key strategies for reducing emissions adopted by Singapore lies in improving energy efficiency, where energy is used more efficiently, minimising unnecessary wastages.

The Heating System Study has provided rich insights into the energy performance of the oil refining, petrochemical and chemical sectors of Singapore. As the major consumers of NG and electricity in Singapore, it is crucial to understand how efficiently these plants are using energy, in order to seek opportunities to improve their performance, thereby aligning to Singapore's efforts in addressing climate change.

The study has received overwhelming support from the industry, with more plants expressing interest in this study than the number of available slots. Participating plants have actively contributed technical information and committed resources to ensure that this study leads to meaningful results. KBR has also observed keen interest from various plant management teams on the study findings as well as the general performance of heating systems across all 11 participating plants.

This study has concluded with 40 shortlisted opportunities that improve energy performance of the heating systems across 11 participating plants. Cumulatively, the implementation of these opportunities would amount to an energy reduction of 2056 TJ/yr, equivalent to a carbon abatement of 127 ktpa.

In order to turn these shortlisted opportunities into reality, it requires the deployment of innovative, energy efficient technologies to recover waste heat and retrofit of existing equipment and systems. Participating plants will need to undertake more detailed feasibility studies, involving more accurate CAPEX estimates, seek involvement of technology / equipment vendors and develop strong business cases for investment decisions by the plant management teams.

While this study has been successfully executed at all participating plants, KBR has observed that there is untapped carbon abatement potential in some plants. Due to the nature of each plant's processes, the available heat sources and sinks within each plant are unlikely to change significantly over time. This has presented huge challenges in incentivising waste heat recovery, particularly for plants with a significant excess of waste heat but without significant heat sinks. An integrated study of heat source / sink profiles of plants that are situated in close proximity can bring about new perspectives on improving heat integration and waste heat recovery. Fundamentally, waste heat is a useful resource that should be exploited and monetised by plants. Industrial plants need to work collaboratively to explore synergies that help to achieve a win-win situation in minimising energy costs.

10 References

1. NEA, Heating Systems Study, “Assessment Framework for Heating Systems”, 24 June 2020

2. NEA, Heating Systems Study, “Best Practice Guide”, 1 June 2021