Generator Technical and Cost Parameters

ElectraNet

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Executive summary

Aurecon has been engaged by ElectraNet to provide assistance with developing Technical and Cost details for a selected number of power generation technologies for their Project Energy Connect.

The table below summaries the technical and cost parameters developed as further explained throughout this report.

Results Summary

Parameter	Units	Gas Fired OCGT	Gas Fired CCGT	Gas Steam Turbine	Gas Recip Engine	Brown Coal	Black Coal
Heat rates and minimum loads							
Gross heat rate @ 100% MCR	GJ/MWh (LHV)	10.02	7.04	9.72	7.94[3]	-	-
Gross heat rate @ 100% MCR	GJ/MWh (HHV)	11.09	7.79	10.76	8.79[3]	13.33	9.45
Minimum Stable operating load	% of MCR	50%	60% / 30%[1]	20%	40%[2]	60%	42%
Gross heat rate @ Minimum Stable Operating load	GJ/MWh (LHV)	13.22	7.95	10.78	10.25[3]	-	-
Gross heat rate @ Minimum Stable Operating load	GJ/MWh (HHV)	14.63	8.90	11.94	11.35[3]	14.68	10.40
Start-up costs							
Hot start	$/MW	$32	$52	$96	$38	$298	$298
Warm start	$/MW	N/A	$81	$166	N/A	$379	$379
Cold start	$/MW	$103	$115	$218	$54	$549	$549

Notes:

1. *Minimum load for 2+1 configuration / 1+1 configuration*
2. *Minimum load on gaseous fuel*
3. *Excludes pilot (diesel) fuel consumption*

Aurecon also undertook a review of the ACIL Allen 2014 cost and technical parameters report to advise on the appropriateness of the various parameters for the selected technologies. Some of the more general parameters for existing and new entrant plant differ from Aurecon's view however many sits within the range of reasonable expectations, the others may need some further review. The full list of heat rates from ACIL Allen 2014 report for each existing station is still currently used by AEMO for its planning purposes and is seen as the best single publicly available source for these heat rates currently. Although there are a few likely discrepancies, more accurate data is not generally in the public domain.

1 Introduction

1.1 Background

Aurecon has been engaged by ElectraNet to provide assistance with developing Technical and Cost details for a selected number of power generation technologies for their Project Energy Connect.

This report details the scope, the methodology adopted and results of the assignment.

It is understood that the aim of the study is to assist ElectraNet in selecting appropriate parameters to refine its modelling as part of its Energy Connect Project.

1.2 Study Scope

The scope of the study broadly comprised three components as detailed in the Table 1-1 below:

Table 1-1 Scope of Services

Scope Component	Scope Details
Develop a set of technical and cost parameters covering selected power plant technologies	Cost and technical parameters to be developed: ▪ Minimum stable generation (i.e. without oil support) ▪ Plant Heat rates (kJ/kWh) at minimum and maximum generation (which can be used for calculating costs in ElectraNet financial model) ▪ Start-up costs (Cold, Warm, Hot) per start (based on “Kumar N (2012), "Power Plant Cycling Costs", AES 12047831-2-1, NREL” publication) Technologies (Selected Technologies) to be considered: ▪ Open cycle gas turbine (OCGT) ▪ Medium speed duel fuel reciprocating engine plant ▪ Gas fired combined cycle gas turbine (CCGT) ▪ Gas fired boiler and steam turbine plant ▪ Brown coal ▪ Black coal
Review “2014 ACIL Allen Fuel and Technology Cost Review” report	Review the cost and technical parameters included in the ACIL Allen report as relevant for the Selected Technologies and advise on their appropriateness for use by ElectraNet.
Review Technical Input to ElectraNet’s financial model.	Review and comment of ElectraNet’s financial model technical inputs page as part of our scope to ensure the outputs developed from this assignment can be easily applied in the financial model.

1.3 Abbreviations

The list of acronyms and abbreviation used in this report are defined in Table 1-2.

Table 1-2 Acronyms / Abbreviations

Acronym	Definition
AUD	Australian Dollar
CAPEX	Capital Expenditure
CCGT	Combined-cycle Gas Turbine
EPC	Engineer Procure and Construct
DLN	Dry Low NOx
GJ	Gigajoule
HHV	Higher Heating Value
HRSG	Heat Recovery Steam Generator
LHV	Lower Heating Value
MCR	Maximum Continuous Rating
MECL	Minimum Emissions Compliant Load
MSG	Maximum Stable Generation
MW	Megawatt
MWh	Megawatt-hour
NEM	National Electricity Market
NOx	Nitrogen Oxides
OCGT	Open Cycle Gas Turbine
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
O&M	Operations and Maintenance
QPS	Quarantine Power Station
TIPS (B)	Torrens Island Power Station B
TJ	Tera Joule

2 Limitations

2.1 General

This report has been prepared by Aurecon on behalf of, and for the exclusive use of, ElectraNet. It is subject to, and issued in connection with, the provisions of the agreement between Aurecon and ElectraNet.

Power generation conceptual design is not an exact science, and there are several variables that may affect the results. Bearing this in mind, the results provide reasonable guidance as to the ability of the power generation facility to perform adequately, rather than an exact analysis of all the parameters involved.

This report is not a certification, warranty, or guarantee. It is a report scoped in accordance with the instructions given by ElectraNet and limited by the agreed time allowed.

The findings, observations, and conclusions expressed by Aurecon in this report are not and should not be considered an opinion concerning the commercial feasibility of such a project.

This report is partly based on information provided to Aurecon by ElectraNet. This report is provided strictly on the basis that the information provided to Aurecon is accurate, complete and adequate, unless stated otherwise.

If ElectraNet or a third party should become aware of any inaccuracy in, or change to, any of the facts, findings or assumptions made either in this report or elsewhere, ElectraNet or a third party should inform Aurecon so that Aurecon can assess its significance and review its comments and recommendations.

2.2 Thermoflow Inc. software

This report relies on outputs generated from Thermoflow Inc. software by personnel in Aurecon experienced in using this software. The provider of this software does not guarantee results obtained using this software, nor accept liability for any claimed damages arising out of use or misuse of its software. Aurecon's report is provided strictly on the basis that the outputs that have been generated are accurate, complete, and adequate. Aurecon takes no responsibility and disclaims all liability whatsoever for any loss or damage that ElectraNet may suffer resulting from any conclusions based on outputs generated by Aurecon using this software.

3 Methodology and Definitions

3.1 Approach

For each technology, Aurecon has selected an existing power plant in the National Electricity Market (NEM) as the reference plant to develop the minimum stable generation (MSG), Heat Rate and the Start-up cost estimates. Where possible a plant located in South Australia has been selected as the reference plant.

The minimum stable generation values for each of the Selected Technologies have been determined using Aurecon's in-house knowledge and data based on previous works and investigations.

Heat Rate figures for OCGT, CCGT and Gas Fired Boiler technologies have been developed using the following three step process:

1. For each reference plant a Thermoflow model was developed to replicate the plant type (i.e. Gas turbine model, configuration, cooling type, etc) to estimate the plant performance profile including Heat Rate.
2. In addition to step 1 above, Aurecon calculated the actual annual average Heat Rate figures of the reference plant by obtaining actual gas consumption and plant outputs for the period of 1 October 2018 to 30 September 2019. The actual gas consumption figures were obtained from AEMO's gas bulletin board. The actual generation figures were obtained using the NEM Review software package.
3. The figures from the above two steps were the compared and modelling trends adjusted to match the actual measured datapoint.

It is important to note that the Thermoflow software results are typically optimised for the plant's "design" conditions (i.e. generally 100% output and location specific ambient conditions). When simulating "off-design" conditions (i.e. low loads, extreme temperatures) the model results tend to become less accurate. As the simulation moves further away from the design conditions the less accurate the results.

For Coal fired power plant the Heat Rate figures are estimates are based on Aurecon's in-house data and Thermoflow modelling.

The Start-up cost estimates are based on the approach outlined in the *"Kumar N (2012), "Power Plant Cycling Costs", AES 12047831-2-1, NREL"* report. The "Kumar 2012" report reviews historical cycling cost impacts on a number of power plant technologies and presents factors which can be used to estimate the potential future cost impacts. The costs incorporate allowances for start-up fuel consumption, other start-up costs such as auxiliary power, chemicals, water, etc, and allowance for increased capital and maintenance expenditure associated with thermal cycling fatigue. These are then presented on a "per MW installed capacity" basis for Hot, Warm, and Cold start types.

3.2 Basis and assumptions

The key basis and assumptions used for this study includes the following:

- USD:AUD exchange rate of 0.7
- Natural gas cost of AU$10/GJ
- Diesel / fuel oil cost of AU$26/GJ
- OCGT typical figures based on Quarantine Power Station
- CCGT typical figures based on Pelican Point Power Station
- Gas fired steam turbine plant typical figures based on Torrens Island
- Black coal typical figures based on Bayswater Power Station
- Brown Coal typical figures based on Loy Yang A

3.3 Definitions

3.3.1 General

The key technical and cost parameters developed in this study are defined in the Table 3-1 below

Table 3-1 Definition of key terms

Term	Definition
Minimum stable generation	The minimum load (as a percentage of the rated gross capacity of that unit) that the generator unit can operate in a stable manner for an extended period of time (without supplementally oil or similar support) and reliably ramp-up to full load while continuing to comply with its emissions licences.
Gross output	Electrical output as measured at the generator terminals.
Auxiliary load	The percentage of rated generation output of each unit (as measured at the generator terminals) that is consumed by the station (including cable and transformer losses) and not available for export to the grid. The auxiliary load is provided as a percentage of the rated output at full load.
Net output	Electrical output exported to the grid as measured at the HV side of the generator step-up transformer. The net output of the unit can be calculated as the rated gross output at the generator terminals minus the auxiliary load.
Heat rate	The ratio thermal energy consumed in fuel over the electrical energy generated
Efficiency	Calculated using: Efficiency (%) = 3600 / Heat Rate (kJ/kWh) x 100
ISO Conditions	Following Ambient Conditions: Temperature: 15 Deg C Relative Humidity: 60% Elevation: 0 meters above mean sea level
Annual Capacity Factor	= Annual MWh generated / (MW capacity x 8760)
Annual Average Load Factor	The average “% load” that the unit(s) operate when online over the annual period
Annual Average Heat Rate	= Total annual gas consumption (GJ) / Total annual electricity generated (MWh)

3.3.2 Start-up costs

For clarity, please see below the cost components that are included in the start cost figures reported (as defined in Kumar, 2012):

- The additional cost of “Capital and Maintenance” relating to increased thermal cycling, including;
  - Operator non-fixed labour
  - General engineering and management cost (including planning and dispatch)
  - Maintenance and overhaul expenditures for boiler, turbine, generator, air quality control systems and balance of plant key components
  - Overhaul capital maintenance expenditures for boiler, turbine, generator, air quality control systems and balance of plant key components
- Cost of start-up auxiliary power
- Cost of start-up fuel
- Cost of start-up consumables (chemicals, water, additive, etc.)

The above costs are converted into a “$/MW installed” cost that can be attributed to each start. It is important to note that the “cost per start” excludes the normal plant OPEX costs which are applicable regardless of plant start frequency.

4 Technical and Cost Data

This Section provides a brief description of the technology, the reference plant selected for each technology, discussion on the technical and cost parameters in relation to each technology and the presentation of the technical and cost parameters.

4.1 Open cycle gas turbine plant

OCGT plants deploy a wide variety of gas turbine types, broadly classified as Areo-derivative and Industrial gas turbines. Within the large scale industrial class, gas turbines are further classed based on advancement in technology and other operating parameters (firing temperature, output, efficiency) as D Class, E Class, F Class and H Class gas turbines.

For this study, Quarantine Power Station (QPS) was selected as the basis to develop the required technical parameters. QPS was selected due to its location in SA and the plant represents a typical OCGT plant connected to NEM. QPS consists of 5 gas turbines of two different makes. The power station started operation initially with 4 x Alstom 10B gas turbines but was later expanded by the addition of 1 x GE 9E gas turbines in 2007. For this report we have based the technical parameters on the GE 9E machines. Key features of the QPS are given in Table 4-1 below

Table 4-1 OCGT Reference plant – QPS Data

Item	Particulars
GT Model	Alstom 10B and GE 9E
Unit size	25MW and 120MW
Total Plant Size	~ 220 MW Nominal
Fuel type	Natural gas
Age	13 years (GE 9E)
Configuration	5 x OCGT

4.1.1 Minimum Stable Load – OCGT

Minimum operating load for OCGT, technically, can be as low as 5% to 10% of the maximum continuous rating (MCR) provided there are no NOx emissions limitations. However, if Dry Low NOx (DLN) burners are used for emissions control, in general, for loads below 50% the emissions from gas turbine notably increase. This is because between 50% and 100% the DLN burner operate on Premix mode which results in lower emissions within this range of operation. Below 50% load premix mode of operation becomes unstable and hence the combustion shifts to diffusion mode resulting in higher emissions. The minimum load the gas turbine can operate complying to emissions standards, commonly termed minimum emissions compliant load (MECL) is therefore approximately 50% or MCR although some reports have indicated figures as low as 40%. The notable exception to this rule is that for gas turbines with sequential combustion (e.g. GE Alstom GT24/26), by turning off the secondary burners, the load can be reduced to 20% or lower while being emission-compliant.[1] There are only two Alstom GT26 gas turbines in Australia which use this technology which are Tallawarra A and Swanbank E CCGT power stations.

4.1.2 Heat Rate – OCGT

Heat Rate of gas turbines vary when as they operate away from the maximum load point. Typical Heat Rate of OCGT plant at MCR ranges from 10.4 GJ/MWh to 12 GJ/MWh (HHV) at ISO Conditions with Areo-derivative showing better Heat Rates than Industrial turbines.

[1] *https://www.power-eng.com/2013/06/12/gas-turbine-combined-cycle-fast-start-the-physics-behind-the-con/#gref*

Aurecon has developed a Heat Rate curve for the various loads for a GE 9E gas turbine. The curve has then been fit to the annual average heat rate as determined using actual publicly available data. This is shown in Figure 4-1.

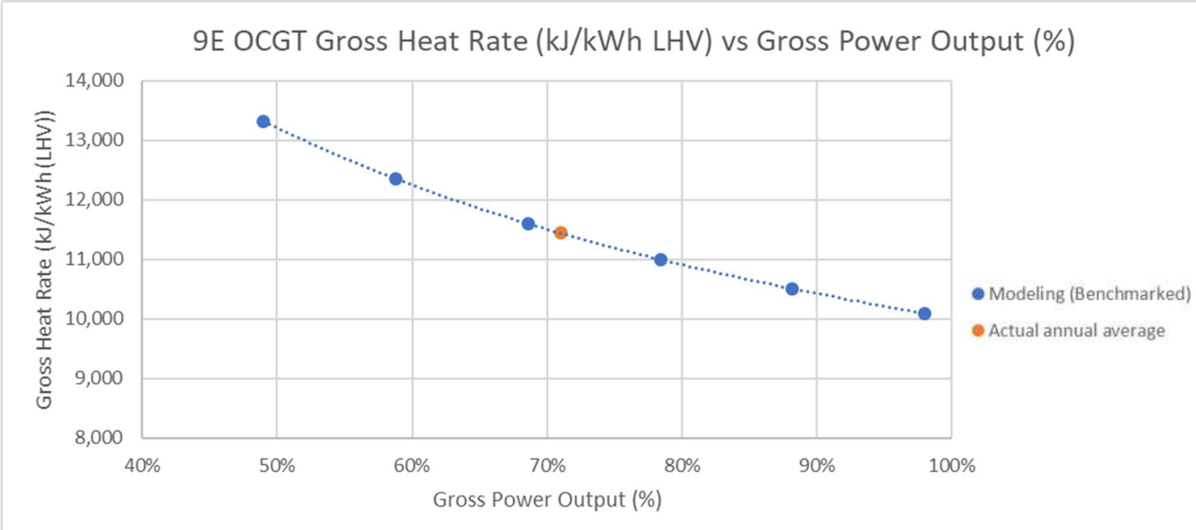

Figure 4-1 Heat Rate variation with load – GE 9E OCGT

The actual annual average Heat Rate at QPS as determined using gas consumption data obtained from AEMO gas bulletin board and annual generation data obtained from NEM Review is detailed below:

- Annual Gas Consumption: 2,628 TJ/a (HHV basis)
- Annual Plant Generation: 207,531 MWh (Gross)
- Average annual load factor: 71%
- Estimated annual average gross Heat Rate: 11.44 GJ/MWh (LHV Basis)
- Estimated annual average gross Heat Rate: 12.67 GJ/MWh (HHV Basis)

From the above the gross Heat Rates at maximum and minimum load are shown in the table below.

Table 4-2 Gross heat rate details for OCGT

Condition	Load (% MCR)	Gross heat rate (LHV basis)	Gross heat rate (HHV basis)
Maximum load	100%	10.02 GJ/MWh	11.09 GJ/MWh
Minimum load	50%	13.22 GJ/MWh	14.63 GJ/MWh

The above heat rate curve and data has been converted to an energy consumption profile sufficient for use as part of a PLEXOS model. This is shown in the figure below.

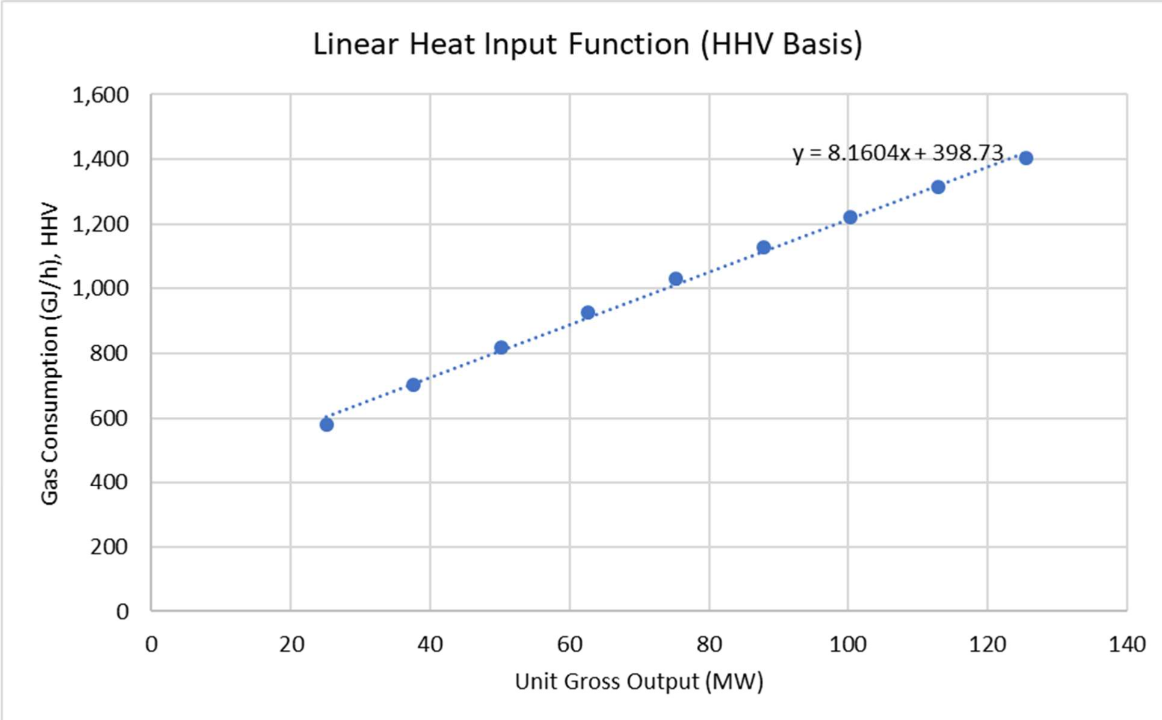

Figure 4-2 **Linier heat input function (for PLEXOS) − OCGT**

4.1.3 Plant Start-up Costs − OCGT

The different start-up types and typical start times for existing industrial gas turbines are shown in Table 4-3.

Table 4-3 **Plant Start details for OCGT**

Start types	Definition / Shut down period	Start-up time	Start-up cost
Hot start	Less than 2 hours	15 minutes	$32 / MW
Warm start	N/A	N/A	N/A
Cold start	Above 2 hours	25 minutes	$103 / MW

It is important to note that industrial gas turbine overhaul frequencies are dictated by a combination of operating hours and number of starts. Changes to a units annual operating hours and/or annual number of starts may change the general OPEX costs associated with routine inspections and overhauls. Changes in these OPEX related costs (which are not thermal cycling related) are not included in the above costs.

4.2 Combined cycle gas turbine plant

As with OCGT, the type of gas turbines deployed for CCGT operation can range from Aero-derivative to any class of industrial type turbines. Although CCGT plants can be configured using multiple number of gas turbines and steam turbines, the most popular CCGT configurations are:

- One gas turbine, one dedicated heat recovery steam generator (HRSG) and one steam turbine, commonly terms as 1 on 1 (1+1) configuration and,
- Two gas turbines, two dedicated HRSGs and one steam turbine, commonly referred to as 2 on 1 (2+1) configuration.

Depending on the plant size, dual and triple pressure HRSGs might be used. The steam turbine output is typically about 1/3 of the overall plant output.

For this study, we have selected the Pelican Point CCGT plant as the basis to develop the required technical parameters. Key features of Pelican Point are given in Table 4-4.

Table 4-4 CCGT Reference plant

Item	Particulars
GT Model	13E2 by Alstom
CCGT Configuration	2+1
Unit size	2 x 160 MW GT, 1 x 165 MW ST
Total Plant Size	~ 485 MW
Fuel type	Natural gas
Age	19 years

4.2.1 Minimum Stable Load – CCGT

Minimum operating load for CCGT plant with heavy duty industrial gas turbine could be somewhere between 25% to 40% provided there are no gaseous emission limitations. With gaseous emission limitation the same issues as highlighted for OCGT (Refer Section 4.1.1) applies to CCGT thus limiting the minimum load with emissions compliance to somewhere between 50 to 60% MCR. The minimum load for steam turbine could be between 20% to 40% of the rated capacity.

For pelican point power station, which is a 2+1 configuration, there are actually two minimum load points, one in 2+1 configuration and the other in 1+1 configuration. The design minimum load for these two operating configurations are shown below:

- 2+1 operating configuration - 60% MCR
- 1+1 operating configuration - 30% MCR

4.2.2 Heat Rate – CCGT

Heat Rate of CCGT plant at ISO Conditions typically range from 8 to 6.8 GJ/MWh (HHV) depending on the class/type of gas turbines, the cooling system and the steam water cycle parameters. Heat Rate of CCGT vary when the plant operates away from the maximum load points. Figure 4-3 below shows Heat Rate curve of a 2+1 CCGT plant using 13E2 gas turbines at different loads developed using GT Pro model. The curve has then been fit to the annual average heat rate as determined using actual publicly available data.

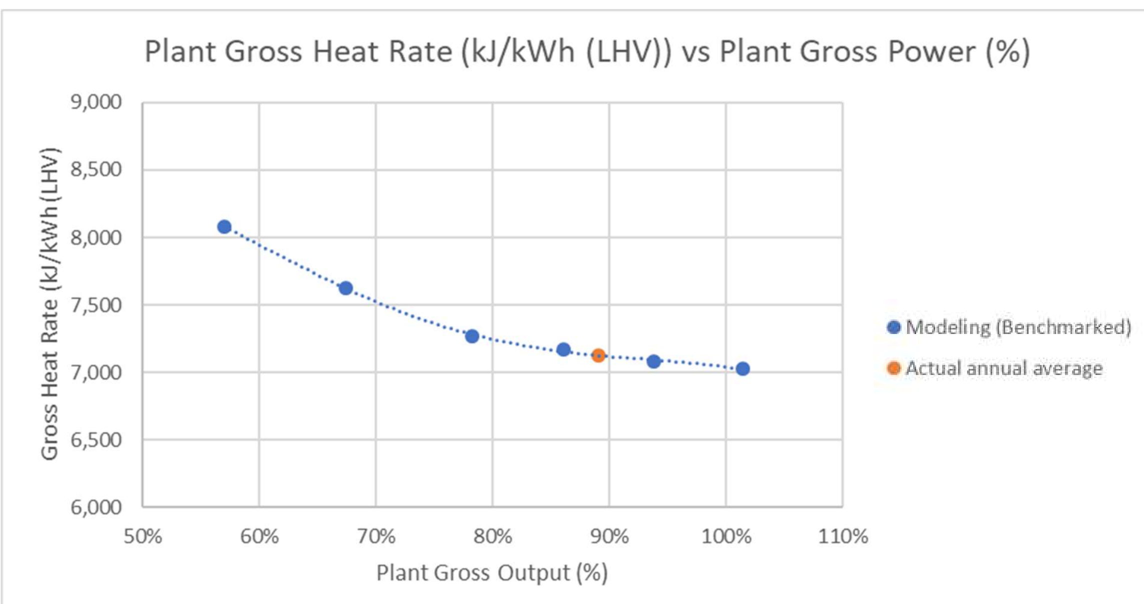

Figure 4-3 Heat Rate Variation with Load - 2 x 1 CCGT (13E2 GT)

The actual Heat Rate at Pelican Point as determined using gas consumption data obtained from AEMO gas bulletin board and annual generation data obtained from NEM Review are detailed below:

- Annual Gas Consumption: 25,355 TJ/a (HHV basis)
- Annual Plant Generation: 3,212,388 MWh (Gross)
- Average load factor: 79% (1/4 of operating time spent in 1+1 mode)
- Average load factor (2+1 only basis) 89%
- Estimated annual average gross Heat Rate: 7.13 GJ/MWh (LHV Basis)
- Estimated annual average gross Heat Rate: 7.89 GJ/MWh (HHV Basis)

From the above the gross Heat Rates at maximum and minimum load are shown in the table below.

Table 4-5 Gross heat rate details for OCGT

Condition	Load (% plant MCR)	Gross heat rate (LHV basis)	Gross heat rate (HHV basis)
Maximum load (2+1 configuration)	100%	7.04 GJ/MWh	7.79 GJ/MWh
Minimum load (2+1 configuration)	60%	7.95 GJ/MWh	8.90 GJ/MWh
Maximum load (1+1 configuration)	50%	7.04 GJ/MWh	7.79 GJ/MWh
Minimum load (1+1 configuration)	30%	7.95 GJ/MWh	8.90 GJ/MWh

The above heat rate curve and data has been converted to an energy consumption profile sufficient for use as part of a PLEXOS model. This is shown in the figure below.

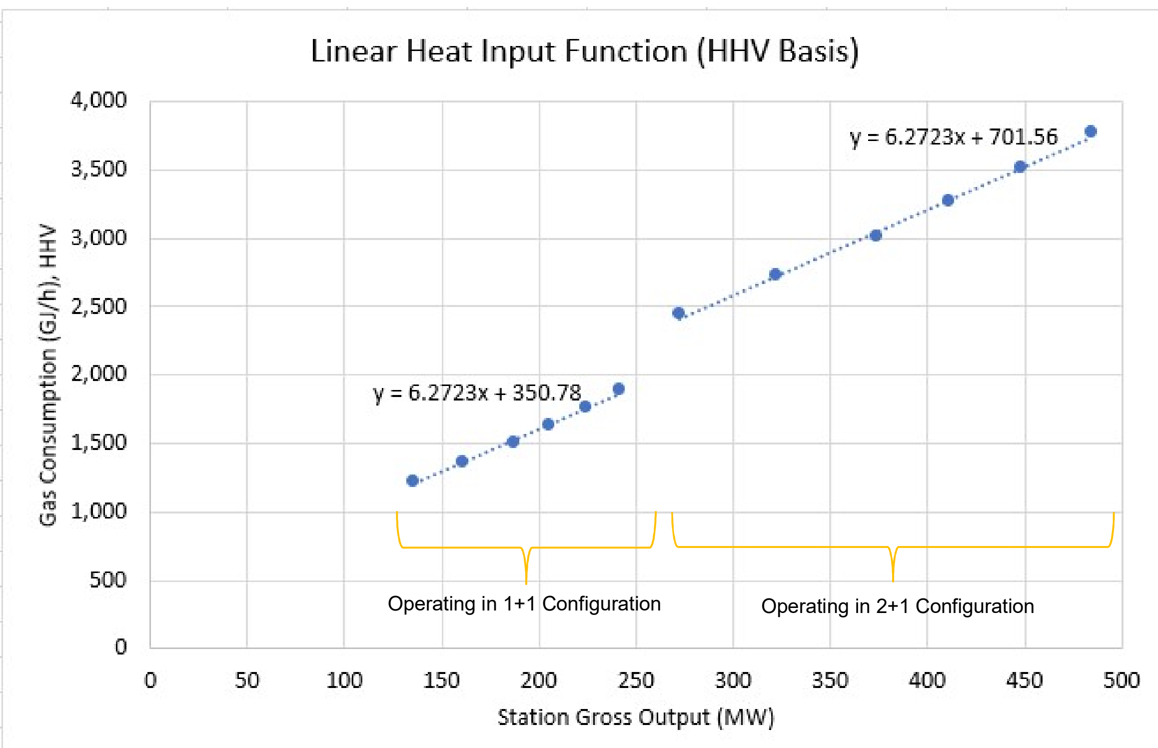

Figure 4-4 Linier heat input function (for PLEXOS) – CCGT (2+1 E Class)

4.2.3 Plant Start-up Costs – CCGT

The different start-up types for CCGTs, start-up time and costs are defined in table below:

Table 4-6 CCGT Plant Start up details

Start types	Definition/ Shut down period	Start-up times	Start-up cost
Hot start	Less than 5 hours	1.3 hours	$52 / MW
Warm start	5 to 40 hours	2.3 hours	$81 / MW
Cold start	Above 40 hours	3.7 hours	$115 / MW

It is important to note that industrial gas turbine overhaul frequencies are dictated by a combination of operating hours and number of starts. Changes to a units annual operating hours and/or annual number of starts may change the general OPEX costs associated with routine inspections and overhauls. Changes in these OPEX related costs (which are not thermal cycling related) are not included in the above costs.

4.3 Gas fired steam turbine plant

Gas fired boiler plants work according to the same principle as coal fired plants expect for the source of fuel. There are only a few gas fired steam turbine plants in the NEM namely, Torrens Island Power station (TIPS) A and B in SA and Newport Power Station in Victoria.

For this study TIPS (B) has been selected as the reference pant. TIPS (B) consists of 4 x 200 MW units. The plant was commissioning in 1976. Table 4-7 provides details of TIPS (B).

Table 4-7 Torrens Island Power Station B Details

Item	Particulars
Plant Output	800 MW
Unit Size	200 MW
Turbine	Parsons Turbine
Fuel type	Natural gas
Age	44 years

4.3.1 Minimum Stable Load – Gas fired boiler

Existing gas fired boilers can typically operate at lower loads than its coal fired counterparts - down to approximately 20% MCR[2]. Note that the original design minimum load for Torrens Island was 30% MCR however several years ago a series of tests were performed and a new minimum stable load of 20% MCR was determined for the Torrens Island units.

More recently AEMO has directed that at least two Torrens Island units are online at any time. As such these units are now regularly operated down at their minimum load point.

4.3.2 Heat Rate – Gas Fired Boiler

Plant Heat Rate depends to a large extend on the steam water cycle parameters (i.e. steam pressure, temperature, etc) and the cooling system type. Typical Heat Rate of existing gas fired range from 10.3 to 11.4 GJ/MWh.

Figure 4-3 below shows Heat Rate curve for a generic gas fired boiler plant using Torrens Island B station steam conditions and cooling technology at different loads developed using our Thermoflow software

[2] https://www.energycouncil.com.au/analysis/barker-inlet-a-new-technology-responding-to-the-market/

package. The curve has then been fit to the annual average heat rate as determined using actual publicly available data (shown in orange). Further datapoints for single days at low load conditions are also shown (in grey) and are further discussed below.

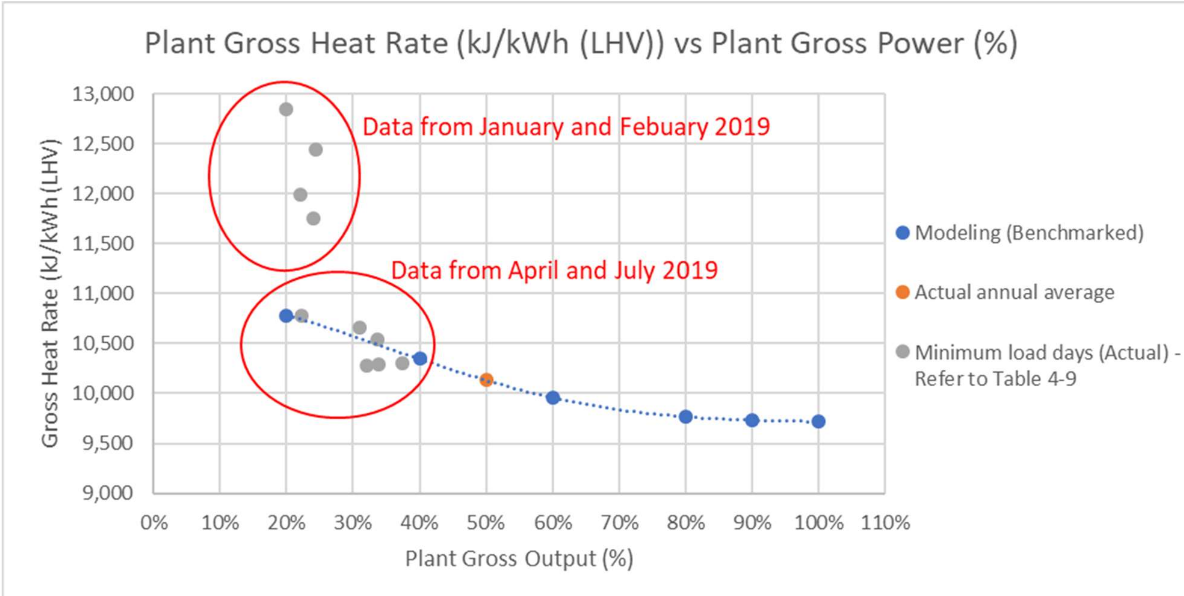

Figure 4-5 Heat Rate Variation with Load - TIPS

The Heat Rate at Torrens Island Power Station (A and B) was determined using gas consumption data obtained from AEMO gas bulletin board and annual generation data obtained from NEM Review are detailed below:

- Annual Gas Consumption: 29,454 TJ/a (HHV Basis)
- Annual Plant Generation (both gas and fuel oil): 2,650,917 MWh (Gross)
- Annual Plant Generation (natural gas only): 2,624,407 MWh (Gross) (approximated)
- Average annual load factor: 50%
- Estimated annual average gross Heat Rate: 10.14 GJ/MWh (LHV Basis)
- Estimated annual average gross Heat Rate: 11.21 GJ/MWh (HHV Basis)

It is important to note that Torrens Island can also operate its B3 and B4 units on fuel oil. To Aurecon's knowledge approximately 1% of the electricity generation from Torrens Island was generated from fuel oil during the analysis period. This has been addressed in the heat rate calculation above.

From the above the gross Heat Rates at maximum and minimum load are shown in the table below.

Table 4-8 Gross heat rate details for gas fired boiler plant

Condition	Load (% MCR)	Gross heat rate (LHV basis)	Gross heat rate (HHV basis)
Maximum load	100%	9.72 GJ/MWh	10.76 GJ/MWh
Minimum load	20%	10.78 GJ/MWh	11.94 GJ/MWh

The above heat rate curve and data has been converted to an energy consumption profile sufficient for use as part of a PLEXOS model. This is shown in the figure below.

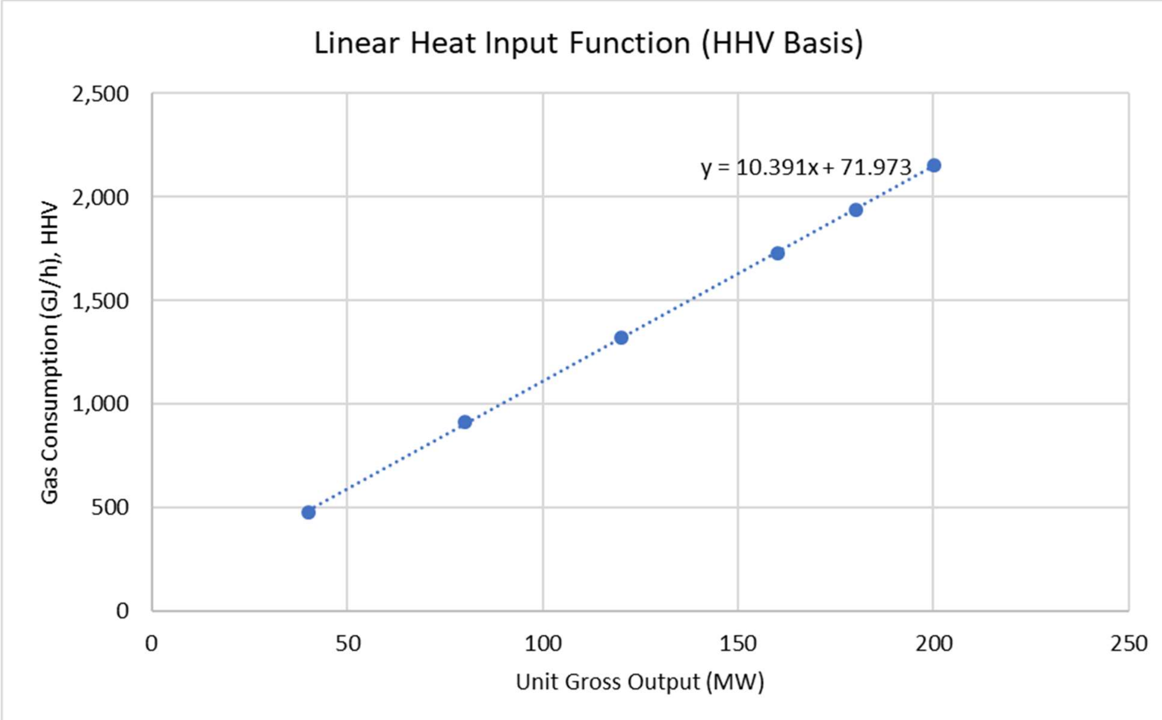

Figure 4-6 **Linier heat input function (for PLEXOS) – TIPS**

A check of the minimum load heat rate was also completed against the NEM Review and AEMO gas bulletin board data for days where minimum load was continuously sustained. The results are presented below and also plotted on the heat rate curve in Figure 4-5. Note that there are typically discrepancies between daily reporting periods which average out over time. As such the below should be considered as a guide only.

Table 4-9 **Gross heat rate calculations for TIPS on minimum load days**

Dates	Gas Consumption (GJ)	Plant Generation (MWh)	Average % Part Load	Average Gross Heat Rate (GJ/MWh, HHV)
1/01/2019	28,226	2,127	22%	13.27
5/01/2019	29,943	2,303	24%	13.00
6/01/2019	27,312	1,921	20%	14.22
9/02/2019	32,333	2,348	24%	13.77
15/04/2019	37,012	3,247	23%	11.39
16/04/2019	41,029	3,597	25%	11.41
20/04/2019	17,544	1,487	31%	11.80
21/04/2019	18,835	1,614	34%	11.67
20/07/2019	25,418	2,131	22%	11.93
21/07/2019	35,033	3,078	32%	11.38

From Figure 4-5, which overlays the above minimum load day data on the modelled heat rate curve, it is seen that there is a group of data points that align well with the modelled curve and another that doesn't. The outlying group are all from 1st January to 8th February 2019 and are displaying higher than expected heat rates. The likely reasoning could include; higher ambient temperatures, gas quality differences, and/or differences in operating unit combinations.

The above minimum load heat rates for the April and July period aligns generally with our estimated minimum load heat rate in Table 4-8. Assuming the April and July periods are representative of the "average" conditions the modelled results appear reasonable on an annual average basis. The out lying datapoints however do illustrate the variability in real conditions at a single operating point (i.e. +/- 10%) due to unconsidered factors. As such it is recommended to consider how the results are being applied elsewhere and allow further tolerances where needed (i.e. summer month vs winter month factor).

4.3.3 Plant Start-up Costs – Gas fired boiler

The different start-up types for Gas fired boiler, start-up times and cost are defined in table below:

Table 4-10 Gas Fired Boiler Plant Start up details

Start types	Definition/ Shut down period	Start-up times	Start-up cost
Hot start	Less than 4 hours	2 hours	$96 / MW
Warm start	4 to 48 hours	3.5 hours	$166 / MW
Cold start	Above 48 hours	12 hours	$218 / MW

4.4 Medium speed reciprocating engines

For power generation applications, there are two general classifications of reciprocating engine - medium speed and high-speed. Medium-speed engines operate at 500 – 750 rpm and typically range in output from 4 to 18 MW. High-speed engines operate at 1,000 – 1,500 rpm with a typical output below 4 MW. There are also three general fuel classes for reciprocating engines. These are gaseous fuel, liquid fuel, and dual fuel. Duel fuel engines can operate on either gaseous or liquid fuel, however always rely on a small consumption of diesel as a pilot fuel.

In the NEM there is only 1 grid scale medium speed reciprocating engine power station (i.e. Barker Inlet Power Station) however further similar plants are planned. As such for this report we have selected a medium speed dual fuel type reciprocating engine power station as the reference plant. Details of the reference plant is provided in Table 4-11 below.

Table 4-11 Reference Plant for medium speed reciprocating engine plant

Item	Particulars
Plant Output	212 MW
Unit Size	18 MW
OEM	Wartsila
Fuel type	Dual Fuel (gas and liquid)
Age	New

4.4.1 Minimum Stable Load – Reciprocating Engine

Typical minimum loads of medium speed reciprocating engines are as follows:

- Gaseous fuel operation − 40% MCR
- Liquid fuel operation − 10% MCR

4.4.2 Heat Rate – Reciprocating Engine

The gross Heat Rate for the above reference plant at maximum and minimum load is shown in the table below. These are based on typical OEM data and Aurecon's in-house knowledge.

Table 4-12 Gross heat rate details for reciprocating engine plant (on gaseous fuel)

Condition	Load (% MCR)	Gross heat rate (LHV basis)	Gross heat rate (HHV basis)
Maximum load	100%	7.94 GJ/MWh	8.79 GJ/MWh
Minimum load	40%	10.25 GJ/MWh	11.35 GJ/MWh

Note:

1. *For these dual fuel reciprocating engines there is an additional 1.5 GJ/h (HHV) of pilot fuel (diesel) consumption per 18 MW engine that is online. This consumption is continuous regardless of operating load.*

The above heat data has been converted to an energy consumption profile sufficient for use as part of a PLEXOS model. This is shown in the figure below.

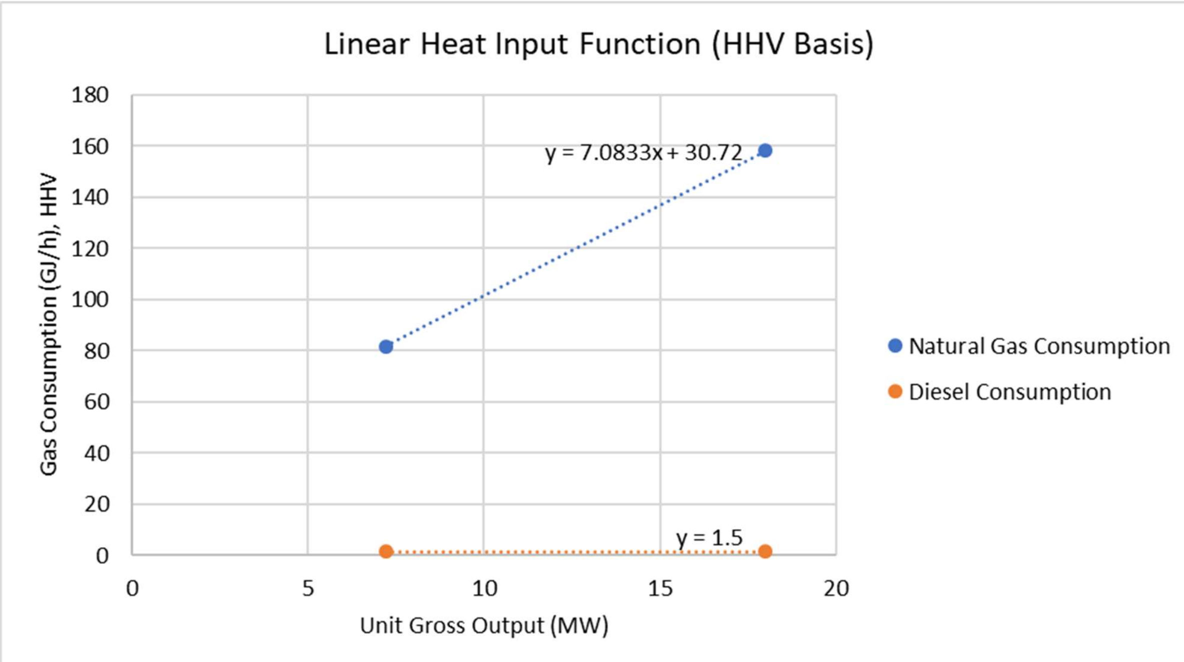

Figure 4-7 Linier heat input function (for PLEXOS) – Single 18 MW medium speed reciprocating engine

It is important to note that the above is for a single unit. For a multi-engine instillation (i.e. Barker Inlet Power Station), as the load drops and the station output is reduced the heat rate will be optimised by turning off single engines rather than operating all 12 at reduced part loads. This should be considered in any system / market modelling.

4.4.3 Plant Start-up Costs – Reciprocating Engine

The different start-up types for reciprocating engine power plants and start-up time are defined in the table below.

Table 4-13 Reciprocating engine Start up details

Start types	Definition/ Shut down period	Start-up times	Start-up cost
Hot start	Less than 1 hour	5 minutes	$38 / MW
Warm start	N/A	N/A	N/A
Cold start	Above 1 hour	10 minutes	$54 / MW

4.5 Coal fired power plant

Coal fired power plant are typically classified as sub critical and super critical (more recently ultra-super critical and advanced ultra-supercritical) plants depending on the steam temperature and pressure. In the NEM there are approximately 48 coal fired units installed across 16 power stations in QLD, NSW and VIC. The unit sizes range from 280MW to 750MW and use a range of coal types from low grade brown coal through to export grade black coal.

For this report we have selected an Hitachi type subcritical unit as reference plant for brown coal and IHI-Toshiba type subcritical unit for black coal. Details of the reference plants are provided in Table 4-14.

Table 4-14 Reference Plant for Coal Fired Plants

Item	Brown Coal	Black Coal
Plant Output	2,210 MW	2,640 MW
Technology Type	Sub-critical	Sub-critical
Make	Hitachi	IHI-Toshiba
Unit Size	~ 560MW	~660 MW
Fuel type	Brown Coal	Black Coal
Age	32 years	34 years

4.5.1 Minimum Stable Load – Coal Fired

Typical minimum loads of existing coal power plants without oil firing range from 40% to 60% of nominal load. For brown coal plants without oil firing the minimum load is approximately 60% of the MCR whilst for black coal this could as low as 40%.

4.5.2 Heat Rate – Coal Fired

For existing coal fired sub-critical power plant Heat Rate typically range from 9.5 GJ/MWh to 13.5 GJ/MWh depending on, among others, the type of coal, the steam conditions and cooling type.

The gross Heat Rates for the above reference plants at maximum and minimum load are shown in the table below. These are based on AEMO's reported data and Aurecon's in-house knowledge of these plants.

Table 4-15 Gross heat rate details for brown coal

Condition	Load (% MCR)	Gross heat rate (HHV basis)
Maximum load	100%	13.33 GJ/MWh
Minimum load	60%	14.68 GJ/MWh

Table 4-16 Gross heat rate details for sub-critical black coal

Condition	Load (% MCR)	Gross heat rate (HHV basis)
Maximum load	100%	9.45 GJ/MWh
Minimum load	42%	10.40 GJ/MWh

The above heat data has been converted to an energy consumption profile sufficient for use as part of a PLEXOS model. This is shown in the figure below.

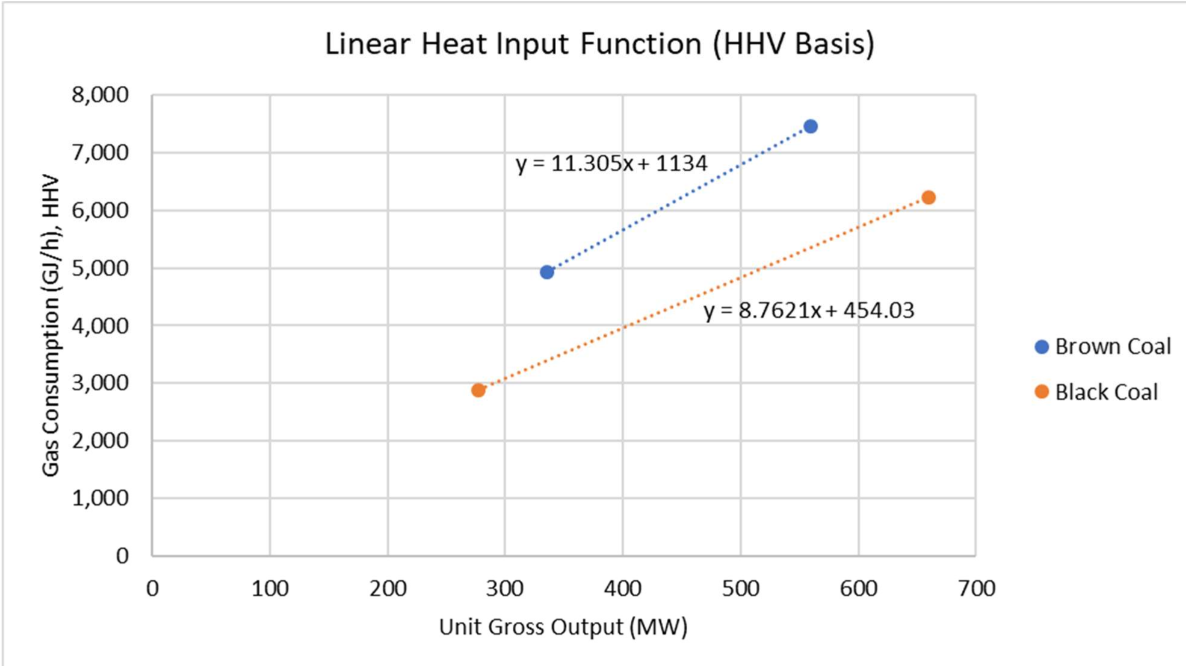

Figure 4-8 **Linier heat input function (for PLEXOS) − Black and Brown Coal Plant (subcritical)**

4.5.3 Plant Start-up Costs – Coal Fired

The different start-up types for coal fired power plants and start-up time are defined in Table 4-17.

Table 4-17 **Coal fired Plant Start up details**

Start types	Definition/ Shut down period	Start-up times	Start-up cost
Hot start	Less than 12 hours	1.5 hours (Black coal), 2 hours (Brown coal)	$298 / MW
Warm start	12 to 40 hours	3.5 hours	$379 / MW
Cold start	Above 40 hours	12 hours	$549 / MW

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