Climate Change Strategy FY2029-30

KASA Consulting

Jindal Shadeed Iron & Steel LLC Production Facility, Oman

Report

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JINDAL SHADEED

KASA CONSULTING
Environment I Safety I Quality

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0	Draft	KASA	JSIS	02/09/2021
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KASA Consulting Author Overview
(Peter Jansen (BE Env, MIEAust, RABQSA Auditor)

The primary contact and Project Manager from KASA Consulting responsible for delivery of this Climate Change Strategy is KASA Consulting's Associate Director, Peter Jansen.

Peter's holds a degree in Environmental Engineering, is a certified auditor under RABQSA and is a standing member of the Association of Mining and Exploration Companies (AMEC). His 30 years of environmental experience is drawn from senior roles with the private and regulatory sectors within Australia and overseas.

Originally established in in Perth Western Australia in1999, KASA Consulting has grown into a multi-disciplinary consultancy, providing environmental, safety, health and quality management related services to a wide range of construction, mining, oil and gas, industrial, government and service sector clients both nationally and internationally.

KASA has had the opportunity to provide our consulting services to Jindal Shadeed since 2015 including but not limited to a detailed independent environmental audit of the facility for submission to the then Ministry of Environment and Climate Affairs (MECA).

The team at KASA also has extensive experience in environmental approvals and HSE management, providing services to industry leaders, including Vale Oman, Jindal Shadeed, Oman Cement, Rio Tinto Iron Ore, Worsley Alumina, Alcoa, Alinta Energy, Baileys Group, BHP Billiton, Bluewaters Power, Chevron Texaco, City of Melville, Cobham Aviation Services, CSBP Limited, Edith Cowan University, Forge Resources NL, Griffin Coal, Harvey Beef, Lanco Resources Australia, LandCorp, Lynas Rare Earths Limited, Orica Australia, PanAust, Phu Bia Mining, Sinosteel Midwest Corporation, Straits Resources, Toll Mining Services, Transfield Worley, WA Water Corporation, Westralia Airports Corporation and Woodside Energy.

A core service from KASA Consulting is the estimation and reporting of greenhouse gas and energy data for a range of clients in the mining, industrial, power generation and primary industries sectors in Australia. These clients fall into the same Federal greenhouse and energy reporting regimes as any Jindal Shadeed's Australian and Western Australian assets that may trigger National Greenhouse and Energy Reporting (NGER) requirements.

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GLOSSARY

Term	Definition
BAT	Best Available Technology
CY	Calendar Year
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
ESG	Environmental, Social and Governance
FY	Financial Year (1 April to 31 March)
GHG	Greenhouse Gas
HBI	Hot-Briquetted Iron
HDRI	Hot Direct Reduced Iron
IFRS	International Financial Reporting Standards
IPCC	Intergovernmental Panel on Climate Change
JSIS	Jindal Shadeed Iron and Steel LLC
JSPL	Jindal Steel and Power Limited
KASA	KASA Consulting
NGER	National Greenhouse and Energy Reporting (Australian)
QTB	Quenched and Tempered Bar
SF_6	Sulphur Hexafluoride
SIS	Shadeed Iron & Steel
Sm^3	Standard Cubic Metres
SMS	Steel Melting Shop
SRM	Steel Rolling Mill
TPI	Transition Pathway Initiative

EXECUTIVE SUMMARY

Jindal Shadeed Iron and Steel LLC (JSIS) commissioned KASA Consulting (KASA) to undertake the following scopes of work:

- Completion of a greenhouse gas (GHG) verification and estimate for all emission sources at the organisation's production facility located in the Sohar Industrial Port;
- Based on production projections and planned abatement measures, project GHG emissions and GHG intensity for the organisation up to the financial year 2029/30;
- Encompass the above in a Climate Change Strategy for the facility.

This document presents JSIS Climate Change Strategy.

JSIS integrated steelworks is based on MIDREX Iron's Hot-Briquetted Iron (HBI) and Hot Direct Reduced Iron (HDRI) technologies which are acknowledged as "state-of-the-art" methods of steel production. Primary activities associated with JSIS production facilities that influence GHG emissions include:

1. Direct Reduced Iron Plant;
2. Steel Melting Shop;
3. Steel Rolling Mill; and
4. Other ancillary / support facilities.

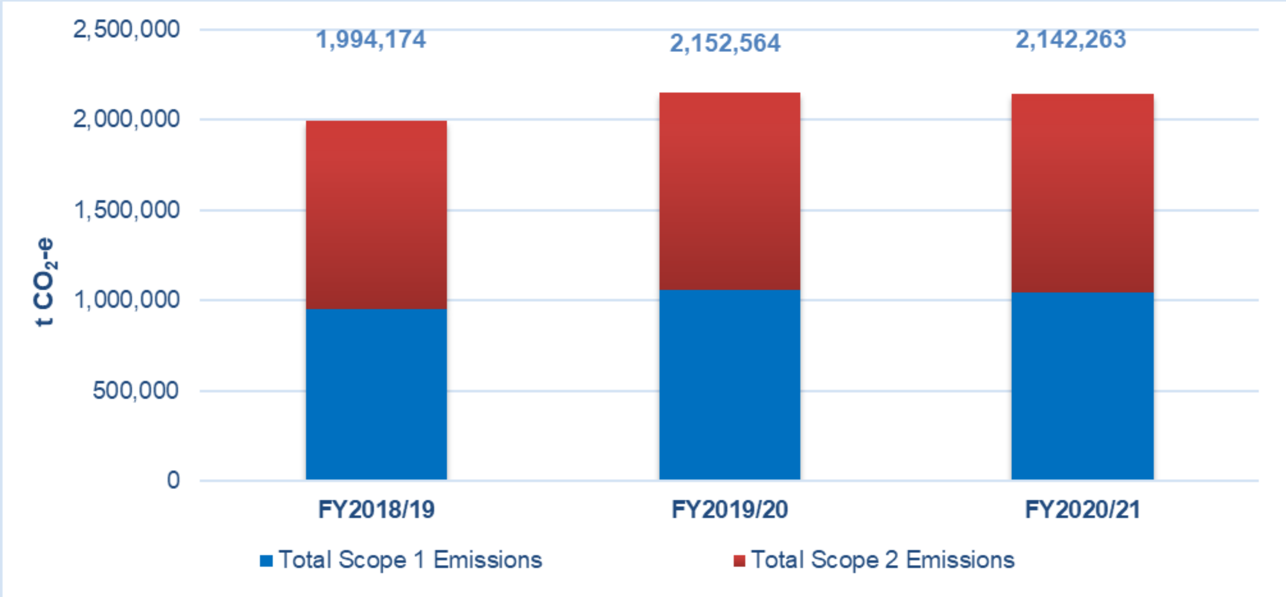
GHG emissions generated from each of those Departments are sourced from the consumption of:

- Electricity;
- Natural gas;
- Liquid fuels (petrol and diesel); and
- Sulphur hexafluoride (SF_6) switchgear.

The GHG verification process achieved the following:

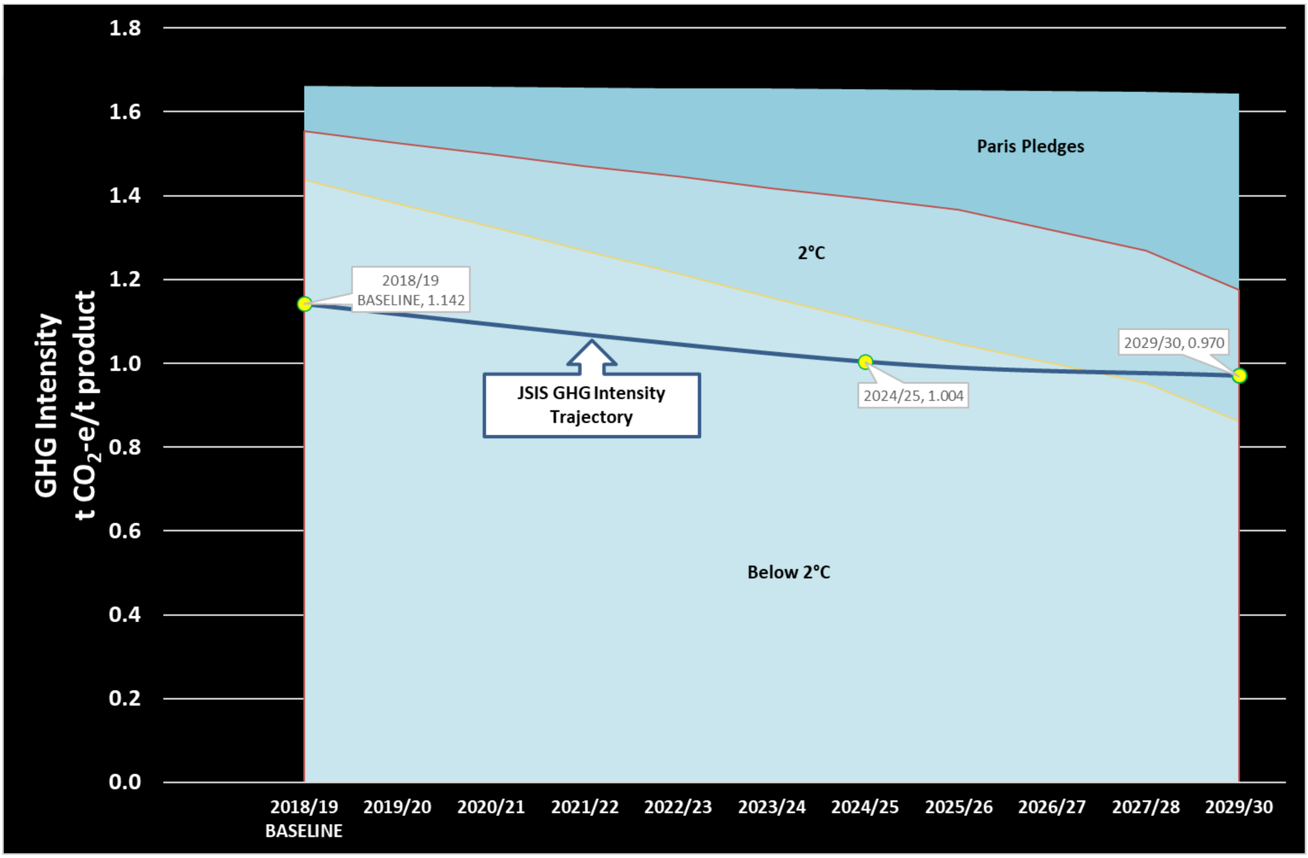
1. Characterisation of key potential GHG pollutants emitted from project activities was achieved using actual input data from JSIS for the period FY2018/19 (Baseline) to FY2020/21;
2. GHG emission sources have been identified and accurately estimated across the facility;
3. Calculation of Scope 1 and Scope 2 GHG emissions from all sources using published calculation methodologies and emission factors defined in adopted published literature (specifically the Australian *National Greenhouse and Energy Reporting Scheme Measurement Technical Guidelines for the estimation of emissions by facilities in Australia* (CER, 2017) as consistent with IPCC provisions;
4. Calculated GHG emissions for FY2018/19 (Baseline) to FY2020/21 are shown in Insert 0-1 below. Total greenhouse emissions range between 1.97 Mt CO_2-e per annum to 2.14 Mt CO_2-e per annum;

Insert 0-1: Comparison of 2018/19-2020/21 Emissions
All Department Areas (including DRI, SMS, SRM)



5. The application of existing production data in conjunction with calculated GHG emissions determined that the GHG intensities (i.e., quantity of CO_2-e generated per tonne of product were as follows:
   - **FY2018/19 (BASELINE):** 1.142 t CO_2-e per tonne of product
   - **FY2019/20:** 1.129 t CO_2-e per tonne of product
   - **FY2020/21:** 1.057 t CO_2-e per tonne of product
6. Preliminary comparison against studies by the International Energy Agency (IEA) has reported typical intensities between 1.6 to 2.2 t CO_2-e/t of product averaging 1.4 t CO_2-e/t of product in 2019 (IEA, 2021).
7. The global Transition Pathway Initiative (TPI) presents carbon performance trajectories for the steel sector that align with the goals of the Paris Agreement, 2°C and Below 2°C" benchmarks. Insert 0-2 depicts JSIS performance against these benchmarks and demonstrates that the organisation is well placed relative to these benchmarks.

Insert 0-2: JSIS GHG Intensity Trajectory relative to TPI Benchmarks (FY2018/19 – FY2029/30) All Department Areas (including DRI, SMS, SRM)



The assessment concluded that:

- JSIS systems for data collation and recording are sufficiently robust to inform GHG emission calculations and analyses;
- JSIS facility emissions are commensurate with operations that adopt the use of Best Available Technology (BAT) in production of steel; and
- JSIS GHG intensity performance exceeds available published data for other steel plants globally.

Based on the outcomes of the above findings JSIS defined its projections for production of crude steel as well as proposed abatement measures up to FY2029/30. This information was used to complete the following as detailed in this report:

1. Estimate forecasted gross GHG emissions and GHG intensity for the facility up to FY2029/30 in Mt CO_2-e/annum.
2. Estimate the impact of proposed abatement measures, specifically the replacement of purchased electricity from the grid to renewable electricity purchases in reducing net GHG emissions from the facility;
3. Develop a Climate Change Strategy that galvanises the above commitments to GHG reductions, proposed performance indicators and milestones for the facility up to the year FY2029/30.

Table 0-1 below summarises the projected GHG reductions and target GHG intensity for JSIS as encompassed in the JSIS Climate Change Strategy.

Table 0-1: Projected GHG Emissions and Intensity Target at FY 2024/25 and FY2029/30

Year	FY2018/19 Baseline	FY2024/25	FY2029/30
GHG ($MtCO_2$-e/annum)	1.994	2.515	2.557
Production (Mtpa)	1.746	2.38	2.42
Abatement Project		**Renewable Electricity Purchases in Place**	
Abatement Qty ($MtCO_2$-e/annum)	0	0.126	0.210
Net ($MtCO_2$-e/annum)	1.994	2.389	2.347
TARGET GHG Intensity tCO_2-e/t	**1.142**	**1.004**	**0.970**

1 INTRODUCTION

1.1 Purpose

Jindal Shadeed Iron and Steel LLC (JSIS) has commissioned KASA Consulting (KASA) to assist with its development of a Climate Change Strategy for the organisation's production facility located in the Sohar Industrial Port.

The Climate Change Strategy draws upon the outcomes of the GHG estimation and projections to the year FY2029/30 and offers a framework for JSIS to work towards a long-range forecast to achieve a net zero CO_2-e emissions goal by 2050.

1.2 Scope

In order to develop a robust Climate Change Strategy including targets to be met, KASA Consulting was engaged by JSIS to estimate its current GHG emissions and intensity using a sample period of FY2018/19 to FY2020/21. The independent analysis applied a comprehensive gap analysis and robust calculation methodology to provide a statement of current emissions for identified GHG emissions.

The GHG estimation process was informed by a review of existing estimates completed by JSIS for financial years FY2018/19 through FY2020/21[1], and includes:

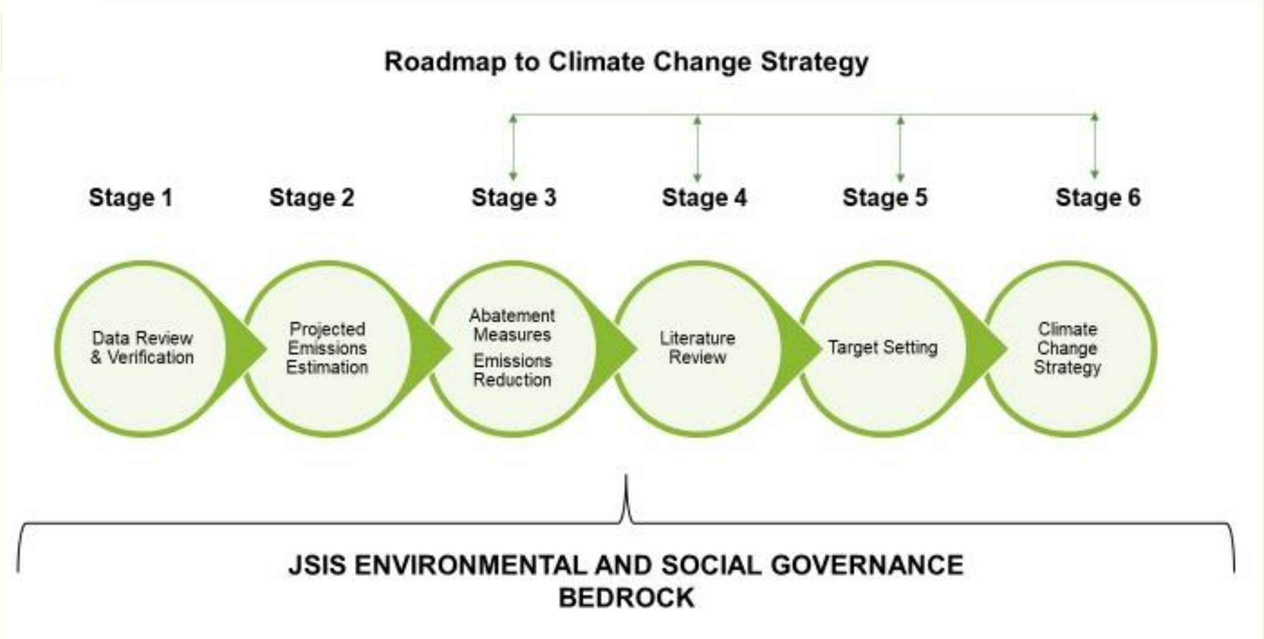
1. Confirmation of a full and transparent characterisation of the range of potential GHG pollutants emitted from project activities;
2. Confirmation that GHG emission sources have been adequately characterised in order to accurately estimate Scope 1 and Scope 2 GHG emissions associated with relevant JSIS activities;
3. Calculation of Scope 1 and Scope 2 GHG emissions from all sources using published calculation methodologies and emission factors; and
4. Review of the application of existing production data relative to GHG emissions to determine the GHG intensities (i.e., quantity of CO_2-e generated per tonne of product produced overall and by main Department Areas.
5. Estimate forecasted gross GHG emissions and GHG intensity for the facility up to FY2029/30 in Mt CO_2-e/annum on the basis of forecasted production data supplied by JSIS to FY2029/30.
6. Estimate the impact of adopted abatement measures, specifically the replacement of purchased electricity from the grid to renewable electricity purchases in reducing net GHG emissions from the facility;
7. Develop a Climate Change Strategy that galvanises the above commitments to GHG reductions, proposed performance indicators and milestones for the facility for FY2024/25 up to the year FY2029/30.

[1] Financial Years (FY) are defined as the period 1 April to 31 March each year in accordance with International Financial Reporting Standards (IFRS) reporting requirements including Sustainability Reporting.

Further detail on the assessment methodology is summarised in Section 4 below with a full presentation of the GHG assessment documented in the Greenhouse Gas Assessment (KASA Consulting, 2021).

Insert 1-1 illustrates the sequence of tasks applied in order to complete the scope of work to achieve the Climate Change Strategy.

Insert 1-1: Roadmap for Development of Climate Change Strategy



2 BACKGROUND

2.1 Company Overview

JSIS is the largest integrated steel plant in Oman, strategically located in the ancient port city of Sohar. The JSIS integrated steelworks is situated on a 120 ha jetty-base prime property, next to Sohar Container Terminal and adjacent to the busy Muscat-Dubai highway (Figure 2-1).

JSIS is a fully-owned subsidiary of Vulcan Steel (Mauritius).

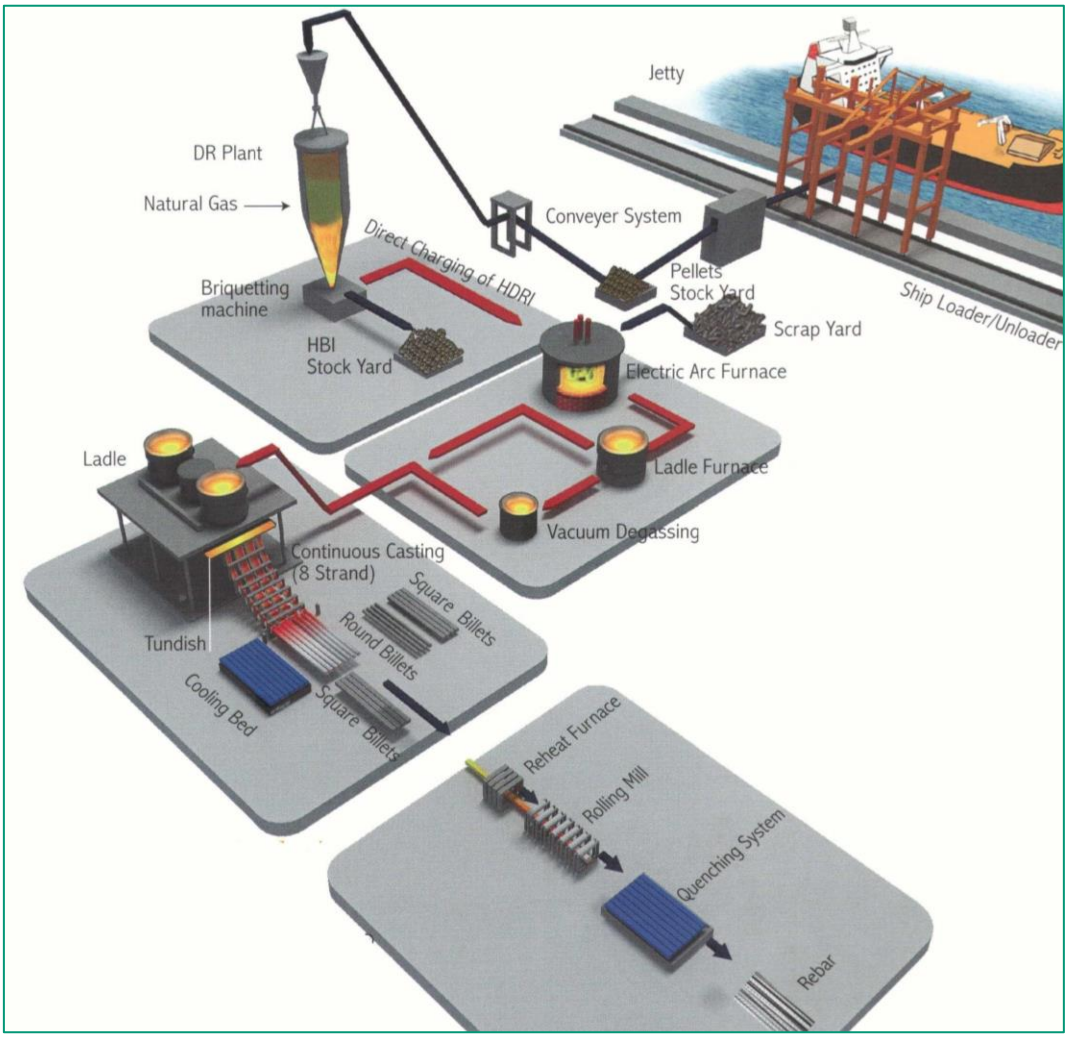
2.2 Process Description

The JSIS integrated steelworks is based on MIDREX Iron's Hot-Briquetted Iron (HBI) and Hot Direct Reduced Iron (HDRI) technologies which are acknowledged as "state-of-the-art" methods of steel production.

Figure 2-2 illustrates the high-level process overview for the current facility, and the production areas are further described in the sections below.

Figure 2-1: Regional Location

Figure 2-2: Current Process Overview



2.2.1 Direct Reduced Iron Plant

Direct reduction involves the production of solid primary iron from iron ores and a reducing agent (e.g., natural gas). The solid Direct Reduced Iron (DRI) product is mainly applied as feedstock via a gravity feed system of HDRI to an Electric Arc Furnace (EAF).

The JSIS integrated steelworks includes one DRI plant with a capacity of 1.8 Mtpa. The DRI plant comprises a vertical shaft furnace, reformer, heat recovery unit, seal gas system and a natural gas pre-treatment system. The spent gas from the furnace and the flue gas from the reformer are effectively re-used within the process to eliminate waste gas from the process.

2.2.2 Steel Melting Shop

The Steel Melting Shop (SMS) consists of steel making facilities with production capacity of 2.4Mtpa comprising of:

- 200t Electric Arc Furnace;
- 200t Ladle Refining Furnace;
- 200t Vacuum Degassing Unit; and
- Two continuous casters to produce square and round billets / blooms.

2.2.3 Steel Rolling Mill

The JSIS facility includes a 1.4 Mtpa Steel Rolling Mill (SRM) for the production of rebar using quenched and tempered bar (QTB) and self-tempering technology.

The SRM includes:

- Reheating Furnace;
- High Pressure Descaler;
- H-V combination Rolling Mill; and
- Heat treatment equipment with QTB technology.

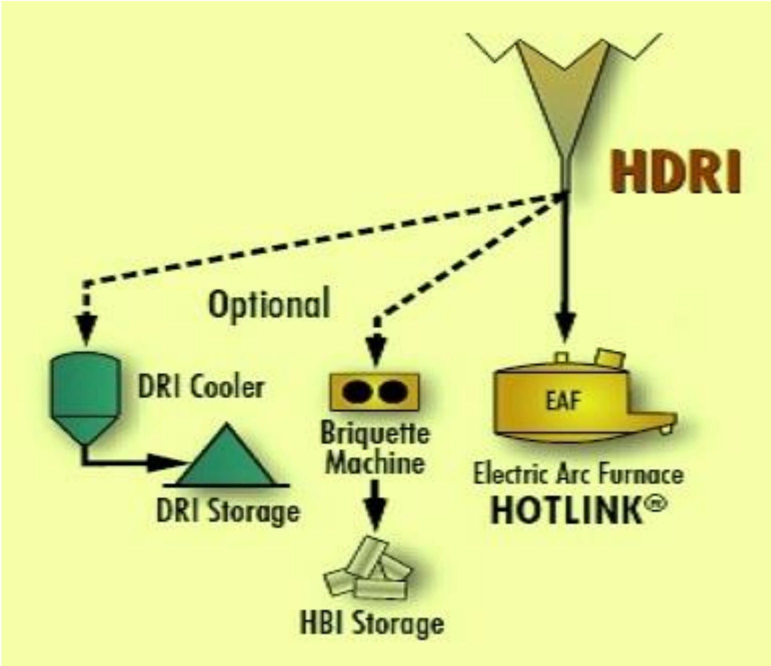
2.3 Energy and GHG Mitigation Initiatives Completed to Date

As stated in Section 2.2, JSIS has established and is operating a State-of-the-Art facility that already has in place a range of Best Available Technologies (BAT) to optimise production and efficiency. A review of adopted technologies against published literature summarised in Appendix A confirmed this, with the initiatives that contribute to existing energy efficiency and GHG mitigation summarised in Table 2-1:

Table 2-1: Energy and GHG Mitigation Initiatives Completed to Date

Area	Initiative	Detail[2]
General measures for energy efficiency improvements	Preventive maintenance	JSIS implements procedures for regular and routine maintenance of its equipment and assets in order to optimise their performance and efficiency, keep them running and prevent any costly unplanned downtime from unexpected equipment failure.
	Energy monitoring and management system	JSIS has installed metering systems to continuously monitor its energy (natural gas and electricity) consumption and is able to identify and address potential situations that result in reduced efficiency in energy consumption.
	Combined heat and power cogeneration	Cogeneration or CHP (Combined Heat and Power) solutions installed at JSIS facility are designed to generate both heat and power increasing overall power plant efficiency.
	High-efficiency motors	JSIS has installed high efficiency motors that maximise the motors' efficiency compared to standard motors by reducing resistance and other losses.
DRI	Hot link technology for feeding hot DRI to Steel Melt Shop	A major initiative to maximise energy efficiency at the JSIS DRI is the use of Hot Link technology where DRI is discharged from the vertical shaft furnace at a temperature of around 700 deg C and transported in hot condition to the steel melting shop for charging of DRI directly in electric arc furnace (EAF) in hot condition. The charging of hot DRI in EAF directly from a vertical shaft DRI kiln is known as hot charging. This offers less requirement of energy in the EAF for heating the DRI to its melting temperature and offers a substantial increase in productivity of EAF due reduced tap to tap time and hence the heat duration. The key environmental benefit of hot DRI charging is through retaining the sensible heat in the DRI rather than dissipating it to the atmosphere thereby lowering overall emissions in two ways. First, the lower electricity demand reduces power plant emissions per ton of steel produced. Second, for those EAFs employing carbon injection, reduced energy requirements in the EAF result into less CO_2 given off.

[2] Major Source: Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Iron and Steel Industry (USEPA, 2012)

Area	Initiative	Detail[2]
		This process uses primarily gravity transport and was pioneered by Midrex®. This process uses the same technology as used for gravity feed of HDRI for HBI production. The HDRI from the DRI shaft kiln is discharged into a surge bin outside and above the steel melting shop. From this surge bin HDRI is directly gravity fed to the EAF. HOTLINK modules are equipped to handle any upset conditions via the surge bin. This system supply HDRI to the EAF as per the demand of the EAF. HOTLINK process is used when the distance between the DRI shaft kiln and the EAF is less than 40 meters. The process is shown schematically below. 

Area	Initiative	Detail[2]
DRI (Cont'd)	General	• Installation of capacitor bank in PGC electrical circuit & decrease in power consumption. • Switch over of seal gas compressor to Liquid ring compressor & reduction in power. • Addition of super heat NG in Process gas compressor suction & reduction in power. • Minimizing HBI generation by Generating Maximum HDRI resulting in savings in power.
SMS	Ultra-high-power transformers	JSIS has installed Ultra-high–power (UHP) transformers which help to reduce energy loss and increase productivity.
	Bottom steering/steering gas injection	Bottom stirring is accomplished by injecting an inert gas into the bottom of the EAF to increase the heat transfer in the melt. In addition, increased interaction between slag and melt leads to an increased liquid metal yield of 0.5 percent. Furnaces with oxygen injection are sufficiently turbulent, reducing the need for inert gas stirring. The increased stirring can lead to electricity savings of 10 to 20 kWh/ton (0.04 to 0.08 GJ/tonne).
	Foamy Slag practice	Foamy slag covers the arc and melt surface to reduce radiation heat losses. Foamy slag is obtained by injecting carbon (granular coal) and oxygen or by lancing of oxygen only. Slag foaming increases the electric power efficiency by at least 20 percent in spite of a higher arc voltage.
	Oxy- fuel burners	Oxy-fuel burners increase the effective capacity of the furnace by increasing the speed of the melt and reducing the consumption of electricity and electrode material, which reduces GHG emissions.

Area	Initiative	Detail[2]
	Engineered refractories	Refractories in EAF have to withstand extreme conditions such as temperatures over 2,900°F (1,600°C), oxidation, thermal shock, erosion and corrosion. These extreme conditions generally lead to an undesired wear of refractories. Engineered refractories can be either sintered or cast and are therefore be used in a wide range of components at EAF mills (e.g., furnace, ladle furnace, vessels). The refractories can reduce ladle leakages and the formation of slag in transfer operations with savings of 10 kWh/ton (0.04 GJ/tonne) steel.
	VSD's and Flue gas monitoring and control	The use of variable speed drives (VSD's) can reduce energy usage of the flue gas fans, which in turn reduces the losses in the flue gas.
	Eccentric bottom tapping	Eccentric bottom tapping leads to slag-free tapping, shorter tap-to-tap times, reduced refractory and electrode consumption, and improved ladle life. Associated energy savings can be estimated to be 13.6 kWh/ton (0.054 GJ/tonne).
	Efficient ladle preheating and tundish heating	In this initiative JSIS preheat the ladle of the caster with gas burners and prevent heat losses that can occur through lack of lids and through radiation. These losses are reduced by installing temperature controls, installing hoods, by efficient ladle management (reducing the need for preheating), using recuperative burners, and using oxy-fuel burners. Tundishes are heated to reduce the heat loss of the molten steel, to avoid bubbles in the first slab at the beginning of the casting sequence, and to avoid degeneration of the refractory due to thermal shocks.
	Additional general measures	• Hot DRI to Steel melt shop via gravity feeding at temp > 600 deg C. • Increase Hot DRI storage capacity from 240T (1 bin) to 600 Tons (total 3 bins till 2020). • Installation of 4th Bin for Hot DRI –smaller buffer vessel to increase hot DRI further > 630 deg C.

Area	Initiative	Detail[2]
		• Side wall injection of oxygen in Electric arc furnace to reduce electrical power • State of art electrode regulation system, to maximize power factor of transformer • Foamy slag practice by injecting carbon from side walls. • Both caster facilities having arrangement of direct Hot charging to rolling mill for saving Natural Gas. • Installation of Cold setting facility for Tundish preparation , eliminating drying requirement of tundish
Hot Rolling Mill	Proper heating temperature	JSIS target heating temperature in the rolling mill in order to balance the many permutations that arise from the combination of rolling equipment, temperature, steel grade, desired end shape, cooling water temperature, etc., and to maximise energy gains from varying heat levels.
	Avoiding overload of rate furnaces	Overloading a furnace can lead to excessive stack temperatures. To achieve the proper rate of heat transfer, JSIS ensures combustion gases remain in the heating chamber for the right amount of time. This can be to the detriment of achieving ambitious production goals but come at the cost of excessive fuel consumption. The overload problem can be corrected by improving heat transfer or not operating in a mode that strives for overly ambitious production goals. Overloading a reheat furnace with billets will typically reduce mill production rates and is not considered an economical operation in the long term. Avoiding overloading with respect to the fuel feed minimises the risk of increased emissions from the furnace.
	Hot charging	Hot charging is the process of heating slabs prior to charging them into the reheating furnace of the hot mill. The higher the preheat temperature, the greater the energy savings in the hot mill furnace.

Area	Initiative	Detail[2]
	Flameless burners	Flameless air-fuel combustion uses air as oxidizer, while flameless oxy-fuel uses commercial oxygen as an oxidant. This technology carries out combustion under diluted oxygen conditions using internal flue gas recirculation and the flame becomes invisible. Flameless oxy-fuel gives high thermal efficiency, higher levels of heat flux, and reduced fuel consumption compared to conventional oxy-fuel
	Insulation of furnaces	JSIS has not utilised conventional insulating materials but instead adopted the use of ceramic low-thermal–mass insulation materials which reduce the heat losses through furnace walls. The potential energy savings for insulating a continuous furnace have been estimated to range from 2 to 5 percent, or approximately 0.16 GJ/tonne of product
	Walking beam Furnace	A walking beam furnace represents the state-of-the-art of efficient reheating furnaces. Here, the stock is placed on stationary ridges and a revolving beam walks the product along through the furnace until the exit where the beam returns to the furnace entrance. The use of this furnace can result in a reduction in electricity usage by 25 percent per tonne produced and a reduction in overall fuel consumption by 37.5 percent per tonne produced compared to alternative furnaces.
	Controlling Oxygen Levels and Variable Speed Drives on Combustion Air Fans	Controlling oxygen levels and using VSDs on the combustion air fans on the reheating furnace helps to optimize combustion in the furnace.
	Rolling mills Energy-efficient drives	The semi-finished steel products from the casting operations are further processed to produce finished steel products in a series of shaping and finishing operations in the JSIS rolling mill. Mechanical forces for cold rolling will create much more force and energy needs, while hot rolling happens much faster with less forces; however, there are significant energy costs to heat the metal to near eutectic temperatures. High-efficiency alternating current (AC) motors employed by JSIS can save 1 or 2 percent of the electricity consumption of conventional AC drives. Electricity savings have been estimated to be 3.6 kWh/ton (0.014 GJ/tonne) of hot rolled steel.

Area	Initiative	Detail[2]
	Additional general measures	• Adhering to the practice to switch off the pre-set of stand motors if Mill is stopped for more than 15 Minutes. • Timers have been installed in Shed Lights for automatic switching OFF & ON of lights during Day & Night. • Timers have been installed in Trafo rooms for automatic switching OFF & ON of lights during Day & Night • Optimizing & monitoring Air-Fuel ratio regularly in Reheating Furnace to reduce the NG consumption. • Making 95 to 98% of the hot charging based on the availability of Caster • Using Pause Function in RHF Level-2 during Mill stoppage to decrease and increase the temperature set points gradually. • Regular monitoring and controlling Furnace pressure. • Running RHF in PHL mode for better control of temperature resulting in better fuel efficiency.

3 DEFINITIONS

3.1 Scope 1 Emissions

Scope 1 greenhouse gas emissions are the emissions released to the atmosphere as a direct result of an activity. Scope 1 emissions are sometimes referred to as direct emissions. Examples are:

- Emissions from the burning of diesel fuel in mobile or stationary equipment;
- Emissions from consumption of petrol or diesel transport fuels;
- Consumption of natural gas, e.g., in direct reduction furnaces;
- Direct emissions produced from the manufacturing processes; and/or
- Leakage of sulphur hexafluoride (SF_6) from selected electrical switchgear used on the premises.

3.2 Scope 2 Emissions

Scope 2 greenhouse gas emissions are the emissions released to the atmosphere from the indirect consumption of an energy commodity. For example, 'indirect emissions' come from the use of electricity produced by the burning of fossil fuels in another facility.

Scope 2 emissions from one facility are part of the Scope 1 emissions from another facility.

For example, a power station burns fossil fuels to power its generators and in turn creates electricity. Burning of fossil fuels causes greenhouse emissions to be emitted; these gases are attributed to the power generator as Scope 1 emissions. If the electricity is then transmitted to a downstream user and used there to power equipment, the gases emitted as a result of generating the electricity are then attributed to the mine as Scope 2 emissions.

This assessment assumes that Scope 2 emissions associated electricity consumption are directly related to that purchased from the grid, and therefore appropriate emissions estimation methodology for ‘purchased electricity’ has been applied.

3.2.1 Sewerage and Domestic Wastes

Whilst estimates of emissions from sewerage and domestic waste have been made as a conservative approach, it should be noted that these emissions have been excluded from JSIS baseline or projected emissions calculations in this Climate Change Strategy document.

4 ASSESSMENT METHODOLOGY

4.1 Emissions Estimation Methodology

In order to undertake an estimation of GHG from JSIS operations, it is typical to utilise established calculation methodologies including the use of appropriate energy and emission factors as relevant and specific to the nation or region in which the operation is located. Whilst the Oman Department of Climate Change Adaptation serves to advise and regulate emissions from industry in the Sultanate of Oman, documented guidance on Government mandated methodologies has yet to be published.

Accordingly, KASA Consulting has adopted methodologies and guidance for emissions determinations using well established Australian guidance.

GHG emissions for the proposal are based on methodologies and emission factors for determining Scope 1 and 2 emissions as defined in the Australian *National Greenhouse and Energy Reporting (NGER) (Measurement) Determination 2008* as amended (CER, 2019), with due reference to the most recent NGER Technical Guidelines (for 2018-19) (CER, 2017).

These guidelines were developed by the Australian Clean Energy Regulator (formerly the Australian Greenhouse Office) who were contributors to the development of the *Greenhouse Gas Protocol - A Corporate Accounting and Reporting Standard* (World Resources Institute, 2015). The adopted Australian Guidelines are more recent that the Greenhouse Gas Protocol and the emissions estimation methodologies are consistent with the key principles relating to GHG accounting defined in the protocol i.e. Relevance, Completeness, Consistency, Transparency and Accuracy.

A review of JSIS production process has identified the following key activities that would contribute to GHG emissions:

- Consumption of natural gas primarily within the DRI, SMS and SRM departments;
- Diesel and petrol consumption in operations activities light and heavy vehicles;
- Consumption of electricity purchased from the grid primarily in the SMS, DRI and SRM Department Areas including the desalination plant, water treatment plant, air separation plant, the sea water intake substation and other auxiliary components; and
- Leakage of SF_6 from switchgear.

In sourcing data to analyse and inform emissions estimation, KASA Consulting undertook a gap analysis of information and data required from JSIS against that provided for the assessment. The gap analysis determined that sufficient data and information was available from JSIS to ensure a high degree of confidence in the calculated emissions.

While conservative estimates were made of the following, they were not included in the scope or projections in the Climate Change Strategy:

- Methane emissions from sewerage and domestic wastewater; and
- Methane and nitrous oxide emissions from domestic (putrescible) solid waste.

A full description of the adopted calculation methodologies is provided in the Greenhouse Gas Assessment (KASA Consulting, 2021).

5 CURRENT GREENHOUSE EMISSIONS STATEMENT

5.1 Greenhouse Gas Emissions Sources

The key Departmental Areas associated with production of steel at JSIS include:

- Direct Reduced Iron Plant
- Steel Melting Shop
- Steel Rolling Mill

Primary contributors to GHG emissions from each departmental area are summarised in Table 5-1 below, which presents FY2020 totals:

Table 5-1: Calculated GHG (t CO_2-e) by Key Departmental Areas (FY2018/19 Baseline)

Department	Electricity t CO_2-e	NG t CO_2-e	Total t CO_2-e	Production tonnes
DRI	114,799	881,182	995,981.7	1,548,297
SMS	782,171	17,252	799,423.4	1,746,424
RM	69,917	53,062	122,979.5	1,146,664
Ancillary	74,596		75,789 (incl SF_6, transport/mobile equipment fuels)	
OVERALL	**1,041,483**	**951,496**	**1,994,174**	**1,746,424**

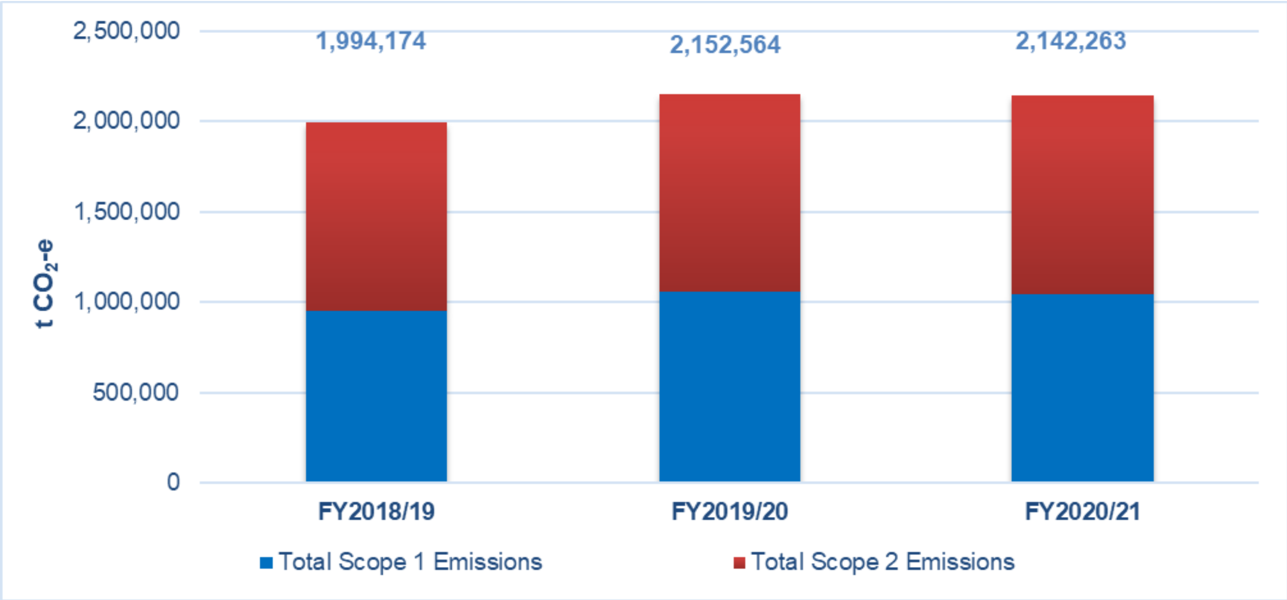
Further detail on the raw data inputs to the emissions estimation are presented in the Greenhouse Gas Assessment (KASA Consulting, 2021).

5.2 Calculated Greenhouse Gas Emissions

Insert 5-1 presents total Scope 1 and Scope 2 emissions for the years FY2018/19 to FY2020/21.

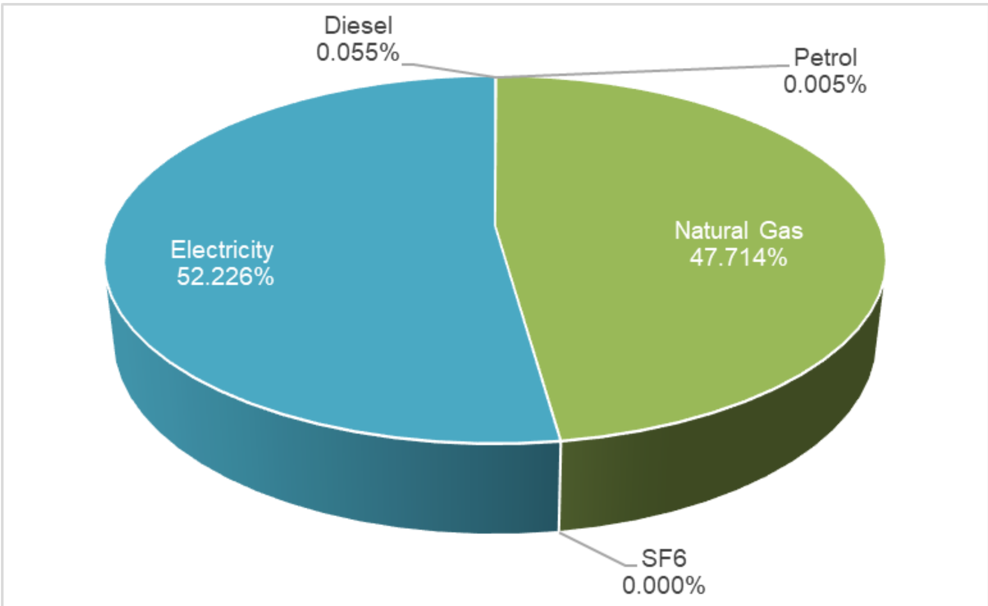
The data represents contributions from all Departmental Areas (including DRI, SMS and SRM) and shows that GHG emissions are generally consistent year on year.

Insert 5-1: Results Comparison – FY2018-FY2020 Emissions
All Department Areas (including DRI, SMS, SRM)



Insert 5-2 depicts the breakdown in GHG emissions by source for the year FY2018/19. The data represents contributions from all Departmental Areas (including DRI, SMS and SRM) The data clearly demonstrates that the GHG emissions profile is dominated by the consumption of electricity and natural gas, particularly attributable to the SMS and DRI production departments respectively.

Insert 5-2: CO_2-e Breakdown – FY2018/19 (Baseline)



5.3 GHG Emission Intensity Estimates

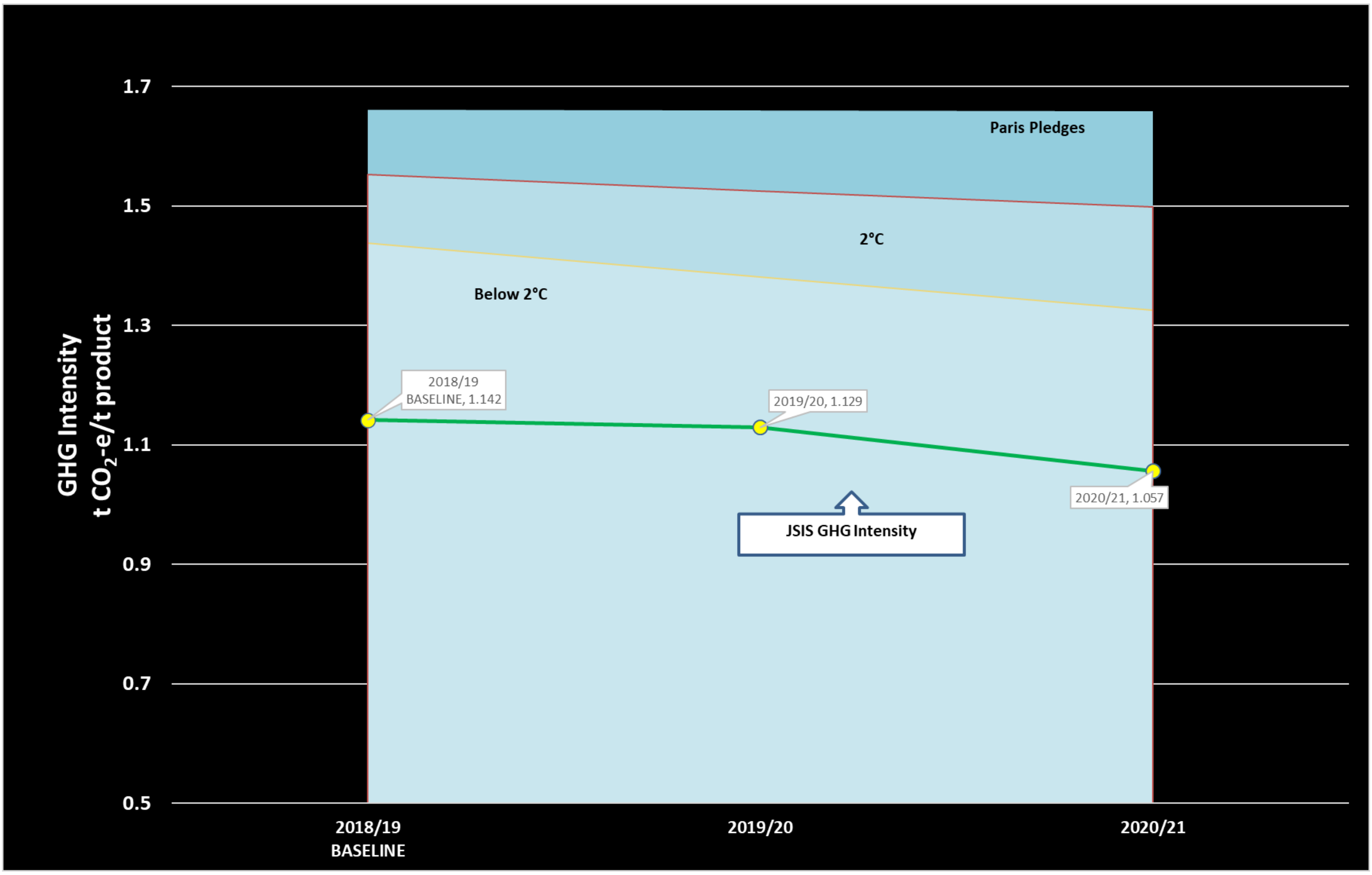
GHG intensity is the measure of the tonnes of CO_2-e emitted per tonne of product produced. The measure allows for analysis of the performance of each departmental area and the overall facility relative to other similar operations at other facilities. The higher the GHG intensity, the greater the volume of CO_2-e emitted in the generation of each tonne of product.

In order to provide context and to benchmark JSIS' emissions intensity performance, reference is made to the Transition Pathway Initiative (TPI) which is a global initiative led by asset owners and supported by asset managers (TPS, 2021). Aimed at investors, it assesses companies' preparedness for the transition to a low-carbon economy, supporting efforts to address climate change. The TPI is noted as rapidly becoming the 'go-to' corporate climate action benchmark.

The TPI presents carbon performance trajectories for the steel sector that align with the goals of the Paris Agreement, 2°C and Below 2°C" benchmarks

Insert 5-3 depicts JSIS' performance against these benchmarks and demonstrates that the organisation's current baseline performance is well under these benchmarks based on current expectations.

Insert 5-3: JSIS Baseline GHG Intensity FY2018/19-FY2020/21
All Department Areas (including DRI, SMS, SRM)



6 CLIMATE CHANGE STRATEGY DEVELOPMENT

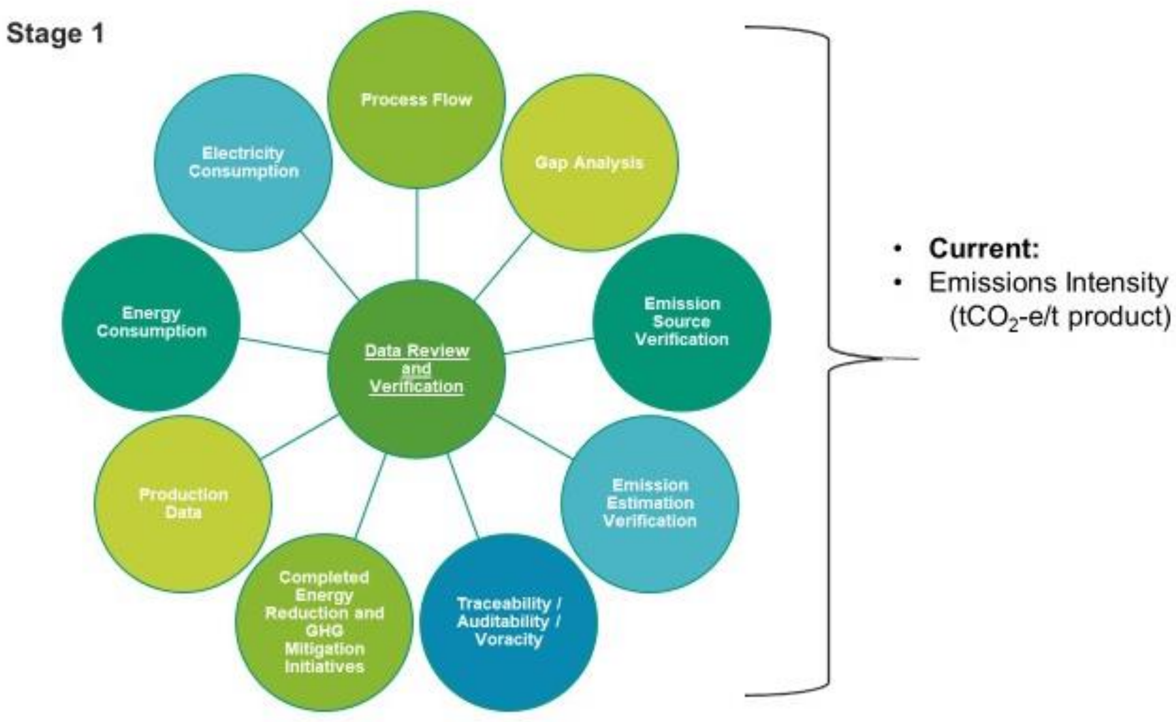
In recognition of the above current state of the global climate, many organisations are proactively seeking to improve their performance by reducing the greenhouse footprint of their activities. JSIS is committed to doing the same with an overarching goal of achieving a net zero CO_2-e greenhouse footprint by the year 2050. JSIS also commits to striving for intermediate targets to demonstrate progressive reductions in GHG emissions by setting a 2030 goal for its GHG intensity reduction .

To establish a framework to meet these goals, the following tasks have been implemented in order to fully inform a Climate Change Strategy that dovetails and is ratified in the organisation's Environmental and Social Governance principals.

6.1 Development Stage 1

As discussed, the first stage of development was to undertake a robust gap analysis and quantification of the current GHG emissions and intensity of JSIS activities. This was completed and presented in the Greenhouse Gas Assessment (KASA Consulting, 2021).

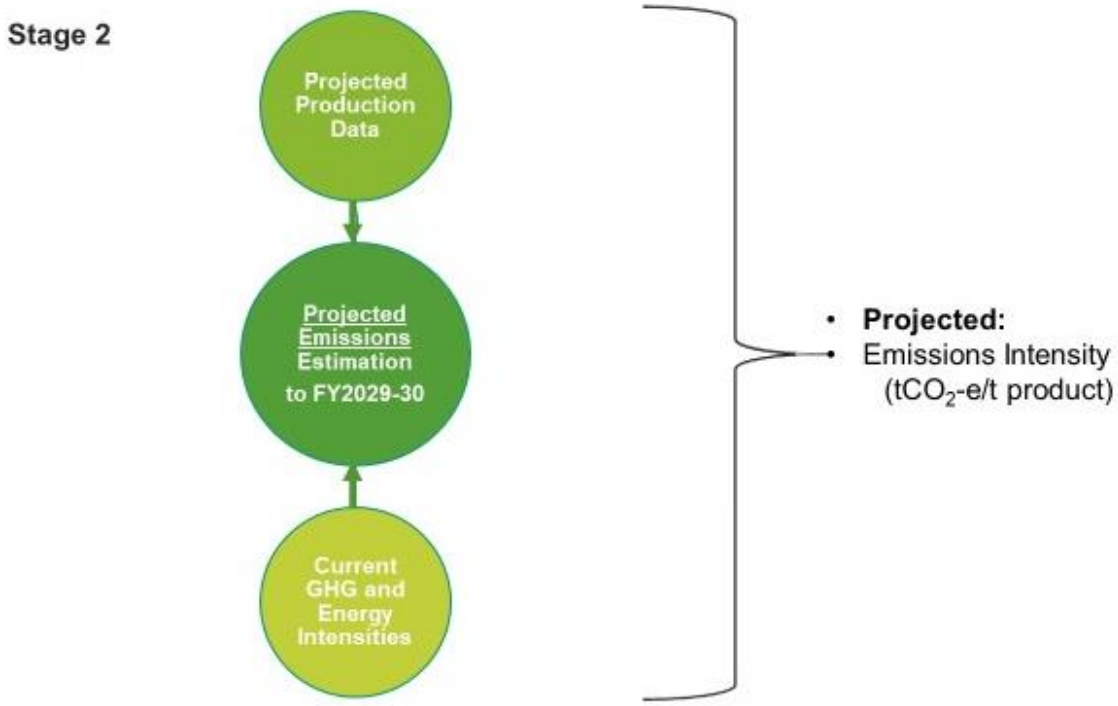
Insert 6-1: Strategy Development Stage 1



6.2 Development Stage 2

- JSIS applied forecasted production data to estimate extrapolated GHG emissions for the forthcoming period up to FY2030.

Insert 6-2: Strategy Development Stage 2

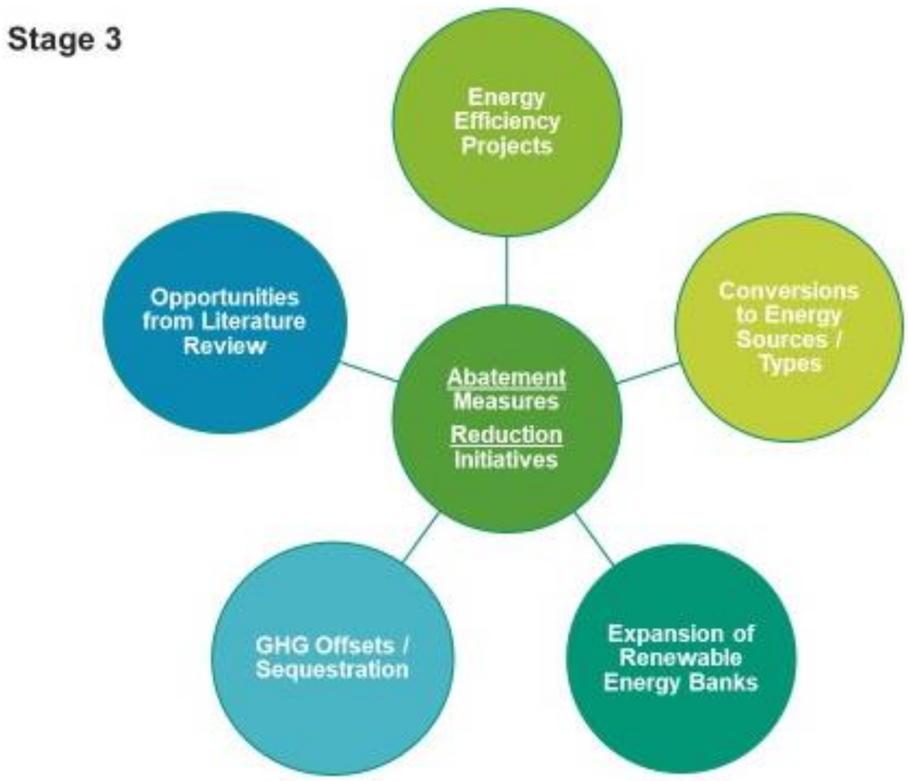


The outcomes of this forecast are presented in Section 7.2.

6.3 Development Stage 3

- A review of potential GHG abatement measures was undertaken with technical experts and subject matter experts within JSIS with a view to identifying projects that implemented over the forecasted operations window at FY2030 and FY2050.

Insert 6-3: Strategy Development Stage 3



A summary of the types of initiatives considered is provided as Appendix A.

As detailed in Section 2.3, many of the initiatives identified are already part of JSIS Business as Usual (BAU) given that the facility already utilises Best Available Technology to maximise energy efficiency and reduce potential GHG emissions.

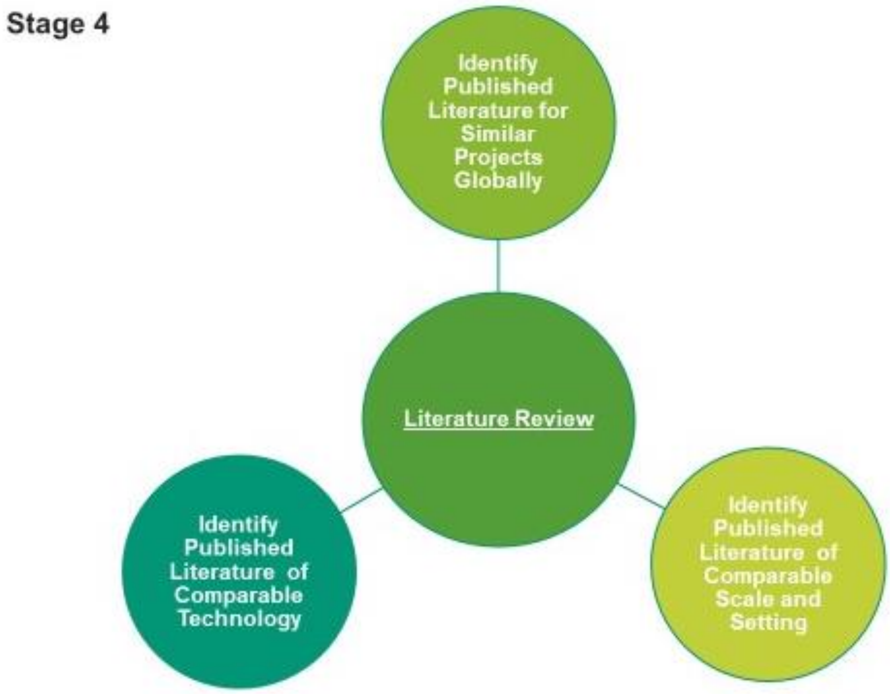
Of other potential projects identified, these were deemed not to be feasible relative to the cost-benefit they would bring relative to the potential to contribute markedly to achieving JSIS GHG reduction targets.

In order to realise its FY2029/2030 GHG emission targets, JSIS determined that the most feasible way to achieve this was to maximise potential offsets in its grid electricity consumption through renewable energy purchases. This would occur through purchase arrangements with the Omani Authority for Public Services Regulation by buying Green Energy generated from their Ibri II Solar PV project currently undergoing commissioning. Further discussion on this adopted GHG reduction project is presented in Section 7.

6.4 Development Stage 4

A comparison of emission intensity results against published literature for equivalent plant, equipment and operations globally was completed.

Insert 6-4: Strategy Development Stage 4



This process was conducted concurrently with Stage 3 in order to identify potential GHG emissions initiatives undertaken by other organisations that may be considered for adoption by JSIS.

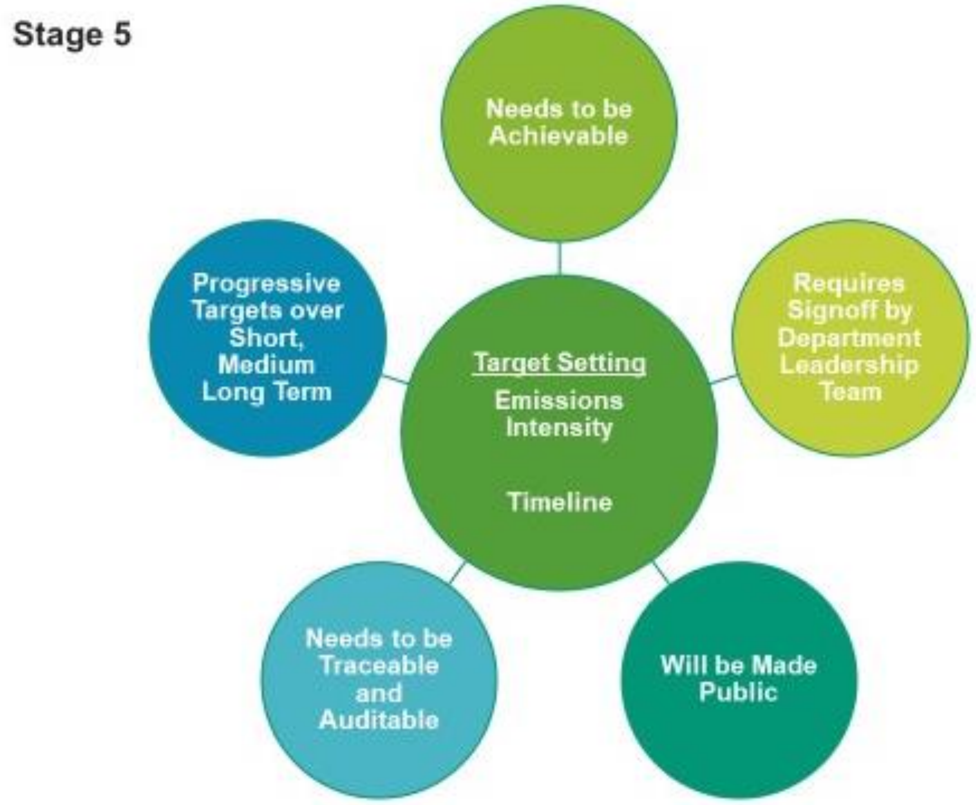
The review identified the fact that the current design and operating regime of JSIS' facility already meets, if not exceeds, Best Available Technology, and this is evident in comparison of current GHG intensities for JSIS relative to global published data.

6.5 Development Stage 5

Upon identification and commitment to JSIS' adopted GHG reduction project, the organisation has defined GHG intensity targets to be met by 2030, and an overall GHG emission goal to be achieved by 2050.

JSIS will ensure that these targets are traceable, measurable and auditable with progress audited by an independent reviewed on an annual basis.

Insert 6-5: Strategy Development Stage 5



7 CLIMATE CHANGE STRATEGY

On the basis of the above, a Climate Change Strategy (CCS) been developed in consultation with JSIS that defines initiatives to be adopted to mitigate projected GHG emissions and improve calculated the annualised GHG intensity for the facility.

The strategy is consistent with and fully integrated into the organisation's Environmental and Social Governance (ESG) framework, with performance reported on annually.

Insert 8-1 provides a roadmap to the key elements of the JSIS Climate Change Strategy.

Insert 7-1: Strategy Development Stage 6

7.1 Drivers for Climate Change Strategy

7.1.1 Jindal Shadeed Sustainability Policy

In developing this Climate Change Strategy, due recognition of the organisation's Sustainability principles upheld by JSIS have been considered and adhered to. As publicly stated by the company, JSIS has been an ardent advocate and practitioner of sustainable development since its inception and is whole-heartedly committed to improving its sustainability performance and making a positive difference in the society. JSIS aims to incorporate sustainability into its businesses by strengthening economic, social, environmental, human and governance pillars and mitigating the impact of operations.

JSIS Sustainability Objectives are summarised by the company as follows. The objectives presented in **bold** are nominated as those being targeted and directly relevant to this Climate Change Strategy:

- ***We have recognised climate change as one of the most pressing problems that is being felt across the globe. We are striving hard to avoid and manage climate-related risks and reduce our carbon emissions. We have implemented some of the most innovative technologies and best practices at our plants to address the various environmental issues and reduce our overall carbon footprint.***
- ***We are committed to achieve sustainable development goals and strive to build a strong and lasting relationship with our stakeholders, make investments to mitigate the effects that our operations have on the environment and incorporate transparency and accountability into our management policies and decisions.***
- *At the heart of our sustainability strategy lies our valuable employees and their safety. We have placed the utmost importance for the safety and well-being of our people. We are committed to carry out all our operations free from workplace hazards and occupational illnesses. We strive hard to implement world-class Global OHS Safety Standards, which provide a central framework for unit-specific safety management manuals, systems and procedures for all our stakeholders and employees.*
- **Embedding sustainability practices into our work, our people, the communities that we are a part of, in addition to our esteemed stakeholders would help us to carve out a sustainable path with defined actions and goals, that will contribute to a greener and cleaner future and a better living world.**

Objectives and Targets

- Objectives and targets are set on an annual basis for our operations to help drive improvements.

Environmental Objectives

- Level of SOx, NOx and Dust in exit gas from stacks, **Consumption of natural gas/tonne of production, power consumption/tonne of production, Waste generation/tonne of production, minimise environmental impacts on biodiversity,** Environmental measures to reduce eco toxicity.

Community and Social Responsibility

- **JSIS is committed to adhering to and raising its standards as part of its commitment to continuous improvement. Where national law and the standards defined are different, we follow the higher standard; where they conflict; we will adhere to the federal rules and regulations while seeking ways to respect the standards defined to the greatest extent possible.**
- **JSIS is an equal opportunity employer and provides equal opportunity to each individual with the same skill sets, promotes knowledge enrichment, and encourages employees to take time off to maintain the work-life balance.**
- **JSIS promotes workplace diversity and inclusion. JSIS invests in providing a healthy and safe work environment to each individual working. JSIS strictly rejects the ideas and practices of child labour, forced or bonded labour, human trafficking, and workplace harassment. Apart from this, JSIS is sensitive to respecting the local culture and customs. JSIS follows a culture of open and participative communication.**

Responsible Sourcing

- **Code of ethics for suppliers, trainings for suppliers on sustainability, Vendor evaluation, Supplier satisfaction survey, Vendor meets.**

Climate Change

- **Greenhouse Gas reduction initiatives, Conservation of energy, Low Energy Intensity, Low CO_2 Intensity, health and safety of employees, work-life balance, grievance.**

A copy of the company's Sustainability Policy is presented overleaf.

جندال شديد للحديد والصلب ش.م.م

Jindal Shadeed Iron & Steel LLC

SUSTAINABILITY POLICY

We at Jindal Shadeed value our stakeholders i.e. our employees, communities around our operations, customers and supply chain partners . Our sustainability endeavors would be incomplete without their active participation. We are committed for the sustainability principles i.e. Inclusivity, Integrity, Stewardship and Transparency in our day to day business. Towards this end, we strive to engage our stakeholder groups and respond to their concerns. Jindal Shadeed is committed to :

- Ensure transparency, fairness and equality in all our dealings with our stakeholders.
- Establish environmental management system to fulfill the all requirements and continual improvement in our environmental performance.
- Comply with all the legal requirements related to HSE, HR and all the departments of JSIS.
- Monitor and minimize transport impact. Reducing our travel emissions wherever possible.
- Optimize use of key resources including minerals, petroleum products, water and energy.
- Use water in sustainable manner by reusing waste water and reducing water consumption.
- Increase cooperation with neighboring facilities, authorities and local administrations on health, safety and environment issues.
- Maximize material efficiency, reuse, reduce and recycling of the wastes, resource optimization and innovation.
- Enhance awareness, skill and competence of our personnel so as to enable them to demonstrate their involvement, responsibility and accountability for sound SOH performance
- Motivate our Human Resources for superior performance and innovation through skill development and by providing them a safe, fair and challenging work environment.
- Serve community by meaningful engagement and proactive management, Partnering CSR initiatives through Donor Agencies /Project Implementing Agencies / Corporate Partners / Corporations / bodies. Providing maximum assistance during times of disasters. Providing employment to local Omanis.
- Investigate, implement and ensure the sustainability of greenhouse gas emission reduction methods.
- Continual improvement in all the performance areas like Quality, Safety, Environment and Sustainability.
- Establishing engagements with shareholders to understand and control risks and opportunities (based on control hierarchy), taking into account their anticipation and local economic effects.
- Ensure effective communication arrangement so as to ensure that our employees and other shareholders understand the responsibilities of Quality - Environment - Occupational Health and Safety, business ethics and anti corruption.
- Take precautions for sustainable resource use, mitigation of climate change, protection of ecosystem and biodiversity,
- Ethical business practices, good governance, accountability ,transparency, human rights, no child and forced labours.
- Strongly implement principles of business conduct, ethics, anti-corruption, anti-bribery and responsible sourcing in the supply chain. We are committed for fair treatment to our customers , suppliers, community, regulatory bodies, employees, investors and all our stakeholders.
- Pride ourselves on being an equal opportunity employer and not discriminating on the basis of race, caste, religion, color, ancestry, gender, marital status, sexual orientation, age, nationality, ethnic origin or disability.
- Follow the practice of non-engaging child workers . We don't engage or support the use of forced labour. We provide environment for the workforce to work voluntarily, without any threat of punishment or retaliation.
- Ensure that all employees take proactive steps to ensure that the overall working environment it provides are conductive for good mental health and employee wellbeing.
- The protection and promotion of the mental health and wellbeing of all employees.

Sanjay Anand

Date : 1st April 2021

Chief Operating Officer and Head

ص.ب ٤٠٤، الرمز البريدي ٣٢٢، فلج القبائل، سلطنة عمان، هاتف ٢٦٨٥٠٤٠٣ / ٢٦٨٥٠٤٥٩ ٩٦٨+، فاكس ٢٦٨٥٠٤٣٨ ٩٦٨+

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www.jindalshadeed.com

7.1.2 Oman Ministry of Environment and Climate Affairs

In its Second National Communication submitted to the United Nations framework Convention on Climate Change, the Oman Ministry of Environment and Climate Change Climate change acknowledged that climate change is projected to lead to changes in the physical and chemical environments and poses enormous direct or indirect risks to the sustainability of a range of Oman's sectors including infrastructure, agriculture, community health .

The report stated Oman understanding of the need to transition to a low carbon future that reflects new thinking, new frameworks, and new methods. The transition will also need to find practical ways to promote clean energy initiatives, facilitate access to new low-carbon technologies, and develop long-term partnerships to exploit sustainable energy opportunities.

7.2 Proposed Greenhouse Gas Emission Reduction Projects

On the basis of the above, JSIS has identified the most feasible and effective opportunity to reduce its contribution to greenhouse gas emissions, and to strive for a reduction in its GHG footprint in the short to medium term is through redirecting its sourcing of electricity demands for its operations away from fossil fuel generated electricity, and towards sustainable renewable energy sources.

As detailed in Section 5.2, over 50% of reported GHG emissions are associated with electricity consumption with resultant Scope 2 components in the order of 1.1Mt CO_2-e/annum, primarily associated with SMS processes.

7.2.1 Ibri Solar Project

As a proactive and accelerated measure to reduce its carbon footprint, JSIS has entered into advanced stage of dialogue with government agency (Authority for Public Services Regulation) to buy Green Energy directly out of the Ibri II Solar PV project currently undergoing commissioning.

The Ibri II is a 500MW photovoltaic (PV) solar power project located in the Ad-Dhahirah region of Oman. It will be the first utility-scale renewable energy facility in the Sultanate of Oman. The Ibri II independent power producer (IPP) project is being implemented under build, own and operate (BOO) model by the Shams Ad-Dhahira Generating Company, which is a special purpose vehicle (SPV) incorporated by ACWA Power (50%), Gulf Investment Corporation (40%), and Alternative Energy Projects (10%). The project is backed by a 15-year power purchase agreement with the Oman Power and Water Procurement Company (OPWP). Government is preparing the necessary legislation framework and energy wheeling policy for marketing and delivering the carbon-free electricity through national electrical grid to interested parties.

JSIS has submitted an expression of interest to procure the above green energy delivered through electrical grid to replace part of its energy requirement and aims to achieve the carbon-reduction target subject to the implementation of the proposed industry-favourable wheeling policy and associated framework.

7.2.2 Quantification of GHG Emissions and Intensity Reductions

In determining the potential offset that could be achieved from sourcing a portion of JSIS electricity demand from the Ibri Solar Project, the following has been assumed:

1. Jindal Shadeed's annual energy requirement is an estimated 1.5 billion kWh at present load conditions.
2. Based on the energy requirements from 8 am to 5 pm (daylight hours), this equates to approximately 600 million kWh of electricity requirement, which can be replaced with renewable(solar) energy in absence of a viable energy storage technology.
3. It is considered that the maximum GHG reduction achievable is through replacing above mentioned 600 million kWh of electricity with green energy as on date.

On the basis of the above assumptions and limitations, the estimated GHG emission reduction is depicted in Insert 7-2, Table 7-1 and Appendix B.

Based on projected production tonnage for crude steel up to the year FY2030, an estimate of the lowest possible resultant greenhouse intensity can also be derived. An interim target for FY2025 is also presented below.

Table 7-1: Projected GHG Emissions and Intensity Target at FY 2024/25 and FY2029/30

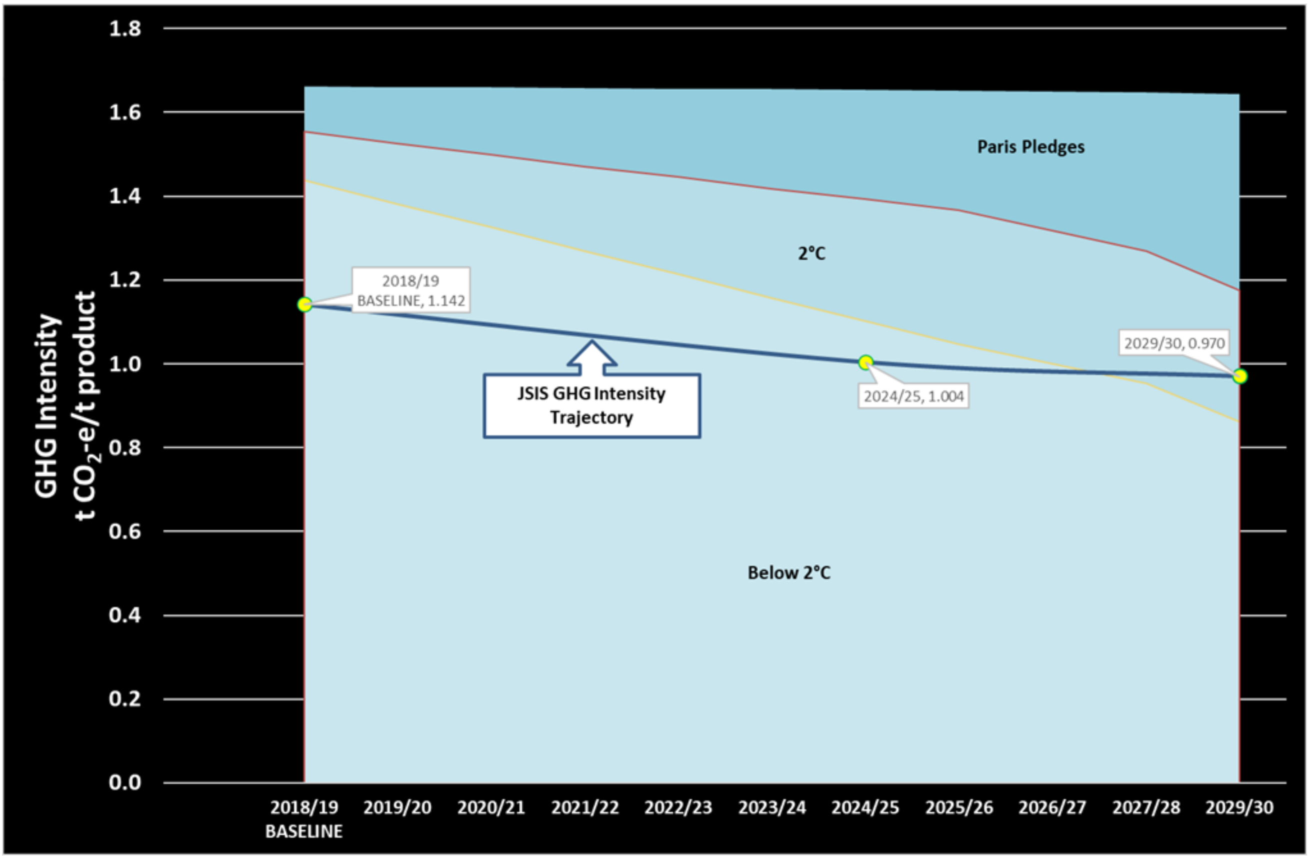
Year	FY2018/19 Baseline	FY2024/25	FY2029/30
GHG ($MtCO_2$-e/annum)	1.994	2.515	2.557
Production (Mtpa)	1.746	2.38	2.42
Abatement Project		**Renewable Electricity Purchases in Place**	
Abatement Qty ($MtCO_2$-e/annum)	0	0.126	0.210
Net ($MtCO_2$-e/annum)	1.994	2.389	2.347
TARGET GHG Intensity tCO_2-e/t	**1.142**	**1.004**	**0.970**

***Note:**

As detailed in Section 2.3, JSIS currently operates a State-of-the-Art steel production facility that has as part of its inherent design and core operating philosophy an extremely energy and production efficient process driven by a range of measures and initiatives discussed previously. Also as discussed, the literature review of published technologies and performance summarised in Appendix A demonstrated a range of initiatives that could be undertaken by facilities to reduce its carbon footprint but are already implemented by JSIS.

These initiatives have resulted in JSIS' baseline being notably lower than other steel production facilities and thereby limits the scale of GHG intensity reductions that can be demonstrated by FY2029/30 due to the already low baseline the company is starting from.

Insert 7-2: Projected GHG Emissions and Intensity to FY2029/30



7.2.3 Net Zero CO_2-e Goal

In terms of JSIS long term goals, the company has expressed a strong intention to reach a net zero CO_2-e footprint by the year FY2050. The mechanisms to achieve this are subject to ongoing feasibility assessments as well as advances in technologies that may become available in the years ahead.

Preliminary expectations are that the net zero goal will be realised through:

- Management commitment to define and implement a Green Hydrogen Project at JSIS similar to those that have been successfully achieved by other companies globally as part of those organisations' portfolio of reduction measures;
- Continued sourcing of green electricity via the Ibri Solar Project or similar;
- Assuming that the plant capacity remains the same (i.e. 2.4 Mtpa) and the electricity requirement remains the same (i.e. 1.5 billion kWh), JSIS company is committed to replace fossil fuel based electricity with green energy by installing a 750MW capacity hybrid (solar & wind) Renewable Energy System by 2050. The electricity thus produced shall be exported to the national grid and imported back to JSIS' Sohar steel works through net metering terms of energy trade.
- Continued measures as detailed in Section 2.3;

- Continued assessment on the opportunity and feasibility of implementing a potential Geo-sequestration Carbon Capture and Storage Project in collaboration with the Omani Climate Change Department. Realisation of this opportunity is subject to the policy position of the Omani government on its geo-sequestration projects.

Further details on each of the above initiatives will be reported progressively as studies and feasibility assessments continue.

8 REFERENCES

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APPENDICES

Appendix A: Potential Abatement Projects Subject to Internal Feasibility Assessment

To: Nicholas Gilani

From: Peter Jansen

Copy: Pawan Singh

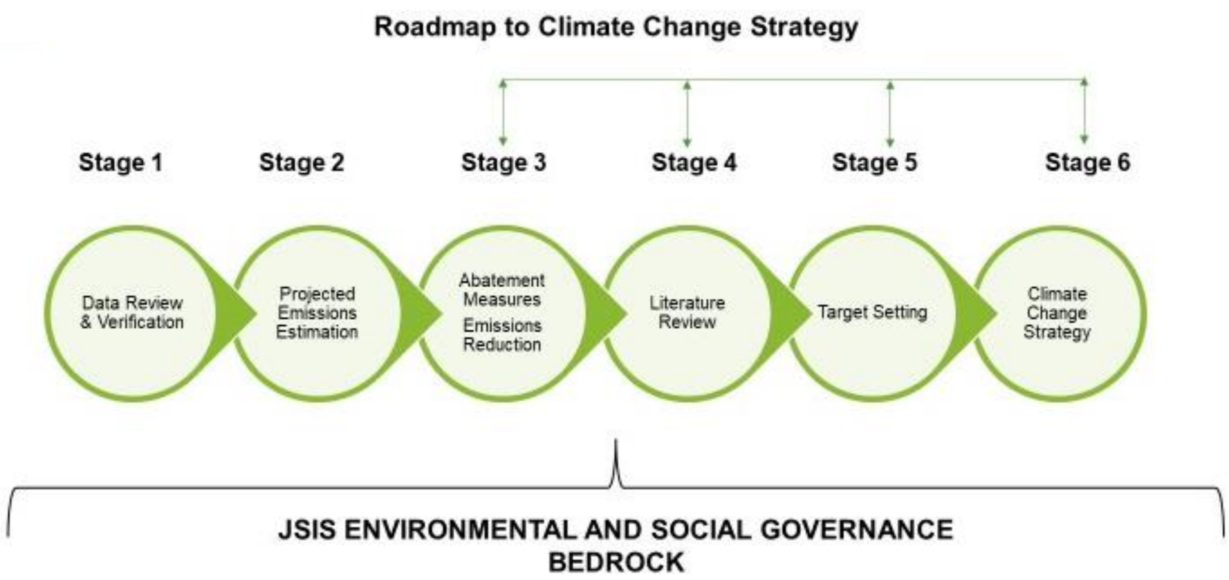
Date: 8 September 2021

Re: Conceptual Climate Change Strategy Emission Reduction

1 BACKGROUND

KASA Consulting was engaged to assist with development of a Climate Change Strategy (CCS) consistent with JSIS's own ESG principals.

In order to achieve this deliverable, KASA proposed a staged approach summarised below. JSIS committed to supply KASA with all information required for Stages 2 to 6, with KASA offering opinions or recommendations to augment the literature and research information provided by JSIS to finalise the CCS deliverable[1].



JSIS proposed to utilise the CCS deliverable to support the company's pursuit of financial bonds through its financiers.

[1] KASA's scope excludes provision of process engineering, design or technical advice on proposed technology.

2 CONSTRAINTS

- KASA's estimate of greenhouse intensity for JSIS demonstrates that the organisation is already performing below published industry greenhouse gas intensity performance.

- This therefore presents limitations on further reductions through process changes or improvements energy efficiency without a degree of CAPEX.

- Advice from SCB is that the framework for Sustainability Linked Bonds (SLB's) must include targets and reductions that are material and consistent with 2030 and 2050 (nett zero) targets.

- The solutions require a step up from what we had originally anticipated could be acceptable.

- SCB have articulated in general terms that there will be the implications and penalties of not meeting the targets that will be set in stone by the next review period, it would be unwise to simply throw in numbers that could set JSIS up for failure.

3 OPTIONS TO ACHIEVE DESIRED GREENHOUSE REDUCTIONS

Attachment 1 summarises the range of potential initiatives, research and literature reviews conducted by JSIS (Pawan) with KASA review. Adopted actions will be set in stone in the SCB SLB framework.

- Given their nature, JSIS Technical Dept input is vital before JSIS signs off on any of these recommendations (if any);

- Most if not all require some CAPEX;

- All require a review by JSIS process engineers and some form of feasibility assessment before coming back to me with the projected savings I will reflect in my report;

- As a proactive and accelerated measure to reduce its carbon footprint, JSIS has entered into advanced stage of dialogue with government agency (Authority for Public Services Regulation) to buy Green Energy directly out of the Ibri II Solar PV project currently undergoing commissioning.

- The Ibri II is a 500MW photovoltaic (PV) solar power project located in the Ad-Dhahirah region of Oman. It will be the first utility-scale renewable energy facility in the Sultanate of Oman. The Ibri II independent power producer (IPP) project is being implemented under build, own and operate (BOO) model by the Shams Ad-Dhahira Generating Company, which is a special purpose vehicle (SPV) incorporated by ACWA Power (50%), Gulf Investment Corporation (40%), and Alternative Energy Projects (10%). The project is backed by a 15-year power purchase agreement with the Oman Power and Water Procurement Company (OPWP). Government is preparing the necessary legislation framework and energy wheeling policy for marketing and delivering the carbon-free electricity through national electrical grid to interested parties.

- JSIS has submitted an expression of interest to procure the above green energy delivered through electrical grid to replace part of its energy requirement and aims to achieve the carbon-reduction target subject to the implementation of the proposed industry-favourable wheeling policy and associated framework.

- Additional immaterial but positively green/good PR initiates can be included regarding water efficiency targets (to reduce sewerage methane or recycling to reduce domestic waste contributions).

4 ACTIONS:

1. JSIS Technical Department to advise what if any proposed conceptual solutions can feasibly be adopted;
2. For feasible options, JSIS Technical Department to advise KASA what the equivalent energy/electricity savings or production (tonnage) improvement could be achieved;
3. KASA to estimate the impact of this change relative to the proposed CCS and reflect this in the final KASA report.

ATTACHMENT 1
SUMMARY OF OPTIONS TO ACHIEVE DESIRED GREENHOUSE REDUCTIONS

Aspect	Departmental Area	Concept/Opportunity	Reference/Further Information	Likely Impact/Materiality on overall JSIS Intensity	JSIS Determination to Adopt? Y/N
Energy Efficiency	All	a. Enter into purchase agreement with Authority for Public Services Regulation) to buy Green Energy directly out of the Ibri II Solar PV project currently undergoing commissioning	JSIS	Moderate-High 20% reduction	Y
Energy Efficiency	All	b. Implement Solar Project @ 250 MW	Pawan	Moderate-High 20% reduction	Subject to further feasibility assessments
Energy Efficiency	SRM	c. Upgrade reheating furnace to reduce fuel/energy d. Optimise reheating temperature e. Avoid Reheat Furnace Overload f. Hot charging (complete – already in place) g. Improved process control h. Use of recuperative burners i. Use of flameless burners j. Use of energy efficient drive motors	Appendix A	Low	Subject to JSIS Tech Dept advice Several recommendations already in place
Energy Efficiency	SMS	k. improved process control l. adoption of adjustable speed drives m. use of ultra high power transformers n. stirring gas injection o. slag foaming p. oxy fuel burners q. engineered refractories. r. Eccentric bottom tapping s. .efficient Ladle Preheating and Tundish heating **Future Plan a. Improved process control** by flue gas monitoring/control- by utilizing artificial intelligence and machine learning techniques at electric arc furnace. Electricity saving 8kwh/t of steel **b. Air tight EAF** by modifying existing EAF slag door to closed slag door operation. Electricity Saving 2.5 kwh/t of steel. **c. Increased oxygen injection** to reduce electrical power – From present level of 32 Nm3/T to 39 Nm3/T. Power saving – 21 kwh/T.	Appendix B	Moderate-High	Subject to JSIS Tech Dept advice Several recommendations already in place

Aspect	Departmental Area	Concept/Opportunity	Reference/Further Information	Likely Impact/Materiality on overall JSIS Intensity	JSIS Determination to Adopt? Y/N
		z. Efficient Ladle Preheating and Tundish Heating			
General	All	a. Preventive maintenance b. Energy monitoring and management system c. Combined heat and power/cogeneration d. High-efficiency motors e. Variable speed drives: flue gas control, pumps, and fans	Appx C	Low-Moderate	Subject to JSIS Tech Dept advice Several recommendations already in place
Direct Emissions	Ancillary	f. Reduced wastewater generation through water efficiency initiatives – WWTP g. Enhanced waste minimisation and recycling programs	N/A	Low	Subject to JSIS Tech Dept advice Several recommendations already in place

ATTACHMENT 1

ADDITIONAL LITERATURE REVIEW AND SUMMARY OF INIITIAVES

APPENDIX A

Hot Rolling Mills

This section presents energy efficiency measures that are specific to hot rolling that could be used at both Integrated Iron and Steel and EAF plants.

In any hot rolling operation, the reheating furnace is a critical factor to determine end-product quality, as well as to total costs of the operation. Energy use in a reheating furnace depends on production factors (e.g., stock, steel type), operational factors (e.g., scheduling), and design features. Savings may be achieved through optimized processes and by upgrading existing furnaces. The upgrade of a reheat furnace of North Star Steel (Iowa) led to significant fuel, energy cost and labor savings together with savings due to the reduction of scrap use while furnace refractory life and product quality improved.

Proper Reheating Temperature

In choosing the heating temperature for semi-finished products prior to rolling, an attempt should be made to obtain a fine-grained structure in the metal along with the requisite mechanical properties in the rolled product. The heating operation should also ensure dissolution of the inclusions in the metal in the absence of excessive grain growth. A reduction of the heating temperature by 212°F (100°C) decreases unit fuel consumption by 9 to 10 percent. However, lowering the heating temperature will increase the rolling forces and moments, and hence increase the load on the electric drive motors, i.e., it will have the overall effect of increasing the mechanical and electrical loads on the main components of the mill, thereby increasing energy consumption and wear of the mill equipment. (Worrell, 2009) Since there are many permutations that arise from the combination of rolling equipment, temperature, steel grade, desired end shape, cooling water temperature, etc., it is considered difficult to address the specific energy gains that can be made by varying heat levels. (AISI, 2011) As a result, under certain conditions total unit energy consumption may not decrease with a decrease in heating temperature (even without allowance for the losses associated with electric power generation). Therefore, any changes to the heating temperature first should be examined using a systems approach. (Worrell, 2009)

Avoiding Overload of Reheat Furnaces

Overloading a furnace can lead to excessive stack temperatures. To get the proper rate of heat transfer, combustion gases must remain in the heating chamber for the right amount of time. The natural tendency of an overloaded furnace is to run colder than optimal, unless the temperature is set artificially high. This causes the burners to operate at higher than normal firing rates, which increases combustion gas volumes. The higher gas flow rates and shorter time that the gas remains in the furnace causes poor heat transfer, resulting in higher temperatures of the flue gases. The increased volumes of higher temperature flue gases lead to sharply increased heat losses. Overly ambitious production goals might be met, but at the cost of excessive fuel consumption. The overload problem may be corrected by improving heat transfer or not operating in this mode to achieve ambitious production goals.

Because most reheat furnaces are regulated by the amount of and type of fuel that they can consume, overloading is thought to be a very rare event. Overloading a reheat furnace with billets will typically reduce mill production rates and is not considered an economical operation in the long term. Overloading with respect to the fuel feed can cause increased emissions from the furnace, which is also undesirable, and a prohibited operating condition for most facilities. (AISI, 2011)

Hot Charging

Hot charging is the process of heating slabs prior to charging them into the reheating furnace of the hot mill. The higher the preheat temperature, the greater the energy savings in the hot mill furnace. The layout of the plant will affect the feasibility of hot charging because the caster and reheating furnace should be located in proximity to one another to avoid a long, hot connection pathway between the two.

However, even if a facility would prefer to hot charge, the ability to do so is limited. When the meltshop or the roll mill has services interrupted, the entire facility operations are disrupted if there is no longer a break period between the melting and rolling operations. This can offset the advantages of energy savings. (AISI, 2011)

Although actual savings will be highly plant dependent, one estimate of the potential energy savings was as much as 0.05 MMBtu/ton (0.06 GJ/tonne) of hot charged steel. Investment costs were estimated to be approximately $21.3/ton ($23.5/tonne) of hot rolled steel, with annual cost savings of up to $1.04/ton ($1.15/tonne) of hot charged steel and a payback time of 5.9 years.

Process Control in Hot Strip Mill

Improved process control of the hot strip mill may lead to indirect energy savings through reduced product rejects, improved productivity, and reduced down time. This measure includes controlling oxygen levels and VSDs on combustion air fans, which both help to control the oxygen level, and hence optimize the combustion in the furnace, especially as the load of the furnace may vary over time. The savings depend on the load factor of the furnace and control strategies applied. A system installed at ArcelorMittal's Sidmar plant (Belgium) reduced the share of rejects from 1.5 to 0.2 percent and reduced the downtime from more than 50 percent of the time to 6 percent. Estimated energy savings based on reduced rejects was 9 percent of fuel use, or approximately 0.26 MMBtu/ton (0.3 GJ/tonne) of product. The investment costs for one plant in Belgium was

$3.6 million for a hot strip mill with a capacity of 3.1 million tons (2.8 million tonnes), or approximately $1.20/ton ($1.29/tonne) of product. The payback time is estimated as 1.2 years.

Recuperative Burners

Application of recuperative or regenerative burners can substantially reduce energy consumption. A recuperator is a gas-to-gas heat exchanger placed on the stack of the furnace. There are numerous designs, but all rely on tubes or plates to transfer heat from the outgoing exhaust gas to the incoming combustion air, while keeping the two streams from mixing. Recuperative burners use the heat from the exhaust gas to preheat the combustion air. Recuperative burners can reduce fuel consumption by 10 to 20 percent compared to furnaces without heat recovery.

Since modern recuperative or regenerative burner systems can have significantly higher efficiencies than older systems, savings can also be attained by replacement of old or aging recuperative or regenerative burners. Newer designs can also have lower NO_x emissions; consequently, the evaluation of recuperative or regenerative burner systems should include an assessment of the impact on NO_x emissions. Replacement of the recuperator by a newer model can result in substantial savings as is illustrated by an example at North Star Steel (Iowa). Recuperator replacement at this plant was estimated to achieve fuel savings of 9 percent with an expected payback period of 6 months. Another example in Japan shows that a newer model continuous slab reheating furnace can reduce energy consumption by 25 percent in comparison to an older furnace recovering waste heat with a recuperator.

Recuperative burners in the reheating furnace can reduce energy consumption by as much as 30 percent. Although actual savings will be highly facility-specific, one estimate placed energy savings at approximately 0.6 MMBtu/ton (0.7 GJ/tonne) of product, with an investment cost of approximately $3.5/ton ($3.9/tonne) of product. The payback time is estimated as 1.8 years.

Although recuperative burner use is common at many facilities, these burners are regulated via the air permit system due to their potential to create NOx emissions at higher flame temperatures. Therefore, the potential energy efficiency improvements through the use of recuperative burners would be limited unless permit conditions are modified. (AISI, 2011)

Flameless Burners

A widely used technique to enhance furnace efficiency is extensive air preheating, but the drawback is a parallel increase of NO_x emissions. Another technique is the use of flameless burners. Flameless air-fuel combustion uses air as oxidizer, while flameless oxy-fuel uses commercial oxygen as an oxidant. This technology carries out combustion under diluted oxygen conditions using internal flue gas recirculation and the flame becomes invisible. Flameless oxy-fuel gives high thermal efficiency, higher levels of heat flux, and reduced fuel consumption compared to conventional oxy-fuel. These benefits are combined with low NO_x emissions and better thermal uniformity. Since 2003, more than 30 furnaces within the U.S. steel industry have been equipped with flameless oxy-fuel combustion.

ArcelorMittal recently received the Association for Iron & Steel Technology (AIST) 2009 Energy Achievement Award for its work to implement a flameless oxy-fuel operation on its rotary-hearth steel-reheat furnace. ArcelorMittal realized a 60 percent reduction in the furnace's total fuel consumption compared to the original air-fuel operation. The technology also reduced the furnace's annual NO_x emissions output by 92 percent and annual CO_2 emissions by up to 60 percent below the prior air-fuel operating levels. The conversion also enabled

ArcelorMittal to achieve a 25 percent increase in material throughput and a 50 percent reduction in scale formation (R&D Magazine, 2010).

This technology is commonly used in the EAF industry but, as with recuperative burners above, the use of fameless burners is limited by permit to keep the preheat air temperature below 900^{o}F so as to lower the rate of NOx formation. Permit modifications also would be needed with this technology to implement this strategy to reduce energy. (AISI, 2011)

Insulation of Furnaces

Replacing conventional insulating materials with ceramic low-thermal–mass insulation materials can reduce the heat losses through furnace walls. The potential energy savings for insulating a continuous furnace were estimated to range from 2 to 5 percent, or approximately 0.14 MMBtu/ton (0.16 GJ/tonne) of product. Capital costs were estimated to be $14.1/ton ($15.6/tonne) of product. The payback time is estimated as 31 years.

Walking Beam Furnace

A walking beam furnace represents the state-of-the-art of efficient reheating furnaces. In a walking beam furnace, the stock is placed on stationary ridges and a revolving beam walks the product along through the furnace until the exit where the beam returns to the furnace entrance. WCI Steel has a walking beam furnace that also employed a state-of-the-art combustion control. The use of this furnace at WCI Steel resulted in a reduction in electricity usage by 25 percent per ton produced and a reduction in overall fuel consumption by 37.5 percent per ton produced compared to three pusher-type furnaces.

Controlling Oxygen Levels and Variable-Speed Drives on Combustion Air Fans

Controlling oxygen levels and using VSDs on the combustion air fans on the reheating furnace helps to optimize combustion in the furnace. Excess air can substantially decrease combustion efficiency as it leads to excessive waste gases. Fuel-air ratios of the burners should therefore be checked regularly. The use of VSDs on combustion air fans on the reheating furnace also helps to control the oxygen level, especially as the load of the furnace may vary over time. The savings depend on the load factor of the furnace and the control strategies applied. Implementing a VSD on a combustion fan of a walking beam furnace at Cardiff Rod Mill (UK) reduced the fuel consumption by 48 percent and had a payback period of 16 months. Energy savings can vary widely depending on the specific installation, but one conservative estimate place the savings at 10 percent, or approximately 0.28 MMBtu/ton (0.33 GJ/tonne) of product. The estimated investment costs were $0.72/ton ($0.79/tonne) of product. The payback time is estimated as 0.8 years.

Heat Recovery to the Product

In cases that it is not possible to hot-charge the slabs directly from the caster, energy can be recovered bringing exhaust gases that leave the high temperature portion of the process into contact with the relatively cool slabs. This will preheat the slab charge. In a plant-wide assessment of North Star Steel (Iowa) it was estimated that using furnace flue gases to preheat the charge to a moderate temperature of 840 to 1,020°F (450 to 550°C) would result in costs savings of about 32 percent. Another study reports a 50 percent reduction of the unit energy consumption of a heating furnace when charging semi-finished products at a temperature above 1,200°F (650°C) and a 70 to 80 percent reduction at charging temperatures above 1,800°F (980°C).

Waste Heat Recovery from Cooling Water

Waste heat can be recovered from the hot rolling mill cooling water to produce low-pressure steam. Estimated fuel savings are 0.034 MMBtu/ton (0.04 GJ/tonne) of product, with a required increase in electricity consumption of 0.15 kWh/ton (0.0006 GJ/tonne) of product. Investment costs were estimated to be $1.2/ton ($1.3/tonne) of product. Operating and maintenance costs may increase by $0.10/ton ($0.11/tonne) of product. The payback time is estimated at over 50 years.

F. Rolling Mills, General Measures

The semi-finished steel products from the casting operations are further processed to produce finished steel products in a series of shaping and finishing operations in the rolling mills at both Integrated Iron and Steel and EAF plants. Rolling mills are either hot or cold (ambient temperature) processes. Mechanical forces for cold rolling will create much more force and energy needs, while hot rolling happens much faster with less forces; however, there are significant energy costs to heat the metal to near eutectic temperatures.

This section presents energy efficiency measures that are applicable to both the hot rolling and cold rolling processes that could be used at both Integrated Iron and Steel and EAF plants. The sections that follow this general measures section discuss the energy efficiency measures specific to each rolling type.

Energy Efficient Drives

High-efficiency alternating current (AC) motors can save 1 or 2 percent of the electricity consumption of conventional AC drives. Based on an electricity demand of 181 kWh/ton (0.072 GJ/tonne) of rolled steel, the electricity savings were estimated to be 3.6 kWh/ton (0.014 GJ/tonne) of hot rolled steel. The additional cost of a high efficiency drive was estimated to be approximately $0.27/ton ($0.30/tonne) of hot rolled steel. The payback time was estimated as 3.2 years.

The estimated payback time from this study is thought to be specific to the operation at the plant on which the study was based. The payback period of these drives is thought to be highly variable, in that it can be significantly longer or even shorter depending upon the many variables involved. (AISI, 2011)

Gate Communicated Turn-Off Inverters

Drive units for main equipment such as rolling mills in steel plants use variable-speed AC operation. As switching devices for large-capacity inverted drives, Gate Turn-Off thyristors have been widely used. However, a Gate Communicated Turn-Off thyristor can be used instead of a Gate Turn-Off thyristor to decrease switching losses. Compared with this Gate Turn-Off the Gate Communicated Turn-Off inverter has higher system efficiency, not only at rated-load operation, but also at light-load operation and reduces energy loss. The Gate Communicated Turn-Off inverters are typically used to drive steel rolling mills and are being adopted in every area of steel mills from high-speed wire rolling to low-speed cold rolling. Moreover, they are applicable as energy-saving drive units for large-capacity fans, pumps, and compressors.

Table 1. Energy Efficiency Technologies and Measures Available for Integrated Steel and Coke Production in the U.S.[a] (Worrell, 1999, 2009; AISI, 2011)

Option	Applicability and Feasibility Codes (see list of codes below)[b]	Payback Time (years)[c]
General Measures for Rolling Mills		
Energy efficient drives	EX	3.2
Gate communicated turn-off inverters		
Install lubrication system	EX	
Hot Rolling		
Proper reheating temperature		
Avoiding overload of reheat furnaces	EX	
Hot charging	EX, N, S	5.9
Process control in hot strip mill	EX	1.2
Recuperative and regenerative burners	C, EX	1.8
Flameless burners	C	
Insulation of furnaces	C, EX	31.0
Walking beam furnace	C, EX, N	
Controlling oxygen levels and/or speed on combustion air fans	C	0.8
Heat recovery to the product	C. N	
Waste heat recovery (cooling water)	C, P	> 50
General		
Preventive maintenance	EX	
Energy monitoring and management system	EX	0.5
Combined heat and power/cogeneration	EE, EX, N	6.1
High-efficiency motors		
Variable speed drives: flue gas control, pumps, and fans	C, EX	10.7

[a] See **Appendix C** for estimates of energy savings and costs for these process changes and measures prepared by Worrell (1999, 2009).
[b] Applicability codes (AISI, 2011):
C = Site-specific variables may affect costs and/or practicality of use of the option at all facilities.
EE = Options that could improve energy efficiency and potentially lower GHG emissions but may increase other pollutants.
EX = Process already widely implemented at many existing facilities.
N = Only feasible for new units.
P = Immature process that is still in research and/or pilot stage as applied to Iron and Steel.
S = Specialized process only technically appropriate for some equipment configurations or types.
[c] Options with payback times of more than three years are not likely to be considered economically feasible by a facility. (AISI, 2011)

APPENDIX B

Energy Efficiency Options for Electric Arc Furnace Steelmaking

Opportunities to improve energy efficiency specific to EAF steelmaking facilities are described below. The energy efficiency measures for casting, rolling, and other finishing processes at EAF facilities are the same as for Integrated Iron and Steel mills described above and in **Table 1**. Energy efficiency opportunities specific to EAF facilities are discussed in the following sections and are included in **Table 2**.

Improved Process Control (Neural Networks)

Process control can optimize operations and thereby significantly reduce electricity consumption as is demonstrated by many examples worldwide. Modern controls which use a multitude of sensors can help to achieve this to a greater extent than older controls. Control and monitoring systems for EAF are moving towards integration of real-time monitoring of process variables, such as steel bath temperature, carbon levels, and distance to scrap, along with real-time control systems for graphite injection and lance oxygen practice. As an example, neural networks systems analyze data and emulate the best controller and can thus help to reduce electricity consumption beyond that achieved through classical control systems. Neural networks can help achieve additional reductions in energy consumption over classic control systems. For EAF, average power savings were estimated to be 8 percent, or 34.5 kWh/ton (0.14 GJ/tonne). Additionally, productivity increased by 9 to 12 percent, and electrode consumption was reduced by 25 percent. Capital costs were estimated to be $372,500 per furnace, with annual cost savings of approximately $1.4/ton ($1.5/tonne). The payback time is estimated as 0.5 years.

By monitoring the furnace exhaust gas flow rate and composition, the use of chemical energy in the furnace can be enhanced. Detailed investigation of the post-combustion of off-gases can be carried by an optical sensor. Using the monitored data as input for a control system, post-combustion of off-gases can be controlled online. Benefits of this practice include reduced electricity consumption, shorter power-on times, increased productivity, a decrease in production costs, a reduction of electrode consumption, reduced natural gas, oxygen and carbon consumption, and a reduction of refractory wear. It has been demonstrated that, if oxygen injected for post-combustion is continuously controlled by real-time data acquisition of CO and CO_2 concentrations in off-gases, a 50 percent increase in recovery rate of chemical energy in fumes can be achieved compared to operation based on predefined set-points.

A specific system that continuously measures CO, CO_2, H_2, and O_2 to control post-combustion was installed at the Hylsa's Planta Norte plant near Monterrey (Mexico) and by Nucor, Seattle (WA). The system led to reductions of 2 percent and 4 percent in electricity consumption, 8 percent and 16 percent in natural gas consumption, 5 percent and 16 percent in oxygen use, 18 percent and 18 percent in carbon charged and injected. At the same time, yield improved (between 1 percent and 2 percent), and electrode consumption decreased (3.5 percent and 16 percent), while productivity increased by 8 percent.

Although neural network manufacturers' claims of efficiency gains are impressive, industry representatives believe it is possible to achieve the same improvement with a well-managed energy system run by a well-trained operator. With the proper tools to measure the furnace operating parameters, which may include electronic monitoring devices much simpler than neural networks, a well-trained operator may be capable of meeting or exceeding the performance of a computer system at a lower cost. (AISI, 2011) Any approach that can produce similar energy savings, reductions in electricity consumption, and reductions in fuel use in a payback time of less than a year should be encouraged.

Adjustable Speed Drives

As flue gas flow varies over time, adjustable speed drives offer opportunities to operate dust collection fans in a more energy efficient manner energy can. Flue gas adjustable speed drives have been installed in various countries (e.g., Germany, UK). The electricity savings are estimated to be 15 kWh/ton (0.06 GJ/tonne), with a payback period of 2 to 3 years. Although dust collection rates were reduced by 2 to 3 percent, total energy usage decreased by 67 percent. Capital costs were estimated to be $1.8/ton ($2/tonne). The payback time is estimated as 2 to 3 years.

Transformer Efficiency—Ultra-High–Power Transformers

Ultra-high–power (UHP) transformers help to reduce energy loss and increase productivity. The UHP furnaces are those with a transformer capacity of more than 700 kilovolt amps (kVA)/tonne heat size. The UHP operation may lead to heat fluxes and increased refractory wear, making cooling of the furnace panels necessary. This results in heat losses that partially offset the power savings. Total energy savings were estimated to be 15 kWh/ton (0.061 GJ/tonne). Many EAF operators have installed new transformers and electric systems to increase the power of the furnaces, e.g., Co-Steel (Raritan, NJ), SMI (Sequin, TX), Bayou Steel (Laplace, LA), and Ugine Ardoise (France). Capital costs were estimated to be $3.9/ton ($4.3/tonne). The payback time is estimated as 5.2 years.

Bottom Stirring/Stirring Gas Injection

Bottom stirring is accomplished by injecting an inert gas into the bottom of the EAF to increase the heat transfer in the melt. In addition, increased interaction between slag and melt leads to an increased liquid metal yield of 0.5 percent. Furnaces with oxygen injection are sufficiently turbulent, reducing the need for inert gas stirring. The increased stirring can lead to electricity savings of 10 to 20 kWh/ton (0.04 to 0.08 GJ/tonne), with net annual production cost reduction of $0.72 to $1.4/ton ($0.8 to $1.6/tonne). Taking into account the increased liquid steel yield may increase the cost savings to $1.3 to $3.1/ton ($1.4 to $3.4/tonne). Power savings were estimated to be 18 kWh/ton (0.072 GJ/tonne). Capital costs for retrofitting existing furnaces were estimated to be $0.85/ton ($0.94/tonne) for increased refractory costs and installing tuyeres, and annual costs for inert gas purchase was estimated to be $1.8/ton ($2.0/tonne). Productivity increases were estimated to reduce costs by $5.0/ton ($5.5/tonne). The payback time is estimated as 0.2 years.

Foamy Slag Practice

Foamy slag covers the arc and melt surface to reduce radiation heat losses. Foamy slag can be obtained by injecting carbon (granular coal) and oxygen or by lancing of oxygen only. Slag foaming increases the electric power efficiency by at least 20 percent in spite of a higher arc voltage. The net energy savings (accounting for energy use for oxygen production) are estimated at 5 to 7 kWh/ton (0.02 to 0.028 GJ/tonne) steel. Foamy slag practice may also increase productivity through reduced tap-to-tap times. Investment costs are about $14.1/ton ($15.6/tonne) capacity. Productivity increases may be equivalent to a cost savings of approximately $2.6/ton ($2.9/tonne) steel. The payback time is estimated as 4.2 years.

Oxy-Fuel Burners

Oxy-fuel burners are used on most EAF in the U.S. (AISI, 2011) These burners increase the effective capacity of the furnace by increasing the speed of the melt and reducing the consumption of electricity and electrode material, which reduces GHG emissions.

The use of oxy-fuels burners has several other beneficial effects: it increases heat transfer, reduces heat losses, reduces electrode consumption and, and reduces tap-to-tap time. Moreover, the injection of oxygen helps to remove different elements from the steel bath, like phosphorus, silicon and carbon. Steelmakers are now making wide use of stationary wall-mounted oxygen-gas burners and combination lance-burners, which operate in a burner mode during the initial part of the melting period. When a liquid bath is formed, the burners change over to a mode in which they act as oxygen lances. Electricity savings may range from 88 to 155 kWh/ft^3 (11 to 20 GJ/m^3) oxygen injected. Natural gas injection is typically 10 standard cubic feet per kilowatt hour, with energy savings ranging from 18 to 36 kWh/ton (0.72 to 0.14 GJ/tonne). Investment cost for modifying a 121 ton (110 tonne) EAF were estimated to be $6.8/ton ($7.5/tonne). Annual cost savings may be approximately $6.4/ton ($7.1/tonne) due to reduced tap-to-tap times. The payback time is estimated as 0.9 years.

Post-combustion of the Flue Gases

Post-combustion is a process for utilizing the chemical energy in the CO and hydrogen evolving from the steel bath to heat the steel in the EAF ladle or to preheat scrap to 570 to 1,470°F (300 to 800°C). It reduces electrical energy requirements and increases the productivity of the EAF. Other benefits include reduction of baghouse emissions, reduction of the temperature of the off-gas system and minimization of high temperature spikes associated with rapid CO evolution. Post-combustion helps to optimize the benefits of oxygen and fuel injection. EAF operations that involve large amounts of charged carbon or pig iron are particularly suitable for implementation of CO post-combustion technology during scrap melting.

It is critical that post-combustion is done early at melt down while the scrap is still capable of absorbing the evolved heat. The injectors should be placed low enough to increase CO retention time in the scrap in order to transfer its heat. The oxygen flow should have a low velocity to promote mixing with the furnace gases and avoid both scrap oxidation and oxygen rebound from the scrap to the water cooled panels. The injectors should also be cooled extremely well as the post combustion area often gets overheated. In order to distribute the chemical energy uniformly and to make its utilization efficient, it is preferable to bifurcate the post combustion oxygen flow and to space out the injectors in the colder areas of the shell. For a particular post-combustion system, electricity savings ranged from 6 to 11 percent and reductions in tap-to-tap time from 3 to 11 percent, depending on the operating conditions. No information was available for costs or payback time.

This technology is commonly used in the U.S. and is considered to be the best control technology for CO emissions. (AISI, 2011)

Direct Current Arc Furnace

The direct current (DC) arc furnace was pioneered in Europe, and these single-electrode furnaces with DC rather than alternating current (AC) have been used in North America for over 20 years. This technology is considered to be limited to new installations because of the prohibitive scale of the retrofit costs. (AISI, 2011)

In a DC furnace, one single electrode is used, and the bottom of the vessel serves as the anode. Based on the distinctive feature of using the heat and magnetic force generated by the current in melting, this arc furnace achieves an energy saving of approximately 5 percent in terms of power unit consumption in comparison with the 3-phase AC arc furnace. In addition, it also has other features, including higher melting efficiency and extended hearth life. Power consumption is 454 to 544 kWh/ton (1.8 to 2.2 GJ/tonne) molten steel. Electrode consumption is about half that with conventional furnaces. This corresponds to 2.4 to 4.9 lb/ton (1 to 2 kg/tonne) molten steel. This measure is applied to large furnaces only. Net energy savings were estimated to be 82 kWh/ton (0.32 GJ/tonne). However, compared to new AC furnaces, the savings are limited to 9 to 18 kWh/ton (0.036 to 0.072 GJ/tonne). The additional investment costs over that of an AC furnace are approximately $5.5/ton ($6.1/tonne) capacity. The payback time is estimated as 0.7 years.

The design of the DC arc furnace also reduces noise and electrical flicker, increases efficiency, and reduces electrode consumption. As of 2007, there are eight DC powered EAF operating in the U.S. and one in Mexico; most of these EAF have been installed in the past 2 years, with the oldest installed in 1991. The manufacturers involved are Fuchs, NKK/United, MAN GHH, and Voest-Alpine. Facilities that are currently using this new technology include Charter Steel, Florida Steel, Gallatin Steel, North Star Steel, and many Nucor plants (e.g., Blytheville, AR; Berkeley, SC; Decatur, AL; Hertford, NC; Norfolk, NE; Darlington, SC).

Scrap Preheating

Scrap preheating is performed either in the scrap charging baskets, in a charging shaft (shaft furnace) added to the EAF, or in a specially designed scrap conveying system allowing continuous charging during the melting process. Scrap preheating is used extensively in Japan, and the use of hot furnace gases for scrap preheating is now being applied in the U.S. Scrap preheating can save 4 to 50 kWh/ton (0.016 to 0.20 GJ/tonne) and reduce tap-to-tap times by 8 to 10 minutes. A prominent example of its application to new EAF with continuous charging is the Consteel process, which is being used at Gerdau-Ameristeel plants in Charlotte, NC, Knoxville, TN, and Sayreville, NJ; and at Nucor plants in Darlington, SC, and Hertford, NC.

Preheating scrap reduces the power consumption of the EAF by using the waste heat of the EAF as the energy source for the preheat operation. The Consteel process consists of a conveyor belt that transports the scrap through a tunnel to the EAF. In addition to energy savings, the Consteel process can increase productivity by 33 percent, decrease electrode consumption by 40 percent, and reduce dust emissions. Electricity savings can be 54 kWh/ton (0.22 GJ/tonne), and investment costs were estimated to be $3.2 million for a capacity of 550,000 tpy (500,000 tonne/yr) or $7.1/ton ($7.8/tonne) of product. Annual costs savings were estimated to be $2.7/ton ($3.0/tonne). The payback time is estimated as 1.3 years. Unless electricity is generated on-site, the GHG reductions will be indirect, i.e., at the power plant.

Because scrap preheating exposes the scrap metal to temperatures much lower than in the EAF for extended periods of time, increased emissions of some criteria pollutants, such as volatile organic compounds (VOC), are thought to be possible. The VOC emissions are commonly fully combusted in the EAF off gas system. In the case of Consteel, they are also created in the off gas system. (AISI, 2011)

Scrap Preheating, Post Combustion—Shaft Furnace (Fuchs)

Shaft-furnace technology (both single- and double-shaft furnaces) was pioneered by Fuchs in the late 1980s. Since 2005, the VAI Fuchs furnace has been known as SIMETALCIS EAF. With the single shaft furnace, up to 70 kWh/ton (0.28 GJ/tonne) liquid steel of electric power can be saved. The finger shaft furnace[7] allows energy savings up to 100 kWh/ton (0.40 GJ/tonne) liquid steel, which is about 25 percent of the overall electricity input into the furnace. The exact energy savings depend on the scrap used, and the degree of post-combustion (oxygen levels). For the finger shaft furnace tap-to-tap times of about 35 minutes are achieved, which is about 10 to 15 minutes less compared to EAF without efficient scrap preheating. The process may reduce electrode consumption, improve yield by 0.25 to 2 percent, increase productivity by 20 percent, and decrease flue gas dust emissions by 25 percent. Retrofit costs were estimated to be $8.5/ton ($9.4/tonne) for an existing 110-ton (100-tonne) furnace. Production cost savings may amount to $6.1/ton ($6.7/tonne). The payback time is estimated as 1 year.

It should be noted that these EAF operations have demonstrated a propensity to emit high volumes of CO. (AISI, 2011)

[7] The most efficient shaft-furnace design is the finger-shaft furnace, which employs a unique scrap retaining system with fingers to preheat 100 percent of the scrap charge using the hot flue gases.

Engineered Refractories

Refractories in EAF have to withstand extreme conditions such as temperatures over 2,900°F (1,600°C), oxidation, thermal shock, erosion and corrosion. These extreme conditions generally lead to an undesired wear of refractories. Refractories can be provided by a controlled microstructure: alumina particles and mullite microballoons coated uniformly with carbon and carbides. The refractories can be either sintered or cast and can therefore be used in a wide range of components at EAF mills (e.g., furnace, ladle furnace, vessels). The refractories can reduce ladle leakages and the formation of slag in transfer operations with savings of 10 kWh/ton (0.04 GJ/tonne) steel.

Airtight Operation

A large amount of air enters the EAF: around 1,000,000 ft^3 (30,000 m^3) in a standard EAF of 165 tons (150 tonnes) of steel with a heat duration of 1 hour. This air is at ambient temperature, and the air's nitrogen and non-reactive oxygen are heated in the furnace and exit with the fumes at high temperature (around 1,800°F) (980°C), resulting in significant thermal losses. Based on the results of pilot scale trials with a 7 ton (6 tonne) EAF at Arcelor Research, the potential benefit for an industrial furnace with an airtight process including a post-combustion practice and an efficient fume exhaust control is about 100 kWh/ton (0.4 GJ/tonne) for an industrial furnace having a current electric consumption of 450 kWh/ton (1.8 GJ/tonne). About 80 percent of the savings can be attributed to a reduction of energy losses in the fumes. The remaining 20 percent are accounted for by reduced thermal losses due to a reduced tap-to-tap time. The exhaust gas can be used as a fuel in the post-combustion chamber, which reduces the amount of natural gas needed for the burner.

The primary reason for failure to operate an airtight EAF is the need to evaluate the material within the EAF continuously while charging the EAF with scrap, and then also balancing the requirement to control emissions from the EAF. This operational complexity is compounded by the fact that the scrap metal is highly variable and will have varied degrees of density that will require varying degrees of energy as the scrap density changes. While the EAF operator can attempt to control these variables, the limitations of optimizing the process are driven more by the variation in the scrap supply than anything else. The complexity is further increased if in an effort to maintain compliance, the operator is biased toward higher evacuation rates. This offsets some of the gains to be made toward better energy efficiency since more energy is used per unit time as the evacuation flow is increased. It is necessary to find a balance between air tightness, scrap density, and access to the furnace for sampling the metal. Complete air tightness will never be achieved, but incremental improvements might be gained in these efforts. (AISI, 2011)

Contiarc® Furnace

The *Contiarc* furnace is fed continuously with material in a ring between the central shaft and the outer furnace vessel, where the charged material is continuously preheated by the rising process gas in a counter-current flow, while the material continuously moves down. Located below the central shaft is a "free-melting volume" in the form of a cavern. Advantages of the Contiarc furnace include (1) reduced energy losses (200 kWh/ton or 0.8 GJ/tonne less than with conventional furnace systems), (2) waste gas and dust volumes are considerably reduced, which results in a lower capacity for the gas cleaning system and also lower electric power consumption (23 kWh/ton or 0.091 GJ/tonne), (3) gas-tight furnace enclosure captures all primary and nearly all secondary emissions, and (4) reduced electrode consumption (about 1.8 lb/ton or 0.9 kg/tonne less than a typical AC furnace).

Flue Gas Monitoring and Control

The use of VSDs can reduce energy usage of the flue gas fans, which in turn reduces the losses in the flue gas. Electricity savings were estimated to be 13.6 kWh/ton (0.054 GJ/tonne) with a payback period of 2 to 4 years. Capital costs were estimated to be $2.8/ton ($3.1/tonne). However, in practice, these systems have proven to be of limited utility since continuous emissions monitoring systems provide a substantial amount of information for EAF operators that includes most of the information that VSD systems provide. Operators have found that VSD systems are not able to predict problems that occur in EAF due to the variability in the scrap and also from energy fluctuations. These factors effect EAF emissions and the ability of the facility to meet emission regulations. (AISI, 2011)

Eccentric Bottom Tapping

Eccentric bottom tapping leads to slag-free tapping, shorter tap-to-tap times, reduced refractory and electrode consumption, and improved ladle life. Energy savings were estimated to be 13.6 kWh/ton (0.054 GJ/tonne). Modification costs for a Canadian plant were $3.3 million for a furnace with an annual production capacity of 760,000 tons (690,000 tonnes) or $4.5/ton ($5.0/tonne). The payback time is estimated as 7 years.

Twin-Shell Furnace

A twin-shell furnace includes two EAF vessels with a common arc and power supply system. The system increases productivity by decreasing tap-to-tap time, and reduces energy consumption by reducing heat losses. A twin-shell furnace may save 17 kWh/ton (0.068 GJ/tonne) compared to a single-shell furnace. Production costs are expected to be $1.8/ton ($2.0/tonne) lower that a single-shell furnace, and the investment costs are expected to be approximately $8.5/ton ($9.4/tonne) over that of a single-shell furnace. The payback time is estimated as 3.5 years.

E. Casting

The following are descriptions of potential energy mitigation options during casting operations that could be used at both Integrated Iron and Steel and EAF plants.

Efficient Ladle Preheating and Tundish Heating

The ladle of the caster is preheated with gas burners with a fuel consumption estimated at 0.02 MMBtu/ton (0.02 GJ/tonne) liquid steel. Heat losses can occur through lack of lids and through radiation. The losses can be reduced by installing temperature controls, installing hoods, by efficient ladle management (reducing the need for preheating), using recuperative burners, and using oxy-fuel burners.

Tundishes are heated to reduce the heat loss of the molten steel, to avoid bubbles in the first slab at the beginning of the casting sequence, and to avoid degeneration of the refractory due to thermal shocks. Combustion-heated tundishes on average are only 20 percent efficient. Although earlier tundishes heated through electrical induction failed to generate enough heat to be effective in the manufacturing process, new methods have been developed to improve heating capacity. Tundishes heated by electrical induction have the potential to reach efficiency levels of 98 percent; however, the use of electricity may result in indirect energy losses in power generation. Energy savings can also be attained by refraining from heating the tundish. Practices at a plant in Brazil have shown that the use of a cold tundish is operationally feasible and that it brings with it several main benefits: a 70 percent reduction in the time for machine return after interruptions at the beginning of the cycle, a 78 percent reduction of natural gas consumption, a 90 percent increase of the lifetime of the tundish lids, and improvement of the working conditions on the casting platform due to heat and noise reductions. (Percentages are expressed on a per process unit basis). The practice was not found to have any influence on the quality of the product at the Brazil plant.

The practice of using cold tundishes does however present some risks for the steel manufacturer since the use of a cold undried tundish could potentially cause premature failure of the dish, which in turn could create catastrophic conditions on the caster. Because of the inherent danger associated with the molten steel that the tundish contains, the decision to attempt using cold tundishes is highly site-specific and cannot be predicted or recommended for all facilities. (AISI, 2011)

At North Star Steel, Iowa, it was estimated that the installation of recuperators for the ladle and tundish heating system would result in fuel savings of 28 percent at the ladle heaters and 26 percent at the tundish dryer. Payback periods were estimated to be from one to 10 years at the time, but have not been verified. (AISI, 2011)

While a tundish heater-dryer (capital cost $45,000) annually saves approximately 1,000 MMBtu (1,050 GJ) of natural gas, ladle heaters (capital cost $70,000) save 13,500 MMBtu (14,000 GJ) of natural gas per year. Although general estimates of the fuel savings are difficult to make, one estimate placed potential energy savings at 50 percent, or approximately 0.017 MMBtu/ton (0.02 GJ/tonne) of crude steel.

Energy Efficiency Technologies and Measures Available for Electric Arc Furnace Steel Production in the U.S.[a] (Worrell 1999, 2009; AISI, 2011)

Option	Applicability and Feasibility Codes (see list of codes below)[b]	Payback Time (years)[c]
Steelmaking - Electric Arc Furnace		
Improved process control (neural network)	EX	0.5
Adjustable speed drives	EX	2–3
Transformer efficiency—ultra-high power transformers	C, EX	5.2
Bottom stirring/stirring gas injection	C, EE, N	0.2
Foamy slag practice	C, EX	4.2
Oxy-fuel burners	C, EX	0.9
Post-combustion of the flue gases	C, EX,	
DC arc furnace	C, N	
Scrap preheating—tunnel furnace (Consteel)	C, EE, S	
Scrap preheating, post-combustion—shaft furnace (Fuchs)	C, EE, N, S	
Engineered refractories		
Airtight operation	P	
Contiarc furnace	C, N, S	
Flue gas monitoring and control	C, EX	4.3
Eccentric bottom tapping on existing furnace	C, N, S	6.8
DC twin-shell with scrap preheating	C, EE, N	3.5
Casting		
Efficient caster ladle/tundish heating	EX	1.3
Near net shape casting - thin slab	C, EX	3.3
Near net shape casting - strip	C	

[a] See **Appendix C** for estimates of energy savings and costs for these process changes and measures prepared by Worrell (1999, 2009). See Table 1 for energy efficiency measures applicable to rolling and finishing operations.

[b] Applicability codes (AISI, 2011):

C = Site-specific variables may affect costs and/or practicality of use of the option at all facilities.
EE = Options that could improve energy efficiency and potentially lower GHG emissions but may increase other pollutants.
EX = Process already widely implemented at many existing facilities.
N = Only feasible for new units.
P = Immature process that is still in research and/or pilot stage as applied to Iron and Steel.
S = Specialized process only technically appropriate for some equipment configurations or types.

[c] Options with payback times of more than three years are not likely to be considered economically feasible by a facility. (AISI, 2011).

APPENDIX C

J. General Measures for Energy Efficiency Improvements

This section presents general energy efficiency measures that could be used at both Integrated Iron and Steel and EAF plants.

Preventive Maintenance

Training programs and good housekeeping programs help to decrease energy consumption throughout the plant. Some estimates place the energy savings at 2 percent of total energy use, or a fuel savings of approximately 1.39 MMBtu/ton (0.45 GJ/tonne) of product and an electricity savings of approximately 0.034 MMBtu/ton (0.04 GJ/tonne) of product. One estimate of annual operating costs was $16,600 per plant, or approximately $0.018/ton ($0.02/tonne) of crude steel.

Energy Monitoring and Management System

Energy monitoring and management systems help provide for optimal energy recovery and distribution between processes at the plant. These systems may reduce energy consumption by 0.5 percent, or fuel savings of approximately 0.10 MMBtu/ton (0.12 GJ/tonne) of product and electricity savings of approximately 0.0086 MMBtu/ton (0.01 GJ/tonne) of product. Based on a system installed at one plant in The Netherlands, the cost of a monitoring and management system was approximately $0.21/ton ($0.23/tonne) of crude steel based on an investment cost of $1.2 million. The payback time is estimated as 0.5 years.

Combined Heat and Power/Cogeneration

All steel plants require both electricity and steam to operate, which make them good candidates for combined heat and power (CHP), also known as cogeneration. Modern CHP systems can be based on gas turbines with a waste heat recovery boiler, combined cycles that integrate a gas turbine with a steam turbine for larger systems, or high pressure steam boilers (both fuel-fired or waste heat boilers) coupled with a steam turbine generator. The type and size of CHP system utilized depends on a variety of site-specific factors including the amount and quality of off-gases from the coke oven, blast furnace, and BOF; the steam requirements of the facility, and the economics of generating power on-site versus purchasing power from the grid. CHP capital costs can range from $900 to $2,500/kW depending on size and technology. (EPA, 2007b) Estimates range from $20.6/ton ($22.7/tonne) of crude steel. The payback time is estimated as 6 years. Over thirty steel and Coke plants have currently installed CHP systems. (ICF, 2010) The newest Coke plants all recover the heat from the battery stack to produce steam and/or electricity. Most Integrated Iron and Steel plants use excess process fuel gases (BFG and COG) for CHP units.

A significant barrier to CHP development and deployment is thought to be due to local electric utility company policies to restrict their use. These policies would need to be addressed on a case-by-case basis before CHP could be implemented. (AISI, 2011)

High-Efficiency Motors

Due to the high number of motors at an Iron and Steel plant, a systems approach to energy efficiency should be considered. Such an approach should look for energy efficiency opportunities for all motor systems (e.g., motors, drives, pumps, fans, compressors, controls). An evaluation of energy supply and energy demand should be performed to optimize overall performance. A systems approach includes a motor management plan that considers at least the following factors:

- Strategic motor selection;
- Maintenance;
- Proper size;
- Adjustable speed drives;
- Power factor correction; and
- Minimize voltage unbalances.

One estimate of overall energy consumption by motors in the steel industry was 22 billion kWh. DOE has estimated that 12 percent of this energy could be saved through the use of more efficient equipment. One estimate places the potential energy savings from motor efficiency improvements at 0.3 MMBtu/ton (0.35 GJ/tonne). (Stubbles, 2000) Payback time is estimated as 1 to 3 years.

Motor management plans and other efficiency improvements can be implemented at existing facilities and should be considered in the design of new construction.

Appendix B: Projected GHG Emissions and Intensity (FY2018/19 to FY2029/30)

Year	2018/19 BASELINE	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30
GHG ($MtCO_2$-e/annum)	1.994	2.153	2.142	2.452	2.473	2.494	2.515	2.515	2.547	2.557	2.557	2.557
Crude Steel Production (Mtpa)	1.746	1.906	2.027	2.32	2.34	2.36	2.380	2.38	2.41	2.42	2.42	2.42
Renewable Electricity Purchases	N	N	N	N	N	Y From Oct 2023	Y	Y	Y	Y	Y	Y
Abatement Qty ($MtCO_2$-e/annum)	0	0	0	0	0	0.063	0.126	0.126	0.126	0.210	0.210	0.210
Net (MtCO2-e/annum)	1.994	2.153	2.142	2.452	2.473	2.431	2.389	2.389	2.421	2.347	2.347	2.347
GHG Intensity tCO_2-e/t	1.142	1.129	1.057	1.057	1.057	1.030	1.004	1.004	1.004	0.970	0.970	0.970
JSIS GHG Intensity tCO_2-e/t	1.142						1.004					0.970
2 Degrees	1.553	1.525	1.498	1.471	1.445	1.418	1.393	1.367	1.317	1.269	1.221	1.175
Below 2 Degrees	1.438	1.381	1.325	1.269	1.213	1.157	1.102	1.046	1	0.954	0.907	0.861
Paris Pledges	1.662	1.66	1.659	1.657	1.656	1.655	1.654	1.652	1.65	1.648	1.646	1.644