Energy Audit Report

Of **BHAVANI INDUSTRIES,** KOLHAPUR

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Under the Joint Initiative of WB-GEF (BEE) and Institute for Industrial Productivity

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Figure 1: Product and Manufacturing Method Classification

1.0 INTRODUCTION

In November 2011 MB Associates assisted a series of audits of operation – with a view to reducing energy consumption – in the Kolhapur foundry cluster. The audits were carried out by Shivaji University personnel as part of a World Bank-GEF-BEE initiative. MB Associates' role was to assist the Institute for Industrial Productivity (IIP) to provide industry specific technical guidance before and during the audits.

The objective of the project was to develop an understanding of the overall performance of the Kolhapur Cluster, carry out a comparison of that performance and provide guidance as to the methods required for improvement. This should enable the foundries to check and improve their efficiency and consumption of resources and energy.

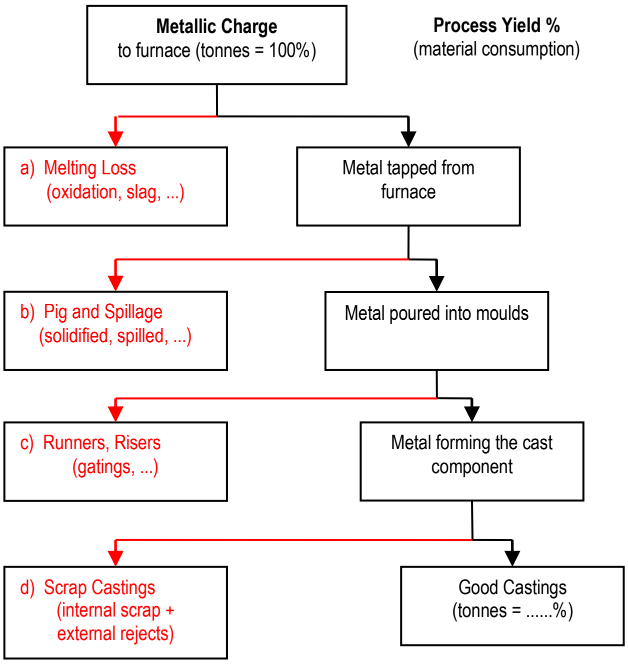
The analysis and the recommendations made in this report are based on the audit data provided by Shivaji University and the information provided by the foundries themselves and observations made during the field visits undertaken in November 2012.

In order for the individual units to better understand the energy audit results and the recommendations made thereof, a brief explanation is provided about Key Performance Indicators (KPIs) in a foundry.

1.1 Key Performance Indicators (KPIs)

1.1.1 Process Yield

This KPI monitors how much of the material processed ends up as good saleable castings. As most of the material which does not end up as good castings is recycled, the loss of material is of minor importance. Much more important is the loss of energy, labour time, and capacity for processing material which does not end up as a saleable product. See below:



Performance:
Tonnes of Good Castings divided by tonnes of liquid melt processed;

This KPI is comprised from 4 sub-indicators
a) KPI 1.1 – Melting loss (%)
b) KPI 1.2 – Pig and spillage (%)
c) KPI 1.3 – Runners and risers (%)
d) KPI 1.4 – Scrap castings (%)

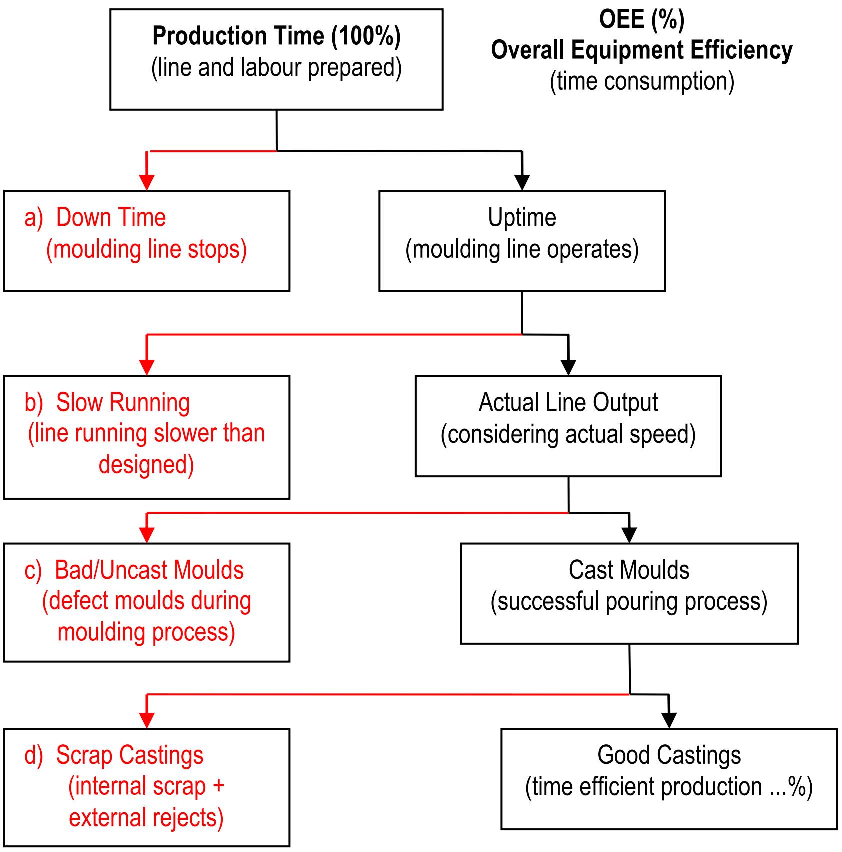
Formula:
KPI 1 = (1-a) x (1-b) x (1-c) x (1-d) x 100%

No	KPI	Definition
1	Process Yield (%)	Material consumption based performance. The weight of net good castings produced as a percentage of the metallic material charged to the melting furnaces; comprised from 4 performance indicators.
1.1	Melting Loss (%)	The material lost during melting (either by oxidation or incorporation into the slag) expressed as a percentage of the metallic material charged to the melting furnaces.
1.2	Pig and Spillage (%)	The amount of liquid metal tapped from the furnace which does not get poured into moulds expressed as a percentage of the liquid metal tapped.
1.3	Runners and Risers (%)	The weight of liquid metal poured into the mould which does not form a casting expressed as a percentage of the liquid metal poured into that mould.
1.4	Scrap Castings and Rejects (%)	The weight of scrap castings (including customer returns) expressed as a percentage of the weight of gross castings produced.

1.1.2 Effective Production (OEE)

Time consumption based performance also known as Overall Equipment Effectiveness indicates the gap between actual and ideal performance.

The time during which the plant produces good saleable castings expressed as a percentage of the time that the plant was available for production. See below:



This KPI is comprised from 4 sub-indicators

a) KPI 2.1 – Down Time (Moulding) (%)
b) KPI 2.2 – Slow Running (%)
c) KPI 2.3 – Bad Moulds (%)
d) KPI 2.4 – Scrap and Rejects (%)

Formula:

KPI 2 = (1-a) x (1-b) x (1-c) x (1-d) x 100%

No	KPI	Definition
2	OEE (%) – Overall Equipment Efficiency	Time consumption based performance. The time during which the plant produces good saleable castings expressed as percentage of the time that the plant was available for production; comprised from 4 performance indicators.
2.1	Downtime (Moulding) (%)	The time that a moulding facility is not operating due to breakdowns or operational reasons expressed as a percentage of the total time available for production (often called the net operating time).
2.2	Slow Running (%)	The production time lost by operating a moulding facility at a speed below the design capacity or calculated output expressed as an equivalent percentage of the net operating time.
2.3	Bad Moulds (%)	The number of moulds that are not poured expressed as a percentage of the total number of moulds produced.
2.4	Scrap and Rejects (%) (internal scrap and external rejects)	The weight of scrap castings (including customer returns) expressed as a percentage of the weight of gross castings produced.

1.1.3 TEEP (Total Effective Equipment Performance)

No	KPI	Definition
3	TEEP (%) – Total Effective Equipment Performance	Time based capacity utilisation. Total effective equipment performance (TEEP) measures OEE effectiveness against calendar hours, i.e. 24 hours per day, 365 days per year. Total Effective Production per annum expressed as a percentage of the total plant capacity if operating for 24 hours per day, 365 days per year.

1.1.4 Energy Consumption

The KPIs referring to energy consumption are monitored for two levels as some 75% of total energy consumption is usually consumed already only in the melting plant and measures for improvement can be concentrated on this department:

- KPI 4.1 – energy consumption in melting
- KPI 4.2 – energy consumption in foundry

The energy consumption includes all types of energy such as electric power, coke (i.e. when combustion melting in cupola furnaces), gas and oil. The energy consumption is expressed in kWh.

No	KPI	Definition
4	Energy Consumption	Energy is one of the most important cost factors apart from raw material and in melting the energy supply often is a limiting capacity factor.
4.1	Energy Consumption in Melting (Melting Efficiency) (kWh/tonne melt)	Furnace power consumption (kWh) divided by the tonnage of metallic material charged to the furnaces *(the melting consumes some 75% of the total foundry energy demand; a good performance of the melt shop saves money and capacity).*
4.2	Energy Consumption in Foundry (kWh/tonne good castings)	Total power consumption (kWh) in the foundry departments divided by the tonnage of net good castings produced *(the cost impact of energy consumption is a competitive mark)*.

1.1.5 Sand Consumption

The performance of sand consumption is monitored with 2 KPIs:

- new (fresh) sand consumption per tonne of good castings (indicates design of casting process)
- rate of sand regeneration (indicates how much sand must be dumped)

No	KPI	Definition
5	Sand Consumption	The sand utilised for making the moulds is supposed to be recycled and regenerated as much as possible. A perfect designed and operated sand regeneration plant will reduce costs for sand purchase and also improve quality of castings.
5.1	Fresh Sand Consumption (tonnes sand/tonnes good castings)	The weight of new (fresh) sand used divided by the tonnage of net good castings produced. This indicator includes sand for moulding as well as sand for core making.
5.2	Rate of Sand Regeneration (%)	The percentage of sand that is re-used at each moulding cycle (as an average of all moulding cycles included in the sampling period).

1.1.6 Labour Productivity

No	KPI	Definition
6	Labour productivity (man hours/tonnes good castings)	Apart from the overall productivity a lean organisation and a high grade of automation have the impact on labour productivity. The total number of man hours worked (excluding management and supervisory hours) divided by the tonnage of net good castings produced.

2.0 BHAVANI INDUSTRIES

2.1 General Description

Annual Tonnage – 2,040 tonnes per annum.

Melting is carried out by means of a divided blast cupola of 30" diameter.

All moulding is hand or floor moulding using a CO_2/silicate system. Cores are produced using a chemically bonded process based on a phenolic resin.

The plant operates a 2 shift system for 6 days per week. Moulding takes place for two days followed by pouring on the third day when there is no moulding.

2.2 Product Mix

All of the 2,040 tonnes per annum produced by Bhavani Industries are covered by the category GHGE – grey iron general engineering castings. An explanation of the categories is given in Figure 1.

2.3 Audit Results

2.3.1 Process Yield

During the audit period some 31,112 kg of metallics was charged to the cupola. The amount of coke charged during this period was 3,783 kg (12.2%). Allowing for a proportional allocation of the bed coke, the total coke consumed was 4,493 kg (14.4%).

Some 28,350 kg of molten metal was produced which equates to a melting loss of 8.9%. Metal poured into the moulds was 26,800 kg so that there was 1,550 kg lost to pig and spillage (5.5%).

The average box yield of the castings produced was 76.2%, giving a gross castings weight of 20,427 kg. The average scrap rate of 4.9% results in a net good saleable casting weight of 19,426 kg.

Thus some 62.4% of the weight of the material charged to the cupola resulted in castings that could be sold.

A representation of the calculation of the Process Yield is given below.

Process Yield Calculation

Material Charged	31,112	100%	100%
Metal Loss	2,762	8.9%	
Liquid Metal	28,350	91.1%	91.1%
Pig and Spillage	1,550	5.5%	
Metal in Moulds	26,800	94.5%	86.1%
Runners & Feeders	6,373	23.8%	
Gross Castings	20,427	76.2%	65.6%
Scrap & Rejects	1,001	4.9%	
Net Good Castings	19,426	95.1%	62.4%

Process Yield – 62.4%

2.3.2 Effective Production

The plant moulds for two days and pours on the third. At the time of the audit some 75 moulds had been produced on the two previous days and no breakdown or stoppages had been reported.

The plant is capable of producing some 70–80 moulds per day depending on the size and complexity. Thus on the two days before the audit the number of moulds that could be produced is 150. The 75 produced therefore represents only 50% of the potential available.

Bad moulds were reported at 5.3%.

Therefore the Effective Production for the plant was 45.4%. This means that the plant produced saleable castings for only 45.4% of the available operating time.

The calculation of Effective Production is given below.

Effective Production Calculation

Production Time	150	100%	100%
Downtime	0	0%	
Operating Time	150	100%	100%
Slow Running	75	50.0%	
Moulding Output	75	50.0%	50.0%
Bad Moulds	4	5.3%	
Good Moulds	71	94.7%	47.4%
Scrap Castings	3	4.2%	
Good Production	68	95.8%	45.4%

Effective production – 45.4%

2.3.3 TEEP

The plant operates for some 600 shifts per annum with moulding on two days followed by pouring on the third. Therefore moulding is carried out for some 400 shifts or 3,200 man hours. This equates to a plant utilisation of 36.5%. However, when the plant is operating, the Effective Production is only 45.4%. Thus the real plant utilisation or TEEP (Total Equipment Effective Production) is only 16.6% (36.5% x 45.4%). This means that the plant operates in such a way that it only uses 16.6% of its total capacity.

2.3.4 Energy

i) *Melting* – the plant consumed coke at the rate of 14.4% of the charged weight. Coke with an ash content of 10.8% ash has an energy equivalent of 8,075 kWh per tonne. Therefore the coke consumed during melting is equivalent to 1,163 kWh per tonne charged.

ii) *Overall Consumption* – during the audit period the energy consumed was as follows:

Melting	36,183 kWh
Other Operations	1,742 kWh
	37,925 kWh

During this time 19.426 tonnes of net good castings were produced giving a total energy consumption of 1,952 kWh per tonne of good castings.

2.3.5 Sand

New sand consumption was 1.42 tonnes per tonne of good castings with very little new sand used for core making. As the plant uses a CO_2/silicate binder system, it is almost impossible to reclaim the sand successfully. This means that all moulding sand has to be purchased as new sand and subsequently dumped.

2.3.6 Productivity

Using the shift patterns and manning levels provided, it has been calculated that the level of productivity in the plant is such that it requires 61.2 man hours (direct labour) to produce one tonne of good castings.

2.4 Comparison of Results

In order for Bhavani Industries to obtain the maximum benefit from the audit, their data will be compared below to other foundries

2.4.1 Kolhapur Cluster

In the table below the Bhavani Industries audit data is compared to the average of all of the Kolhapur audit results.

Bhavani Industries vs. Kolhapur Cluster		
	Bhavani Industries	**Kolhapur Cluster**
Melting Loss	8.9%	6.8%
Pig & Spillage	5.5%	4.6%
Runners & Feeders	23.8%	19.7%
Scrap & Rejects	4.9%	4.6%
Process Yield	62.4%	68.1%
Downtime	Nil	Nil
Slow Running	50.0%	50.0%
Bad Moulds	5.3%	2.4%
Scrap & Rejects	4.9%	4.6%
Effective Production	45.5%	46.6%
TEEP	16.6%	28.8%
Energy Consumption Per Tonne Melted	1163 kWh	1057 kWh
Per Tonne Good Castings	1952 kWh	1770 kWh
Sand Consumption New Sand/tonnes castings	1.42 t	0.50 t
Cores/tonnes castings	Neg	0.08 t
Sand Reclamation	0.0%	59.0%
Productivity Man hours/tonnes castings	61.2	48.9
Direct Ratio	4	4

However, the above table compares the Bhavani Industries performance with other foundries in the area which have different products and production methods. To gain a more realistic guide as to the Bhavani Industries performance, it must be compared to that of similar foundries.

2.4.2 Similar Foundries

In the table below the Bhavani Industries performance data is compared to that of similar foundries in other parts of the developing world (both average and best practice) and Western Europe.

Bhavani Industries Performance Comparison

	Bhavani Industries	Developing Countries Average Performance	Developing Countries Best Practice	Western Europe Average Performance	Western Europe Best Practice
Melting Loss	8.9%	7.7%	1.0%	2.0%	1.0%
Pig & Spillage	5.5%	1.5%	1.0%	3.5%	3.0%
Runners & Feeders	23.8%	25.7%	13.1%	30.0%	27.5%
Scrap & Rejects	4.9%	8.2%	3.9%	2.5%	2.0%
Process Yield	62.4%	62.0%	81.8%	64.5%	68.2%
Downtime	Nil	21.3%	12.5%	5.0%	2.5%
Slow Running	50.0%	8.4%	0.0%	12.5%	10.1%
Bad Moulds	5.3%	1.4%	0.5%	0.5%	0.2%
Scrap & Rejects	4.9%	8.2%	3.9%	2.5%	2.0%
Effective Production	45.5%	65.3%	83.7%	80.6%	85.7%
TEEP	16.6%	15.2%	22.0%	33.7%	37.7%
Energy Consumption Per Tonne Melted	1163 kWh	1447 kWh	901 kWh	625 kWh	620 kWh
Per Tonne Good Castings	1952 kWh	3582 kWh	1521 kWh	1445 kWh	1298 kWh
Sand Consumption New Sand/t castings	1.42 t	1.36 t	0.43 t	0.41 t	0.37 t
Cores/t castings	Neg	N/R	N/R	N/R	N/R
Sand Reclamation	0.0%	88.5%	95.3%	91.0%	93.0%
Productivity Man hours/t castings	61.2	168.1	24	30	25
Direct Ratio	4	N/R	N/R	N/R	N/R

The data above applies to small hand/floor moulding foundries producing grey iron general engineering castings using a chemically bonded sand system. The term "Developing Countries" applies to countries such as Brazil, Russia and Mexico.

It should be noted that scrap levels are quoted in terms of the quality standards prevailing in the country of the foundry concerned. For instance, what is a good casting in Kolhapur may not be a good casting in the UK or Germany.

2.5 Conclusions and General Comments

2.5.1 Process Yield

The melting loss experienced in the cupola was quite high at 8.9% and compares to a value of 6.8% for the average of the plants in Kolhapur that were audited. Figures for the melting loss for similar plants in other parts of the world would be 7.7% for developing countries and 20% in Western Europe. The main reasons for such a high melting loss figure are considered to be

- incorrectly designed DB cupola (wrong size and spacing of tuyeres)
- blast rate and fan pressure not matched to cupola diameter and wind belt size.

The above two issues are also responsible for the high charge coke consumption of 12.2%. A properly designed cupola would reduce the coke usage by some 25%.

Also an issue for the high melting loss is the fact that the cupola stack level was very low during operation. This has the effect of high oxidation and little pre-heating of the charge material.

The pig and spillage figure (i.e. metal that is melted but not poured into the mould) is also high at 5.5%. This compares to 4.6% for the Kolhapur Cluster and 1.5%–3.5% in other parts of the world.

2.5.2 Effective Production

No downtime was recorded for the plant. The facilities available should produce some 70–80 moulds per day depending on the size and complexity required. Therefore in the two days before the audit, some 150 moulds could have been produced. This represents only 50.0% of the potential plant capacity.

Of the 75 moulds produced, 55 of them (73.3%) were of a size and shape such that they could have easily been made on a simple pattern-flow system. Such a system would be expected to produce some 6 moulds per hour with a minimum workforce.

The other 20 moulds would still have to be made by hand as per current production.

There is a quoted Bad Moulds figure of 5.3% which is very high for a chemically bonded sand system. This compares to an average of 2.4% for Kolhapur Cluster, 1.4% for developing countries and 0.5% for Western Europe.

Taking into account the scrap level, the Effective Production of the plant is only 45.4% compared to 46.6% for the Kolhapur Cluster, 65.3% for developing countries and 80.6% for Western Europe.

2.5.3 Other Parameters

The energy consumed during melting was 1,163 kWh/tonne which compares with the Kolhapur average of 1,057 kWh/tonne. The equivalent figure for Western Europe would be 625 kWh/tonne. An important factor in the high energy consumption for melting is the incorrect design of the cupola and its ancillary plant as indicated above.

The overall energy consumption per tonne of finished castings at 1,952 kWh/tonne is similar to that of the remainder of the Kolhapur Cluster which has an average of 1,770 kWh/tonne. A similar foundry in Western Europe would operate at an average of 1,445 kWh/tonne of castings.

There is no sand reclamation carried out at the plant. The binder system used (CO_2/silicate) is almost impossible to reclaim. Where limited wet reclamation is carried out, a highly alkaline liquor is produced which is not possible to dispose of due to the environmental issues involved. Bhavani Industries should change to a low nitrogen furan system and install a sand reclamation plant. Such a system would easily reclaim at a level in excess of 90%. This would save a considerable cost in sand purchase and would improve the surface condition of the castings.

The productivity level of 61.2 man hours per tonne is high largely because of the low Effective Production level. This is illustrated by considering the TEEP value which shows that Bhavani Industries only operates at a plant utilisation of 16.6% of its moulding capacity against 28.8% in other Kolhapur foundries.

Similar foundries in Western Europe would operate at a productivity level of 30 man hours per tonne on average with the better foundries operating as low as 25.

2.6 Potential Improvements

A re-design of the cupola and blowing system would:

- reduce coke consumption
- reduce melting loss
- improve metal temperature
- increase melting rate
- reduce scrap levels
- reduce overall energy consumption per tonne of finished castings

Since material costs represent 66% of the total operating costs of the foundry, a reduction in melting loss of 2.1% (8.9% to 6.8%) represents a reduction in total operating costs of 1.4%. At the same time a reduction in coke consumption of 25% would reduce the total operating costs by 2%.

Thus improving the design of the cupola can add a minimum of 3.4% on the bottom line, which for a foundry of this type probably doubles the profit margin.

Further material savings can be achieved by changing the binder system to a furan, as described, and reclaiming the sand.

An improvement in the Effective Production (as indicated by installing a simple pattern-flow handling system) would take Bhavani Industries from a two shift operation to a single shift working for the same output. This would reduce the labour and energy costs considerably. Alternatively, it would give the opportunity to expand the existing production levels.

Figure 1 Product and Manufacturing Method Classification

Grey iron product categories

Automatic moulding

GABH = automotive engine blocks and cylinder heads
GAAO = automotive other
GAAG = agriculture
GAMI = mining

Mechanised moulding

GMBH = medium sized engine blocks and heads (energy generation)
GMAG = agriculture
GMMI = mining
GMGE = general engineering

Manual (hand) moulding

GHBH = large size engine blocks and heads (energy generation)
GHMI = mining
GHGE = general engineering

Ductile iron product categories

Automatic moulding

DAAU = automotive other
DAGE = general engineering

Mechanised moulding

DMAU = automotive
DMGE = general engineering

Manual (hand) moulding

DHEN = energy generation components
DHCO = compressor components
DHGE = general engineering

Steel product categories

Automatic moulding

SARC = railway components (c)
SAMM = mining components (m)
SAAC = commercial vehicles (c)
SAGC = general engineering

Mechanised moulding

SMRC = railway components (c)
SMMM = mining components (m)
SMPC = pumps and valves (c)
SMPS = pumps and valves (s)
SMGC = general engineering (c)
SMAC = commercial vehicles (c)

Manual (hand) moulding

SHMM = mining components (c)
SHPC = pumps and valves (c)
SHEA = energy components (a)
SHGC = general engineering (c)

c = carbon steel, s = stainless steel
m = manganese steel, a = high alloy steel