mitigation REPORT

SOUTH AFRICA'S GREENHOUSE GAS MITIGATION POTENTIAL ANALYSIS

TECHNICAL APPENDIX D – INDUSTRY SECTOR

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany





mitigation REPORT

SOUTH AFRICA'S GREENHOUSE GAS MITIGATION POTENTIAL ANALYSIS

TECHNICAL APPENDIX D – INDUSTRY SECTOR

The following citation should be used for this report:

Department of Environmental Affairs, 2014: South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis, Pretoria, South Africa.

The suite of reports that make up South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis include the following:

Technical Summary

Main Report

Technical Appendices:

Appendix A: Approach and Methodology

Appendix B: Macroeconomic Modelling

Appendix C: Energy Sector

Appendix D: Industry Sector

Appendix E: Transport Sector

Appendix F: Waste Sector

Appendix G: Agriculture, Forestry and Other Land Use Sector

List of Abbreviations

Abbreviation	Definition
AD	anaerobic digestion
AFOLU	agriculture, forestry and other land use
BAT	best available technology
BF	blast furnace
Capex	capital investment cost
BOF	basic oxygen furnace
CAIA	Chemical and Allied Chemical Industries' Association
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CHP	combined heat and power/co-generation of heat and power
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DEA	Department of Environmental Affairs
DoE	Department of Energy
EAC	equivalent annual cost
EAF	electric arc furnace
ERC	Energy Research Centre (University of Cape Town)
FL	fluorescent lamp
GDP	gross domestic product
GHG	greenhouse gas
GHGI	Greenhouse Gas Inventory for South Africa
GVA	gross value added
GW	Gigawatt
GWh	Gigawatt hour
GWP	global warming potential
HFCs	hydrofluorocarbons
HVAC	heating, ventilation and air conditioning
HYL	gas-based direct reduced iron (DRI) steelmaking process
IEA	International Energy Agency
IEP	Integrated Energy Plan
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
kW	kilowatt
kWh	kilowatt hour

Abbreviation	Definition
$ktCO_2e$	kilotonnes of carbon dioxide equivalent
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MAC	marginal abatement cost
MACC	marginal abatement cost curve
MCA	multi-criteria (decision) analysis
MW	megawatt
MWh	megawatt hour
Mt	million tonnes
$MtCO_2e$	million tonnes of carbon dioxide equivalent
N_2O	nitrous oxide
NAC	net annual cost
NCCRP	National Climate Change Response Policy
NPV	net present value
NT	National Treasury
Opex	operation and maintenance cost
PAMSA	Paper Manufacturers Association of South Africa
PFRK	parallel flow regenerative kiln
RFG	refinery fuel gas
RHE	rural high income electrified
RLE	rural low income electrified
RLN	rural low income non-electrified
SAPIA	South African Petroleum Industry Association
SATIM	South African TIMES model
Stats SA	Statistics South Africa
TWG-M	Technical Working Group on Mitigation
UHE	urban high income electrified
ULCORED	gas-based direct reduced iron (DRI) steelmaking process (not yet in operation)
ULE	urban low income electrified
ULN	urban low income non-electrified
UNFCCC	United Nations Framework Convention on Climate Change
VSD	variable speed drive
WAM	'with additional measures' scenario
WEM	'with existing measures' scenario
WOM	'without measures' scenario
ZAR/R	South African rand

Table of Contents

List of Tables

List of Figures

List of Boxes

Acknowledgements

The South African Greenhouse Gas Mitigation Potential Analysis was supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), on behalf of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) of the Federal Republic of Germany.

The analysis was conducted by Camco Clean Energy, in partnership with Ricardo-AEA, PDG and Conningarth Economists.

The project team acknowledges the support of Dr Bruno Merven and Dr Andrew Marquard, both of the Energy Research Centre of the University of Cape Town, for providing updated energy price projections based on the South African TIMES model (SATIM).

Chapter 1: Introduction

1. Introduction

This appendix identifies the greenhouse gas (GHG) emissions mitigation potential for the South African industry sector. The mitigation potential is presented in the form of marginal abatement cost curves (MACCs) for the years 2020, 2030, and 2050; ranking available mitigation options in terms of their marginal abatement cost. The mitigation potential presented is considered to be technically achievable assuming that all identified mitigation technologies have been technically proven or will be proven prior to becoming available. This chapter includes an overview of the reference emissions projections for the industry sector and lists the potential future abatement opportunities for key subsectors within the industry sector.[1] This includes IPCC emissions sector 1A2 (combustion emissions from manufacturing industries and construction) and the relevant parts of IPCC Sector 2 (process emissions). Emissions associated with fuel combustion in residential and non-residential (commercial and institutional) buildings (IPCC category 1A4) are also included in this chapter at the request of the Technical Working Group on Mitigation (TWG-M). The industry sectors examined and sources of emissions as classified by the IPCC categories are listed in Table 1 below. The draft Greenhouse Gas Inventory for South Africa (GHGI) (DEA, 2013) only contains information on fuel-related emissions from manufacturing and construction (IPCC Sector 1A2) in aggregate. The sectors listed in Table 1, which were examined in more detail, are those which were identified as having either substantial fuel- or process-related emissions *and* for which sufficient additional information was available to model emissions at the sectoral level. Projections were compiled at a less-detailed level for other more minor (from an emissions perspective) industry sectors such as food and tobacco, wood and wood products but mitigation options were not examined.

Table 1: Industrial subsectors with IPCC emissions source classifications included in the mitigation analysis.

Industry sectors (and buildings)	Subsector	IPCC emissions category	
		Fuel combustion (1A)	Process emissions (2)
Metals production	Iron and steel production	1A2a	2C1
	Ferroalloy production	1A2a	2C2
	Primary aluminium production	1A2b	2C3
Minerals production	Cement production	1A2f	2A1
	Lime production	1A2f	2A2
Chemicals production	Chemicals production (including ammonia, nitric acid, carbide, titanium dioxide, petrochemical and carbon black production)	1A2c	2B (including 2B1, 2B2, 2B5, 2B6 2B8)
Mining	Underground and surface mining (non-coal products)	1A2i	
Buildings	Commercial/institutional	1A4a	
	Residential	1A4b	
Other	Pulp and paper production	1A2d	

1. Note that reference case projections cover all subsectors under IPCC emissions sector 1A2 (combustion emissions from manufacturing industries and construction) as shown in Table 2. Only a subset of those sectors has been covered in the mitigation potential assessment shown in Sections 4 and 5, due to data availability.

GHG emissions projections are presented for all activities identified in the GHGI for 2010 and mitigation opportunities are presented for all sectors listed in Table 1. Emissions from the use of electricity have been allocated to the end use sectors. GHG mitigation opportunities are presented that cover emissions from three separate sources, described below:

- Emissions from industrial processes, from the use of greenhouse gases in products, and from non-energy uses of fossil fuel.
- Emissions from the use of fuels in stationary combustion. Emissions result from the combustion of fuels in order to provide heat or mechanical work.
- Indirect emissions from the consumption of electricity.

Estimates of mitigation potential for the industry sector have been calculated independently of changes in other sectors.

Chapter II: Reference Case Projections

2. Approach and Assumptions

2.1 Industry

Two projections have been produced for the industry sector :

A 'reference case projection'; this is a projection of emissions from 2000 to 2050 assuming that no climate change mitigation actions have taken place since 2000. Thus for the period from 2000 to 2010, it does not follow the actual observed path of emissions but the path that emissions would have taken if none of the climate change mitigation actions implemented in this period had taken place. The UNFCCC refer to this as a 'without measures' scenario (WOM)

A 'with existing measures' (WEM) projection: this projection incorporates the impacts of climate change mitigation actions and climate change policies and measures implemented to 2010. For the period 2000 to 2010 the projections follow the actual path of observed emissions.

The projections were produced using a bottom-up methodology, with individual industry sectors modelled separately. The GHGI category 1A2, manufacturing industries and construction, was broken down into specific industry subsectors to allow for more detailed projections of fuel and electricity use required for the mitigation analysis. The overall approach was to take current fuel consumption and to project future fuel consumption based on expected growth rates in each sector. An allowance was made for autonomous energy efficiency improvements (that is improvements to energy consumption in the sector which occur simply as a result of replacing retired equipment with new, more efficient equipment). Emissions were calculated from fuel consumption by multiplying consumption of fuel by the appropriate emissions factor, as specified in the GHGI[2]. Current fuel use was taken either from fuel activity data in the GHGI, or where this was not detailed enough, from the energy balance for South Africa (DoE, 2013). On occasions where the energy balance did not provide sufficient detail, fuel use was estimated based on data on production levels and an estimate of specific energy consumption per unit of production.

Where assumptions were made on specific energy consumption, these are consistent with the assumptions made in the assessment of mitigation options and were sent to industry for review as part of the consultation process on mitigation measures. GDP growth in individual industry subsectors was taken from the macroeconomic modelling completed for this study.[3] The macroeconomic modelling allows the GDP growth to be modelled separately for each sector, but is constrained so that aggregate growth in the economy meets the GDP growth rate targets set for the analysis under the 'moderate growth' scenario as defined by the National Treasury (DoE, 2013).

Autonomous energy improvements were estimated on an industry-specific basis based on data primarily from the UK. This reflects energy efficiency improvements obtained under climate change agreements made with specific industry sectors that set specific targets for energy efficiency improvements. It is generally agreed that at least some of the improvements achieved under these agreements would have happened anyway, albeit on a longer timescale, as the agreements have accelerated implementation of energy efficiency measures. In view of this, it was assumed that autonomous energy efficiency improvements might account for half of the improvement seen, and that without specific measures, such as the agreement, this would be achieved over the natural renewal cycle, which was assumed to be 25 years. Full details of the assumptions made for individual subsectors are given in Table 2. Emissions from 2000 to 2010 are based on the draft national GHGI. Table 2 lists all sectors for which projections of emissions were made. The sectoral GDP growth rates that are referenced in Table 2 may be found in Section 3 of Technical Appendix B: Macroeconomic Modelling. Those sectors for which mitigation analyses were also conducted are listed in Table 1.

Process-related emissions are directly proportional to the amount of product produced, and are generally calculated from production statistics by applying an emissions factor of, for example kgCO_2/tonne, as reported in the draft GHGI[4]. These emissions factors were combined with forecasts of future production to produce projections of future process emissions. Forecasts of future production were based on the forecast GDP growth for the relevant industry sector.

In the case of hydrofluorocarbons (HFCs) used for refrigeration and air conditioning, the GHGI shows that HFC emissions more than tripled between 2005 and 2010. Emissions

2. Fuel combustion emissions factors give the quantity of GHG released per unit of fuel consumed, for example tCO_2/GJ coal burnt.

3. The methodology and assumptions behind this modelling are detailed in Section 3 of Appendix A: Approach and Methodology.

4. For some production processes, for example nitric acid, estimates of process-related emissions are based on actual measurements of gases emitted.

are likely to grow even more rapidly in the future as HFCs are used as substitutes for hydrochlorofluorocarbons (HCFCs) which are due to be phased out completely in South Africa by 2030. A detailed projection of growth was not feasible as an accurate inventory of these substances does not yet exist. Emissions were therefore forecast by looking at average emissions per capita in 2010 in Europe, where HCFCs have already been phased out. It was assumed that emissions per capita in South Africa would grow linearly to reach this level by 2030, and that thereafter they would grow at the same average rate as in Europe of 4% p.a. Due to the lack of a detailed inventory of HFC use mitigation options for HFCs were not considered.

2.1.1 Comparison of 'without measures' and 'with existing measures' projections

The above methodology takes as its starting point actual energy consumption in 2009. The result is a 'with existing measures' projection, as the impact of climate change measures implemented by 2009 will be reflected in the actual observed energy use and emissions. To create a 'without measures' scenario, the impact of climate change mitigation actions implemented between 2000 and 2010 was also assessed. This included quantified information on savings from implemented measures provided by industry to the study team. These savings are consistent with the assumptions made in constructing the MACCs about the level of implementation of mitigation options in 2010. Implementation of measures (and hence emissions savings) was assumed to be linear between 2000 and 2010. It is assumed that the fuel and electricity savings achieved by mitigation options in 2010 will be maintained into the future. The emissions reductions associated with electricity savings are calculated on an annual basis using the appropriate grid emissions factor for each year.

The mitigation options which are assumed to have been implemented between 2000 and 2010 are listed in Table 3, together with the assumed level of uptake in 2010. The level of uptake is defined as the percentage of installations or processes to which the measure is applicable, that are assumed to have implemented the measure by 2010. For example if improved process control has been implemented in half of the production processes to which it is applicable, then uptake is 50%. The emissions reductions that result from this assumed level of uptake are summarised in Table 4. These are calculated using the same assumptions regarding the reduction in emissions that individual measures achieve that are used in constructing the MACCs (see Section 4).

Table 2: Assumptions in Industry Projections

Sector	Fuel consumption in 2009	Electricity consumption in 2009	Growth rate in sector	Autonomous energy improvement
1A2a-i: Iron and steel primary production, blast furnace/basic oxygen furnace (BF/BOF)	Based on international benchmark (as assumed in MACCs of 21 GJ/t currently) for primary fuel consumption and production data from GHGI; fuel mix based on fuel mix for iron and steel sector as a whole in Energy Balance (DoE, 2013).	Included elsewhere	Taken from macroeconomic modelling for iron and steel production.	0.53% improvement from current reference value to best available technology (BAT) reference value of 17 GJ/t over 40 years.
1A2a-ii: Iron and steel primary production (Corex/Midrex processes)	Based on international benchmark (as assumed in MACCs of 15.5 GJ/t currently) for primary fuel consumption and production data from GHGI; fuel mix based on fuel mix for iron and steel sector as a whole in Energy Balance.	Included elsewhere	Taken from macroeconomic modelling for iron and steel production.	0.46% improvement from current reference value to BAT reference value of 12.9 GJ/t over 40 years.
1A2a-iii: Iron and steel secondary production electric arc furnace (EAF)	Included elsewhere	Based on international benchmark (as assumed in MACCs of 2.7 GJ/t currently) for primary fuel consumption and production data from GHGI	Taken from macroeconomic modelling for iron and steel production.	1.46% improvement from current reference value to BAT reference value of 1.5 GJ/t over 40 years.
1A2a-iv: Ferroalloys production	Based on international benchmark used in MACCs of 17.3 GJ/t of fuel and production data from GHGI; fuel mix assumes 30% coke and 70% coal.	Based on international benchmark used in MACCs of 14.5 GJ/t of electricity, and production data from GHGI.	Taken from macroeconomic modelling for basic non-ferrous metals.	0.45% fuel and 0.57% electricity based on improvement to BAT of 14.4 GJ/t for fuel and 11.9 GJ/t for electricity over period of 40 years.
1A2a-v: Iron & steel (I&S) other	Calculated as difference between fuel consumption in I&S sector as estimated in Energy Balance and fuel consumption estimated in above sectors.	Calculated as difference between electricity consumption in I&S sector as estimated in Energy Balance and electricity consumption estimated in above sectors	Taken from macroeconomic modelling for I&S production.	0.9% based on UK data on improvements in metal forming sector.
1A2b-i: Primary aluminium production	Included in 1A2b-ii	Based on value of 15.2 MWh/t as reported in (Cohen et al., 2012) and production data in GHGI	Taken from macroeconomic modelling for basic non-ferrous metals.	0.35% based on improvement from current value to BAT value of 13.2 MWh/t over period of 40 years.

Sector	Fuel consumption in 2009	Electricity consumption in 2009	Growth rate in sector	Autonomous energy improvement
1A2b-ii: Other non-ferrous	Calculated as difference between fuel consumption in non-ferrous metals as estimated in Energy Balance and fuel consumption estimated in primary aluminium .	Calculated as difference between electricity consumption in non-ferrous metals as estimated in Energy Balance and electricity consumption estimated in primary aluminium .	Taken from macroeconomic modelling for basic non-ferrous metals.	0.72% based on UK data on improvement in non-ferrous metals sector.
1A2c: Chemical and petrochemical	Based on data supplied by trade association, Chemical and Allied Chemical Industries' Association (CAIA, 2013) for 2011, with values for 2010 and 2009 estimated on basis of trend in GDP.	Based on electricity consumption reported in Energy Balance for chemicals and petrochemicals minus the electricity consumption in refineries reported by trade association South African Petroleum Industry Association (SAPIA) (SAPIA, 2010, 2013)	Taken from macroeconomic modelling for basic chemicals, other chemicals and man-made fibres (average of these two sectors).	0.92% (based on UK data on improvements in chemicals sector).
1A2d: Paper and pulp	Based on data supplied by trade association, the Paper Manufacturers Association of South Africa (PAMSA, 2013).	Based on data from Energy Balance.	Taken from macroeconomic modelling for paper and paper products.	0.32% based on assessment of current energy intensity compared to BAT levels and assuming improvement to BAT levels over 40 years.
1A2e: Food and tobacco	Based on data from Energy Balance	Based on data from Energy Balance.	Taken from macroeconomic modelling for food, beverages and tobacco	0.95% based on UK data on improvement in food and beverages industry
1a2fi: Cement	Based on data provided by industry giving fuel use of 4.1 GJ/t of clinker and production data from GHGI; fuel mix based on fuel mix for non-metallic minerals in energy sector.	Based on data from international benchmarks (110 kWh/t).	Taken from macroeconomic modelling for non-metallic minerals.	1.11% based on improvement from current value to BAT value over 40 years.
1a2fii: Lime production	Based on estimate from industry of current average intensity of 7.8 GJ/t.	Included in 1A2f-iii	Taken from macroeconomic modelling for non-metallic minerals.	0.62% based on improvement from current value to BAT value of 3 GJ/t over 40 years.

Sector	Fuel consumption in 2009	Electricity consumption in 2009	Growth rate in sector	Autonomous energy improvement
1A2f-iii: Other non-metallic minerals	Calculated as difference between fuel consumption in non-metallic minerals sector as estimated in Energy Balance and fuel consumption estimated in above sectors.	Calculated as difference between fuel consumption in non-metallic minerals sector as estimated in Energy Balance and fuel consumption estimated in above sectors.	Taken from macroeconomic modelling for non-metallic minerals.	0.74% based on UK data on improvement in other non-metallic minerals such as gypsum, kaolin and clay.
1A2i: Mining and quarrying (excluding coal mining)	Individual projections produced for gold, platinum group metals (PGM), diamonds, iron ore, and chromite and manganese based on energy use reported by industry. Fuel use in other types of mining and quarrying estimated by subtracting fuel use in these sectors from fuel use for mining and quarrying sector as a whole as reported in the Energy Balance.	Individual projections produced for gold, platinum group metals (PGM), diamonds, iron ore, and chromite and manganese based on energy use reported by industry. Electricity use in other types of mining and quarrying estimated by subtracting fuel use in these sectors from fuel use for mining and quarrying sector as a whole as reported in the Energy Balance.	Taken from macroeconomic modelling for gold and uranium mining (for gold mining) and other mining (for all other sectors).	In consultation with industry taken from projections of GHG emissions trajectories from the SA mining and mineral processing sectors to 2030 (Cohen et al., 2012). *Gold:* increase in intensity of electricity use 5% p.a. *PGM:* 0% to 2015 then increase in fuel intensity to 2020 of 1% p.a. and of 0.5% p.a. for electricity *Chromite and manganese* 0.84% p.a., improvement in energy intensity between 2012 and 2018 All other minerals, energy intensity assumed to be constant.

Sector	Fuel consumption in 2009	Electricity consumption in 2009	Growth rate in sector	Autonomous energy improvement
1A2g:Transport equipment	Based on data from Energy Balance, with overall total for these subsectors adjusted to give agreement for Sector 1A2 overall with energy activity data from GHGI, as the latter is considered to be a more accurate representation of energy use but is only supplied at an aggregate level for 1A2.	Based on data from Energy Balance.	Taken from macroeconomic modelling for motor vehicles, parts and accessories, and other transport equipment	2.81% based on UK data on improvement in motor manufacturers.
1A2h; Machinery		Based on data from Energy Balance.	Taken from macroeconomic modelling for machinery and equipment, electrical machinery and apparatus	2.81% based on UK data on improvement in motor manufacturers - closest analogous sector.
1A2i :Mining (excluding fuels) and quarrying		Based on data from Energy Balance.	Taken from macroeconomic modelling for coal mining, gold and uranium mining and other mining sectors.	0% differing trends in different parts of the sector; so set to zero for sector as a whole.
1A2j:Wood and wood products		Based on data from Energy Balance.	Taken from macroeconomic modelling for wood and wood products sectors.	1.34% based on UK data on improvement in wood panel manufacture.
1A2k: Construction		Based on data from Energy Balance.	Taken from macroeconomic modelling for building construction, civil engineering and other construction sectors.	0.1% nominal rate of improvement as lack of data for sector; energy use thought to be predominantly in mobile generators etc.
1A2l:Textile and leather		Based on data from Energy Balance .	Taken from macroeconomic modelling for textile and leather products sectors.	0.66% based on UK data on improvement in textiles and leather.
1A2m: Non-specified industry		Based on data from Energy Balance.	Taken from macroeconomic modelling as weighted average for all industry sectors not considered elsewhere.	0.1% nominal rate of improvement as lack of information on specific industries included in this sector.
1A4c; Agriculture, forestry and fishing		Based on fuel data from GHGI and electricity data from Energy Balance.	Taken from macroeconomic modelling for agriculture sector.	0.1% nominal rate of improvement as lack of data for sector; energy use thought to be predominantly in mobile equipment.

Table 3: Mitigation options assumed implemented between 2000 and 2010

Sector	Mitigation Option	Uptake in 2010
Primary aluminium production	Best process selection for primary aluminium smelting	50%
	Energy monitoring & management system	50%
	Improved process control	50%
	Improved electric motor system controls and variable speed drives	50%
	Energy-efficient utility systems	50%
Chemicals (ammonia))	Replace coal-fired partial oxidation processes with natural gas-fired steam reforming production	50%
Chemicals (nitric acid)	N_2O abatement for new production plants	90%
Chemicals (carbon black)	Tail-gas energy recovery for combined heat and power plant (CHP) and minimise flaring	20%
Chemicals production*	Revamp: increase capacity and energy efficiency	50%
	Energy monitoring and management system	20%
	Advanced process control	20%
	Improved electric motor system controls and variable speed drives	20%
	Energy efficient boiler systems and kilns	20%
	Energy efficient utility systems	20%
	Increase process integration and improved heat systems	20%
	Waste heat and/or gas energy recovery and utilisation for cogeneration	100%
Ferroalloys production	Implementing best available production techniques	20%
	Replace semi-closed submerged arc furnace with closed type	20%
	Energy monitoring and management system	20%
	Improved electric motor system controls and variable speed drives	20%
Iron & steel production	Energy monitoring and management system	25%
	Improved process control	25%
	Improved electric motor system controls and variable speed drives	25%
	Energy efficient boiler systems and kilns	25%
	Energy-efficient utility systems	25%
	Improved heat exchanger efficiencies	25%

Sector	Mitigation Option	Uptake in 2010
Lime production	Installation of shaft preheaters	60%
	Use alternative fuels including waste and biomass	10%
	Energy monitoring and management system	40%
	Improved process control	60%
	Improved electric motor system controls and variable speed drives	20%
	Energy-efficient utility systems	20%
	Improved heat exchanger efficiencies	20%
Underground and surface mining	Improve energy efficiency of mine haul and transport operations	50%
	Process, demand & energy management system	50%
	Energy efficient lighting	50%
	Install energy-efficient electric motor systems	50%
	Optimise existing electric motor systems (controls and variable speed drives)	50%
	Onsite clean power generation	20%
Pulp & paper production	Convert fuel from coal to biomass/residual wood waste	20%
	Application of combined heat and power (CHP)	20%
	Energy recovery system	20%
	Energy monitoring and management system	20%
	Energy efficient electric motors, improved controls and variable speed drives	20%
	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)	20%
	Improved process control	20%

* *These energy efficiency measures are considered to be applicable to production processes which are reported in the GHGI separately, as they also have process related emissions (e.g. ammonia, nitric acid and carbon black.), and also to a range of other chemicals produced in the country for which individual product level data is not available.*

Table 4: Estimate of emissions reductions achieved in 2010 through measures implemented between 2000 and 2010 (ktCO$_2$e per year)

Summary	Process related	Fuel related	Electricity related	Total
Primary aluminium production	90		506	597
Chemicals production	1,600	740	236	1,767
Ferroalloys production	217		586	803
Iron & steel production		143		143
Surface and underground mining		253	14,689	14,942
Pulp & paper production		-64	341	277
Total	**1,907**	**1,072**	**16,360**	**18,529**

2.2 Buildings

The emissions projections for the commercial sector are based on building stock growth and historical energy activity data in the sector. Although data was available on existing stock by purpose of buildings, there was not enough information about energy demand in different types of buildings. Therefore demand for fuel in the commercial sector is not split by building type.

The energy demand data for commercial sector buildings is scarce, and stock level data vary from source to source. For these reasons historical fuel consumption was used as a basis for future projections. In other words, the implied stock and demand per m^2 of stock is based on historical fuel consumption.

For the residential sector, the underlying driver of emissions is the number of households. Household numbers are growing faster than population, as the average number of occupants per household is falling, partly in response to rising income levels. Using historical population and household number data, it was observed that household numbers are linearly dependent on historical population numbers. A linear regression model was therefore used to build future projections of household numbers based on population numbers to 2050. Adding GDP as an additional variable did not provide a better fit of the historical data set to a multiple regression model using both population and GDP. Therefore future household numbers are based solely on population growth. This can be expressed as follows:

$$\min_{a,b} \sum_{i=1}^{n} (hh_i - a - b * pp_i)^2$$

Where hh_i are historical observations of household numbers, pp_i are historical observations of population numbers, and n is the number of observations. The sought coefficients a and b are then used to calculate the linear projection of future household numbers for each future year j:

$$\forall j, hh_j = a + b * pp_j$$

The household energy demand is available in good detail in previous studies. Households are split into income categories to facilitate the use of this data. The six resulting income groups are assumed to have a fixed demand for energy, and are each assigned fuel demands for cooking, heating and lighting. However, they are dynamic in size, and the proportions evolve to represent increased income in society and electrification levels.

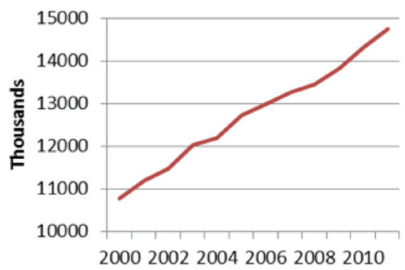
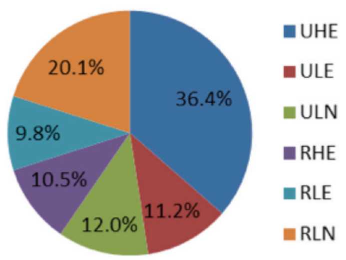
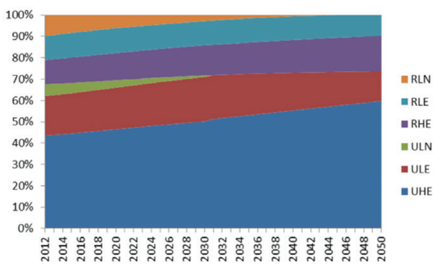
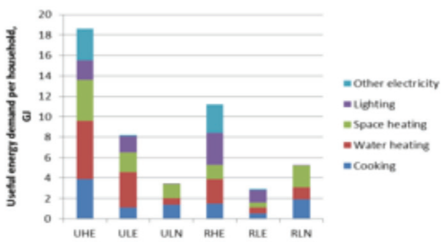
In short, consumption of each fuel, and subsequently emissions associated with it, are calculated based on fixed demand for fuels in each income group, and the development of income group proportions, as follows:

$$\forall f, \forall j, \quad U_{f,j} = \sum_{g=1}^{6} hh_j * hp_{g,j} * d_{f,g}$$

Where j are future years in the time horizon, f – fuels analysed, $U_{f,j}$ – total demand for fuel f in year j; $hp_{g,j}$ – proportion of income group g in year j in %, and $d_{f,g}$ is demand for fuel f in the income group g. Demand for fuels is calculated separately for cooking, heating and lighting.

The main parameters used in the projections of the commercial and residential sectors, their values and sources are shown in Table 5.

Table 5: Building sector assumptions

Parameter	Assumed value	Notes	Sources
Stock growth, commercial sector	1.9%	Same for all years in the time horizon	SBCI (2009)
Historical household numbers			General Household Surveys, Stats SA (2002–2011)
Household groupings in 2001		Split used from the same source as demand levels for consistency. Groups: UHE – urban high income electrified ULE – urban low income electrified ULN – urban low income non-electrified RHE – rural high income electrified RLE – rural low income electrified RLN – rural low income non-electrified	Winkler (2006)
Household grouping development to 2050		Most household growth assumed in urban areas with rural growth at half the rate of the overall household growth rate. 99% and 90% urban and rural electrification by 2030 respectively; 30% and 60% still low income in urban and rural areas. Post 2030 – extrapolated and smoothed.	Winkler (2006), current study
Household energy demand		Given demand refers to useful energy	Winkler (2006)

3. Reference Case Projections

The 'without measures' (WOM) reference case projection and the 'with existing measures' (WEM) projection for the industry sector (including buildings and agriculture) are shown in Figure 1 and Figure 2 respectively, and in tabular format in Table 6 and Table 7. Overall emissions in the sector are forecast to be about five times higher in 2050 than in 2000, rising from 235 $MtCO_2e$ to 1,189 $MtCO_2e$ in the WOM projection and to 1,118 $MtCO_2e$ in the WEM projection. Due to the high carbon intensity of electricity generation in South Africa currently and into the future under the WOM and WEM scenarios, total emissions for the industry sector (including buildings and agriculture) are dominated by those associated with electricity use; these account for 67% of emissions in 2000, falling to about 63% by 2050, as the impact of decarbonising the power sector mitigates somewhat the impact of increasing electricity consumption.

Overall emissions from the manufacturing and construction sectors accounted for 70% (164 $MtCO_2e$) of total emissions from the industry sector in 2000 and 62% (195 $MtCO_2e$) in 2010. Emissions from manufacturing and construction rise strongly though, and account for 81% of total emissions from the sector by 2050 (906 $MtCO_2e$) under the WEM scenario. Of the emissions from the manufacturing and construction sectors in 2010, electricity consumption accounted for 65%, fuel for 20% and process related emissions for 15%. About 50% of these process emissions arise from iron and steel production; other significant contributors to process related emissions are the cement industry, ferroalloys production and aluminium production. While buildings accounted for 28% of emissions in 2000, and 34% in 2010, they are only projected to account for 21% of emissions by 2050, as energy use in buildings is forecast to grow more slowly than in industry.

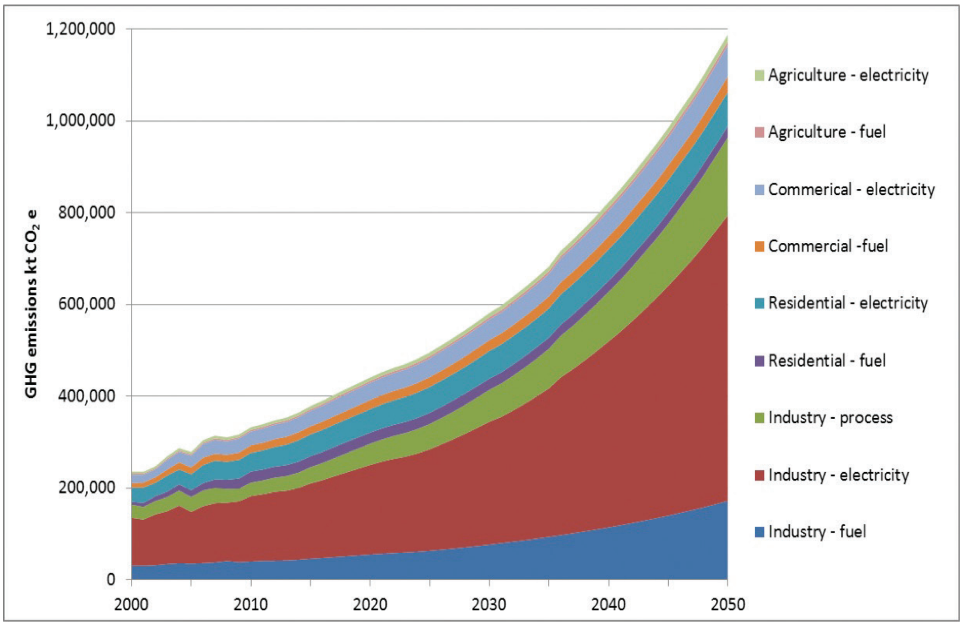


Figure 1: Reference case (WOM) projection for industry

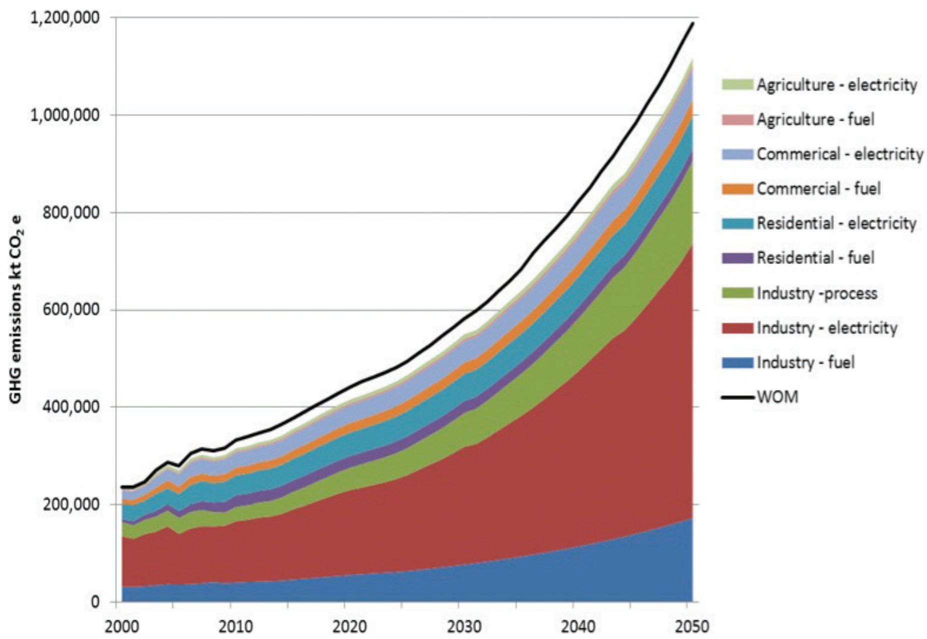


Figure 2: Reference case (WEM) projection for industry

Table 6: Industry sector reference case (WOM): total of all GHGs (in ktCO$_2$e)

Emissions	2000	2010	2020	2030	2040	2050
Industry – fuel	31,055	39,971	55,326	76,748	114,086	172,137
Industry - electricity	104,172	142,393	195,213	267,969	405,339	622,140
Industry –process	28,774	29,145	45,879	69,291	108,122	169,925
Residential – fuel	6,504	24,424	24,229	24,553	24,395	24,667
Residential - electricity	30,666	40,829	51,606	60,266	68,247	73,742
Commercial –fuel	9,547	16,267	19,636	23,703	28,612	34,537
Commercial - electricity	18,353	30,166	37,350	45,360	55,616	67,474
Agriculture – fuel	2,387	3,308	4,111	5,002	6,394	8,311
Agriculture - electricity	4,228	5,985	7,633	9,347	12,139	15,862
Total WOM	**235,684**	**332,489**	**440,984**	**582,237**	**822,949**	**1,188,796**

Table 7: Industry sector with existing measures (WEM): total of all GHGs (in ktCO$_2$e)

Emissions	2000	2010	2020	2030	2040	2050
Industry – fuel	31,055	39,971	55,326	76,748	114,086	172,137
Industry - electricity	104,172	126,057	174,712	242,257	360,732	564,282
Industry –process	28,774	29,145	45,879	69,291	108,122	169,925
Residential – fuel	6,504	24,424	24,229	24,553	24,395	24,667
Residential - electricity	30,666	40,648	48,206	55,877	61,282	66,626
Commercial –fuel	9,547	16,267	19,636	23,703	28,612	34,537
Commercial - electricity	18,353	30,105	36,507	43,703	51,625	62,886
Agriculture – fuel	2,387	3,308	4,111	5,002	6,394	8,311
Agriculture - electricity	4,228	5,985	7,473	9,017	11,280	14,797
Total WEM	**235,684**	**315,911**	**416,080**	**550,151**	**766,528**	**1,118,169**

Chapter III: Identification and Analysis of Mitigation Potential

4. Identification of Mitigation Options

In the context of industrial GHG emissions, mitigation opportunities are defined as physical actions that can be implemented to reduce GHG emissions produced by industrial processes. These include technical measures such as better production techniques and technologies; technologies which can improve production and energy efficiency; and technologies which directly abate emissions. Both new-build projects and retrofit projects are considered. The types of mitigation opportunities identified are categorised below:

- Energy efficiency measures, which reduce overall end-use energy consumption and so reduce direct emissions from stationary fuel combustion (for example, recovery and use of waste process heat) or indirect emission from electricity use on-site (for example, improved electric motor system controls and variable speed drives (VSDs) on compressors, pumps and fans).
- Improved efficiency of onsite heat and power generation techniques, which again reduce overall energy consumption and associated emissions from fuel combustion (for example energy efficient boiler systems and kilns, including replacement of old boilers with new), or reduce imported grid electricity and associated indirect emissions (for example implementation of combined heat and power (CHP) technology).
- Improved production processes, which reduce direct process emissions such as increasing production of steel from scrap metal in electric arc furnaces (EAFs) in place of more carbon-intensive primary production techniques using iron ore.
- Fuel switches, which replace fossil fuels with less carbon-intensive fuels such as natural gas or 'zero-carbon' fuels such as biomass.
- GHG abatement technologies, which directly capture and dispose of emissions (for example combustion and destruction of GHG emissions that would otherwise be vented).

Opportunities to mitigate and reduce industrial GHG emissions have been identified, based on international best practice and under the guidance of the TWG sector experts, for several key manufacturing industries in South Africa. Mitigation opportunities have been identified and quantified following the process described below.

Development of a long list: Based upon desktop research of international GHG mitigation best practice and best available techniques (BAT) for production, a long list of GHG emissions abatement measures was prepared for each industrial subsector.

Refinement of a short list: The long list was disseminated to the TWG-M and feedback was gathered on the applicability and potential of each measures. A short list of mitigation opportunities was then selected, based upon this feedback, for each subsector.

Further quantitative data gathering: The data parameters required to construct the marginal abatement cost curves (MACCs), including the abatement potential and costs, were then gathered using international benchmarks and BAT literature. Questionnaires for each industry subsector were disseminated to the TWG-M members, including all of the quantified measures, to verify the parameters based upon sector expertise from South Africa, and to allow the TWG-M members to provide quantitative information on additional mitigation activities.

Final list of measures: The final list of data was then prepared based upon the TWG-M final feedback.

The extent to which these mitigation technologies can reduce or prevent emissions and their costs have been quantified based on a set of data parameters gathered for each measure.

4.1 Data Parameters

For each measure, the data parameters required to calculate the GHG abatement potential (in tonnes of CO_2e) and the marginal abatement cost (MAC, in cost per tonne of CO_2 abated) over the 2010–2050 period, were gathered based on benchmark documentation and through dialogue with sector task team and TWG-M experts. The summary list of data parameters gathered is described in Table 8. Marginal abatement cost curves (MACCs) for the key focus years (2020, 2030 and 2050) were then constructed using these principal indicators of mitigation performance applying the approach described in Section 5.

Table 8: List of mitigation measure data parameters

	Parameter	Unit	Description
A	**GHG emissions reduction potential (process, fugitive, fuel and/or indirect emissions)**		
A.1	Reference emissions	$ktCO_2e$	Reference emissions in $ktCO_2e$ (in 2010).
A.2	Emissions abatement potential	$ktCO_2e$	Reduction in emissions compared to reference emissions in $ktCO_2e$.
A.3	Emissions abatement potential	%	Potential percentage (%) reduction in emissions compared to reference emissions.
A.4	Applicability	%	% of total emissions that abatement measures can be applied to (e.g. if 100% of emissions come from process electricity consumption, then a process control improvement measure would be 100% applicable).
B	**Energy saving**		
B.1.1	Reference thermal energy consumption	GJ/ tonne product	Reference thermal energy consumption in GJ/tonne product (e.g. crude steel).
B.1.2	Thermal energy saving potential	GJ/t product	Reduction in thermal energy consumption compared to reference energy consumption.
B.1.3	Thermal energy saving potential	%	% thermal energy saving potential compared to reference thermal energy consumption (e.g. if 65% of thermal energy is consumed by the steam reforming step, then a steam reforming process improvement would be 65% applicable).
B.1.4	Applicability	%	% of total thermal energy consumption that abatement measure can be applied to.
B.2.1	Reference electricity consumption	GJ/t product	The reference electricity consumption in GJ/t product.
B.2.2	Electricity saving potential	GJ/t product	Reduction in electricity consumption compared to reference consumption.
B.2.3	Electricity saving potential	%	% electricity saving potential compared to reference electricity consumption (e.g. if 22% of energy consumption is from preparation equipment, then a preparation process control improvement would be 22% applicable).
B.2.4	Applicability	%	% of total electricity consumption that abatement measure can be applied to.
C	**Costs**		
C.1.1	Capital cost	R/site or R/sector	Typical capital investment for measure in 2010.
C.1.2	Additional annual costs	R/year	Additional annual costs e.g. operational and maintenance costs in R/year (not including additional energy cost).
C.1.3	Site production capacity	Tonnes product/yr	Typical site production capacity (tonnes product/year) for reference
C.2.1	Capital cost	R/t	Typical capital investment for measure now. Please specify specific cost in R/t product
C.2.2	Additional annual costs	R/t	Additional annual costs e.g. operational and maintenance costs. Please specify specific cost in R/t product (not including additional energy cost).

Parameter		Unit	Description
C.3	Abatement cost	R/tCO_2e	Abatement cost for measure in R/tCO_2e (in certain cases only the abatement cost was available, e.g. carbon capture and storage (CCS) measures)
D	Availability	%	When the technology is likely to become technically available (2010, 2020, 2030, 2040 and 2050).
E	Reference sector uptake %	%	The likely % uptake of the technology across the sector that will happen anyway under current policy, existing measures, technology development status and economics.
F	Lifetime	Years	Expected lifetime of mitigation technology/equipment/ plant.

4.2 Data Sources and References

The technical effectiveness and cost data gathered for each mitigation option are based on a variety of sources. These sources are as follows:

- Personal communication with sector experts from South Africa during Sector Task Team and TWG-M meetings and via direct email and telephone communication.
- International benchmarks – examples of best practice and best available techniques (BAT).
- Best estimates based upon the experience of the project team.

In all cases, the sources of information are clearly referenced. Also, the team has taken every step possible within the scope and available resource to verify the validity of assumptions and data with the TWG-M experts to ensure applicability and accuracy of GHG emissions mitigation potential.

4.3 Mitigation Options per Sector

Eight generic energy efficiency measures were selected based on international benchmarks and – under the guidance of the TWG-M sector experts – judged to be applicable to most industry sectors. The final list is presented in Table 9.

Table 9: Generic list of energy efficiency measures

No	Abatement measure	Description	Data sources
1	Energy monitoring and management system	Computer-aided management system of process operations, energy systems and energy consumption. Identify energy saving opportunities and improve overall operational energy efficiency.	(EC, 2009a, p45, 83)
2	Improved process control	Optimise control of the production process with effective monitoring, control and process automation equipment. Improve equipment lifetime, energy efficiency, reduce waste, improve production yield and reduce pollutants and GHG emissions.	(EC, 2009a, p76)
3	Improved electric motor system controls and VSDs	Improved electric motor system controls and variable speed drives (VSDs) (e.g. compressors, pumps and fans).	(EC, 2009a, p199, 214, 289])
4	Energy efficient boiler systems and kilns	Energy efficient boiler systems and kilns, including replacement of old boilers with new.	(EC, 2009a p116, 134) (EC, 2007a, p24, 138)
5	Energy-efficient utility systems	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air systems).	(EC, 2009a, 206, 228, 235, 246)
6	Improved heat system, including exchanger efficiencies	Improved heat system (e.g. preheating of air and fuel charged to boilers, reduced heat losses, improved heat exchanger efficiencies, improved process integration etc.).	(EC, 2009a, p94, 164)
7	Waste heat and/or gas energy recovery and utilisation for cogeneration	Recovery of waste process heat and/or gas from production processes and use of energy for onsite power generation. Replaces power from fuel combustion onsite or imported grid electricity.	(EC, 2009a, p163)
8	CHP	The energy losses from power generation and from heat production can be reduced by combined generation of heat and power (CHP, cogeneration). Cogeneration plants raise the conversion efficiency of fuel use from around one-third in conventional power stations to around 80% (or more).	(EC, 2006, p291) (EC, 2009a, p176)

Based on consultation with sector specialists represented on the industry sector task team, generic energy efficiency measures have already been implemented to varying degrees across industry in South Africa.[5] Therefore, the mitigation impact and marginal abatement cost was only assessed for measures considered to have good potential for further up-take and increased energy saving. The selected measures are shown in Table 10.

Table 10: Generic energy efficiency measures selected for each industrial subsector

No	Abatement measure	Metals			Chemicals	Minerals		Mining[6]	Other
		Iron & Steel	Ferro-alloy	Primary aluminium		Cement	Lime		Pulp & paper
1	Energy monitoring and management system	Yes	Yes	Yes	Yes	Yes	Yes		Yes
2	Improved process control	Yes		Yes	Yes	Yes	Yes		
3	Improved electric motor system controls and VSDs	Yes	Yes	Yes	Yes		Yes		Yes
4	Energy efficient boiler systems and kilns	Yes			Yes	Yes			
5	Energy-efficient utility systems	Yes		Yes	Yes	Yes	Yes		Yes
6	Improved heat system, including exchanger efficiencies	Yes	Yes		Yes		Yes		Yes
7	Waste heat and/or gas energy recovery and use cogeneration	Yes	Yes		Yes	Yes			Yes
8	Combined heat and power (CHP)				Yes				Yes

The final lists of sector specific mitigation opportunities that have been selected during the mitigation analysis and deemed to have good mitigation potential are presented below for each industrial subsector. The current implementation status in South Africa is described (where this has been identified by the Sector Task Team).

4.3.1 Metals Production

The metals sector includes iron and steel, ferroalloys and primary aluminium production. Mitigation measures have been identified and MACCs developed for these three metals sub-sectors.

5. The approach used to account for early mitigation actions in the WEM projection is documented in Chapter II. A list of early mitigation actions (including their uptake between 2000 and 2010) and an estimate of the emission reductions achieved are shown in Table 3 and Table 4, respectively.

6. Specific energy efficiency measures have been identified for Mining Sector. Details listed in Section 4.3.4.

4.3.1.1 Iron and steel production

Table 11: List of mitigation options for the iron and steel production sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	BOF waste heat and gas recovery	Energy recovery from basic oxygen furnace (BOF) gas and waste heat. In BOF steelmaking, a charge of molten iron and scrap steel along with some other additives (manganese and fluxes) is heated and refined to produce crude steel. An oxygen lance is lowered into the convertor and pure oxygen is blown into the furnace. The carbon in the steel reacts to form CO and CO_2 and leaves the convertor as gas. Two systems can be used to recover energy from the converter gas. In the first one, BOF gas is combusted in the converter gas duct, and subsequently the sensible heat is recovered in a waste heat boiler. In the second system, BOF gas is cleaned, cooled and stored in a gas holder for further use.	Not implemented	Improved onsite energy generation
2	Top gas pressure recovery turbine	Energy recovery from blast furnace and use to operate top gas pressure recovery turbine (TRT)	Not implemented	Energy efficiency, GHG abatement
3	Electric arc furnaces (EAF) and secondary production route	Increasing production of steel from scrap in electric arc furnaces (EAF)	Already implemented. Potential to increase EAF and scrap production	GHG abatement
4	State-of-the-art power plant	Power plants can play an important role in energy saving and mitigation in integrated steelworks by consuming excess process gases, reducing flaring and providing the necessary steam and power for all key processes. These fuels (BF gas, coke oven gas (COG) and BOF gas) are used in other areas of the integrated works and most integrated steelworks also use purchased fuels (oil and natural gas, for example) in the power plant to supplement them. Direct reduced iron (DRI) process shaft/kiln off gas and heat can also be used for power generation.	Not implemented. Limited onsite power generation in SA. Majority of power is imported.	GHG abatement
5	Top gas-recycling blast furnace (with CCS)	Top gas-recycling blast furnace (TGRBF) - energy/carbon reductants recovery/recycling. CO and H_2 content of the top gas has potential to act as reducing gas elements. Therefore their recirculation to the furnace is considered an effective alternative to improve blast furnace performance, enhance use of carbon and hydrogen, and reduce the emission of carbon oxides. In a TGRBF oxygen is blown into the blast furnace instead of hot air to eliminate N_2 in off-gas. Part of the off-gas containing CO and H_2 is used again as the reducing agent in the BF. CO_2 from the off-gas is captured and stored. Various recycling processes have been suggested, evaluated or practically applied for different objectives. These processes are distinguished by: 1) with or without CO_2 removal, 2) with or without preheating, and 3) the position of injection. This technology will be tested at commercial scale as part of the ULCOS II R&D programme.	Not implemented	Production pathway shift

No	Abatement measure	Description	Implementation status in South Africa	Type
6	CCS - Blast Furnace (post-combustion)	Carbon capture and storage (CCS) is a key element for the decarbonisation of the iron & steel industry. In an integrated steel plant there are basically two factors related to concentration of CO_2 emissions for the application of this technology, namely: the blast furnaces and the power plants that are usually linked to the iron & steel plant. There are two main techniques for the separation of CO_2. Post-combustion capture is based on the separation of CO_2 after combustion. Here the challenge is to separate CO_2 from the exhaust gases using an absorption liquid. The CO_2 is then transported and stored. Pre-combustion capture is based on the separation of CO_2 before combustion. Typically, the fuel is gasified yielding syngas which is converted to H_2 and CO_2 using a water–gas shift reaction. CO_2 is removed from this stream using an absorption liquid, and transported and stored. The hydrogen can be combusted for energy production. Oxyfuel combustion is based on the use of pure oxygen instead of air, ensuring that the flue gases will contain predominantly CO_2, which can be directly transported and stored.	Not implemented	Production pathway shift
7	State-of-the-art power plant (with CCS)		Not implemented	Production pathway shift
8	DRI – Midrex	ULCORED, Midrex and HYL are three processes that produce direct reduced iron from pellets by gas-based direct reduction in a shaft furnace. The three processes are very similar, although they differ in terms of the details of how the gas is produced and heat is recovered. The gas used for reduction can be either natural gas or coke oven gas. Alternatively, the gas can be made by gasifying coal or biomass. The decision to use gas or resort to gasification will depend on local availability and price of the resources. When these technologies are based on a coal gasifier they contain a CO_2 removal step. This means that these options are easy to combine with CCS, subject to minimal additional investment. A purification step might still be necessary depending on the storage specifications. The ULCORED process was developed by the ULCOS consortium and is not yet in operation. Midrex and HYL are both readily available and operating at several locations.	Already implemented. Potential for wider uptake	Improved onsite energy generation
9	DRI – HYL		Not implemented	Energy efficiency, GHG abatement
10	DRI – ULCORED		Not implemented	GHG Abatement

4.3.1.2 *Ferroalloy Production*

Table 12: List of mitigation options for the ferroalloys production sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Implementing best available production techniques	Implementing best available production techniques including improved raw material handling and storage, improved pre-processing of raw materials (e.g. wet grinding, filtering and pelletising systems) and improved core processes (e.g. preheating charge materials, transfer distances after preheating or pre-reduction to smelting should be as short as possible to avoid heat losses).	Technology is commonly applied internationally and has been tested in South Africa.	Energy efficiency measure
2	Replace submerged arc furnace semi-closed with closed type	Closed submerged arc furnace (SAF) can use 20% less over energy (including electricity and potential energy in reductants agent) compared to semi-closed SAF. Conversion may not be possible due to 'locked-in' furnace technology and cost.	Technology is commonly applied internationally but not yet tested in South Africa.	Technology substitution
3	Waste gas recovery and power generation - CO from closed furnace	Recovery of carbon monoxide (CO) in waste gas from closed furnaces for use in power generation (70–90% CO). Electricity generated can be used in the process or sold 'over the fence'. Various power generation technologies are available, for example: - Internal combustion engines (waste CO gas, most widely used currently) - Gas turbines (waste CO gas) - Combined cycle gas turbine (waste CO gas) - Rankine cycle steam turbine (waste CO gas) - Organic Rankine cycle (waste CO) CO can also be used as process fuel to replace fossil fuels.	Technology has been tested both internationally and in South Africa.	Energy efficiency measure, improved onsite energy generation
4	Waste heat recovery and power generation from semi-closed furnace - Rankine cycle	Recovery of waste process heat primarily from semi-closed furnace flue gas for the purpose of power generation. Other sources of waste heat from air pollution control equipment and cooling of hot material. Various waste heat recovery to power generation techniques exist. The most widely used is Rankine cycle steam turbine (waste heat recovery)	Technology has been tested both internationally and in South Africa.	Energy efficiency measure, improved onsite energy generation
5	Use biocarbon reductants instead of coal/coke	Use biocarbon reductants (e.g. charcoal and wood) instead of hydrocarbon reductants (e.g. coke and coal) within the smelting process.	Technology has been tested internationally but not yet commonly applied. Not yet tested in South Africa.	Fuel switch

4.3.1.3 *Primary aluminium production*

Table 13: List of mitigation options for the primary aluminium production sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Best process selection for primary aluminium smelting	To minimise energy consumption and emissions, include computer control of the electrolysis process based on active cell databases and monitoring of cell operating parameters to minimise the energy consumption and reduce the number and duration of anode effects; and an established system for environmental management, operational control and maintenance.	Already implemented. Potential for further improvement	Energy efficiency measure, improved production technique
2	Switch to secondary production and increase recycling	Switch production pathway from primary to secondary. Secondary aluminium production using recycled scrap raw material requires significantly less energy compared to primary aluminium production (IAI, 2011b). World demand for secondary aluminium is estimated to increase at an annual rate of 5%, about twice that of primary, at 2.4% (EC, 2008). Measures could be limited by availability of scrap raw material.	Sufficient scrap is available in South Africa to meet local needs, but the bulk of local scrap is exported owing to better returns on exports. It should be noted that the large scale uptake of EAF requires the necessary supply of scrap.	Improved production technique

4.3.2 Minerals Production

The minerals sector includes cement and lime production. Mitigation measures have been identified and MACCs developed for these two subsectors.

4.3.2.1 Cement Production

Table 14: List of mitigation options for the cement production sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Implement best available technologies (BAT) kiln systems with multistage cyclone preheaters and precalciner	Implementation of energy efficiency measures including reduction of thermal energy use, selection of energy optimised process kiln systems with multistage cyclone preheaters (e.g. four to six stages) and precalciner.	BAT continually strived for. Dry kiln process in use.	Improved production technique (technology substitution)
2	Improved process control	Optimisation of the clinker burning process is usually done to reduce the heat consumption, to improve the clinker quality and to increase the lifetime of the equipment (the refractory lining, for example) by stabilising process parameters.	Already implemented in SA. Potential for further uptake.	Energy efficiency measure
3	Reduction of clinker content of cement products	Reduction of clinker content of cement products by adding fillers and additions, (e.g. sand, slag, limestone, fly ash and pozzolana, in the grinding step).	Implementation at different stages per producer. Depending on the product portfolio of cement producer.	Energy efficiency measure
4	Waste heat recovery from kilns and coolers/cogeneration	Energy recovery from kilns and coolers for cogeneration (e.g. conventional steam cycle process and organic Rankine cycle (ORC) process). Furthermore, excess heat is recovered from clinker coolers or kiln off-gases for district heating.	No producer has yet implemented due to the high investment cost of the technology. For example in the European Union this type of project is grant funded up to 50% by EU fund.	Energy efficiency measure

No	Abatement measure	Description	Implementation status in South Africa	Type
5	Use waste material as fuel	Substitution of fuels with different hazardous and non-hazardous waste materials with high enough calorific value and low moisture content (e.g. wood, paper, cardboard, textiles, plastics, rubber/tyres, industrial sludge, municipal sewage sludge, animal meal and fats, coal/carbon).	South Africa is lagging in the use of waste material as fuel. In Europe and the Americas, the substitution rate for cement plants is more than 50%. In South Africa it is less than 10%. It will avoid CO_2 generation if we could use more waste and alternative fuels.	Fuel switch
6	Geopolymer cement production	Geopolymer cement is cement manufactured with chains or networks of mineral molecules producing 80–90% less CO_2 than ordinary Portland cement (OPC) - the most common type of cement, consisting of over 90% ground clinker and about 5% gypsum.	Technology is entirely untested.	Improved production technique
7	CCS - back-end chemical absorption	Carbon capture and storage (CCS) could enable up to 95% reduction of CO_2 emissions from cement production. About 67% of the emissions originate from limestone decomposition into cement clinker and 33% from fuel combustion. The CO_2 from limestone off-gas (25% to 35% CO_2) can be captured using three approaches: back-end chemical absorption; oxyfueling; and chemical looping. Post-combustion capture could be used for new cement kilns and for retrofitting existing kilns, whereas oxy-combustion would only be available for new cement kilns. Full-scale CCS demonstration projects are expected between 2020 and 2030 and commercial deployment after 2030. It is estimated that between 10% and 43% of the global cement capacity could be equipped with CCS in 2050.	Technology has been tested internationally but not yet commonly applied. Not yet tested in South Africa.	GHG abatement
8	CCS - oxyfuelling	Oxyfuel technology using oxygen instead of air in cement kilns, would result in a comparatively pure CO_2 stream. Using oxygen (oxyfuel) instead of air in new cement kilns with pure CO_2 off-gas might reduce the cost as productivity would be much higher than in conventional kilns, but the process requires more R&D. Oxy-combustion would only be available for new cement kilns.	Technology is entirely untested.	GHG abatement

4.3.2.2 *Lime Production*

Table 15: List of mitigation options for the Lime Production sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Installation of shaft preheaters	Installation of shaft preheaters on lime kilns to improve the thermal energy performance of the kiln by recovering waste heat from the combustion process to preheat the lump lime before entering the kiln.	Technology is commonly applied internationally and has been tested in South Africa.	Energy efficiency measure
2	Replace rotary kilns with vertical kilns or PFRK	South Africa uses rotary kilns. In general, vertical kilns and parallel flow regenerative kilns (PFRK) are the most efficient.	Technology has been tested internationally but not yet commonly applied. Not yet tested in South Africa.	Improved production technique (technology substitution)
3	Use alternative fuels including waste and biomass	Depending on chemical composition of fuel and kiln type , the fuel choice or fuel mix can lead to emissions reductions and improved firing efficiency, e.g. biomass contributes to saving fossil fuels and waste fuels reduce the amount of fossil fuels used and the related CO_2 emissions.	Technology has been tested internationally but not yet commonly applied. Not yet tested in South Africa.	Fuel switch
4	CCS for lime production	Carbon (CO_2) capture and storage (CCS). Applying either post-combustion end-of-pipe technologies or oxyfuel technology, using oxygen instead of air in kilns, would result in a comparatively pure CO_2 stream.	Technology is entirely untested.	GHG abatement

4.3.2.3 Chemicals Production

The chemicals sector includes the production of basic chemicals such as ammonia, nitric acid, carbide, titanium dioxide, petrochemicals and carbon black.

Table 16: List of mitigation options for the chemicals production sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Replace coal-fired partial oxidation processes with natural gas-fired steam reforming production	Per tonne of ammonia the energy requirement for coal based plants is significantly higher than for natural gas-fired facilities. A coal-based unit also produces roughly 2.4 times more CO_2 per tonne of ammonia than a natural gas-based unit. The natural gas-powered steam reforming process uses 28 GJ/t ammonia of energy and produces emissions of 1.6 CO_2 t/t ammonia compared to 42 GJ/t ammonia and 3.8 CO_2 t/t ammonia for coal-powered partial oxidation.	Technology is entirely untested.	Fuel switch
2	CCS for new ammonia production plants process emissions	Integrate carbon capture and storage (CCS) for ammonia production to capture CO_2 in flue gas. Cost of capture of CO_2 from flue gas is likely to be very high and depends on concentration. In most ammonia production plants, part of the CO_2 is used for producing urea-based fertilisers while the rest offers relatively low-cost CCS opportunity where the CO_2 is separated from H_2 using solvent absorption. A pure stream of CO_2 is already captured in South African ammonia production.	Technology is entirely untested.	GHG abatement
3	Revamp: increase capacity and energy efficiency	Example based on the revamp of a 20 year old reduced primary reforming ammonia plant (1100 tonnes/day). Measures included improving the efficiency of the primary reformer furnace/gas turbine combination by extensive preheating of the mixed feed going to the furnace, installation of a highly efficient gas turbine, modifications of the burners, rearrangement of the convection coils and adding additional surface, and improved maintenance (about 50 % of the efficiency increase is achieved by re-establishing the original state of the plant, e.g. closing leaks). Assumed to be widely applicable to other chemicals production plant.	Technology is already commonly applied in South Africa. Potential for further uptake.	Energy efficiency measure
4	N_2O abatement for new production plants	N_2O emissions removal efficiency of 98–99% can be achieved using various measures (e.g. non-selective catalytic reduction (NSCR), Combined NO_x and N_2O abatement reactor and N_2O decomposition in the oxidation reactor.	Technology is already commonly applied in South Africa. Potential for further uptake in new plants.	GHG abatement
5	Tail-gas energy recovery for combined heat and power plant (CHP) and minimise flaring	Use of high efficiency combined heat and power (CHP) to supply power and heat for production.	Technology is entirely untested.	Improved onsite site energy generation, GHG abatement and EE measure

3.3.3 Mining

The mining sector includes mined materials from surface and underground mines, including gold, platinum group metals (PGMs), diamonds, iron ore, chromite, manganese and other mined materials. This analysis does not include coal mined products. Coal mining is included in the energy sector.

Table 17 List of mitigation options for the mining sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Use of 1st generation biodiesel (B5) for transport and handling equipment	Use of 5% biodiesel (B5) for transport and handling equipment/open pit mobile machinery	Technology is commonly applied internationally and has been tested in South Africa.	Fuel switch
2	Improve energy efficiency of mine haul and transport operations	The mining industry has identified many energy savings in activities using diesel. These include: • payload management • managing intersections, gradients and distances travelled through better mine planning • idle time management	Technology is commonly applied internationally and has been tested in South Africa.	Energy efficiency measure
3	Use of 2nd generation biodiesel (B50) for transport and handling equipment	Use of 50% biodiesel (B50) for transport and handling equipment/ open pit mobile machinery	Technology has been tested internationally but not yet commonly applied. Not yet tested in South Africa.	Fuel switch
4	Use of 2nd generation biodiesel (B100) for transport and handling equipment	Use of 100% biodiesel (B100) for transport and handling equipment/open pit mobile machinery	Technology has been tested internationally but not yet commonly applied. Not yet tested in South Africa.	Fuel switch
5	Process, demand & energy management system	Monitoring - real time monitoring and display of demand loads and energy consumption at the BU's control centres. Management system - energy database access to end users that shows process level details on daily basis for management Power factor correction - reduce the reactive load to increase plant PF levels	Technology is already commonly applied in South Africa.	Energy efficiency measure

No	Abatement measure	Description	Implementation status in South Africa	Type
6	Energy efficient lighting	Replace inefficient lighting with efficient FLs and LEDs	Technology is already commonly applied in South Africa.	Energy efficiency measure
7	Install energy-efficient electric motor systems	Replace old, inefficient electric motors (e.g. circuits, grinding, transport, compressors, pumps and fans etc.) with energy efficient motors.	Technology is already commonly applied in South Africa.	Energy efficiency measure
8	Optimise existing electric motor systems (controls and VSDs)	Optimise existing electric motor system controls and install variable speed drives on part load systems to match load with demand (e.g. circuits, grinding, transport, compressors, pumps and fans etc.)	Technology is already commonly applied in South Africa.	Energy efficiency measure
9	Onsite clean power generation	Implement onsite clean energy generation (e.g. PV, hydro, wind etc.)	Technology is commonly applied internationally and has been tested in South Africa.	Energy efficiency measure

4.3.4 Buildings

The buildings sector includes commercial/institutional buildings and residential buildings. GHG emissions mitigation measures have been identified and MACCs have been developed for these two types of buildings.

4.3.4.1 Commercial/institutional buildings

Table 18: List of mitigation options for the commercial/institutional buildings sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Efficient Lighting	Existing buildings and new buildings. replace old FLs with new LEDs	Already implemented. 2010 market uptake assumed to be 5% of buildings – based on SATIM model (ERC, 2013). Opportunity for further mitigation.	Electricity saving
2	Heat pumps - existing buildings	Existing buildings		Reduced cooling demand
3	Heat pumps - new buildings	New buildings		Reduced cooling demand
4	HVAC: with heat recovery - new buildings	New buildings		Reduce heating/ cooling demand
5	HVAC: variable speed drives - existing buildings	Existing buildings		Reduce heating/ cooling demand
6	HVAC: variable speed drives - new buildings	New buildings		Reduce heating/ cooling demand
7	HVAC: central air conditioners - new buildings	New buildings		Reduce heating/ cooling demand
8	Energy efficient appliances	New and existing buildings		Electricity saving
9	Passive building/improved thermal design - new buildings	New buildings		Reduce heating/ cooling demand

4.3.4.2 *Residential Buildings*

Table 19: List of mitigation options for the residential buildings sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Energy efficient appliances	New and existing buildings	Already implemented. 2010 market uptake assumed to be 23% of households – based on SATIM model (ERC, 2013). Opportunity for further mitigation.	Electricity saving
2	Geyser blankets	New and existing buildings	Already implemented. 2010 market uptake assumed to be 5% households – based on SATIM model (ERC, 2013). Opportunity for further mitigation.	Reduce heat demand, fuel saving
3	Improved insulation – new buildings	Improved insulation –		Reduce heat demand fuel saving
4	Improved Insulation – existing buildings	Improved Insulation retrofit – existing buildings		Reduce heating/ cooling demand
5	Efficient lighting – FLs	Replace incandescent lamps with FLs	Already implemented. 2010 market uptake assumed to be 86% of households – based on SATIM model (ERC, 2013). Opportunity for further mitigation.	Electricity saving
6	Efficient lighting – LEDs	Replace FLs with LEDs	Already implemented. 2010 market uptake assumed to be 5% of households – based on SATIM model (ERC, 2013). Opportunity for further mitigation.	Electricity saving
7	Solar water heating	Widespread use of solar water heating in all buildings. New and existing buildings		Fuel saving for heating water
8	LPG for cooking	New and existing buildings. Assumed to replace oil and coal	Already implemented. 2010 market uptake assumed to be 6% of households – based on SATIM model (ERC, 2013). Opportunity for further mitigation.	Fuel switch
9	Passive building/improved thermal design – new buildings	New buildings	Not implemented. Opportunity for mitigation.	Reduce heating/ cooling demand

4.3.5 Other sectors

The other sectors include the pulp and paper production industry. Mitigation measures have been identified for pulp and paper production.

4.3.5.1 Pulp and paper production

Table 20: List of mitigation options for the pulp and paper production sector

No	Abatement measure	Description	Implementation status in South Africa	Type
1	Convert fuel from coal to biomass/ residual wood waste	Avoid emissions from fossil fuels by utilising biomass wastes as fuel in pulp and paper production.	Already implemented in SA. Potential for further implementation.	Fuel switch
2	Application of co-generation of heat and power (CHP)	Paper industry is a high energy consuming industry. Increased speed of paper machines, more sophisticated recovered-paper processing systems and technological developments in general have resulted in higher consumption of electricity in paper mills whereas the specific use of steam has remained virtually unchanged. The energy losses from power generation and from heat production can be reduced by combined generation of heat and power (CHP, cogeneration). Cogeneration plants raise the conversion efficiency of fuel use from around one-third in conventional power stations to around 80% (or more).	Already implemented in SA. Potential for further implementation.	Improved onsite site energy generation
3	Energy recovery system	Use waste biomass by-products from debarking/wood chipping and screening as fuel and burn dissolved organic material in solid fuel boilers to recover energy as process steam and/or electrical power.	Already implemented in SA. Potential for further implementation.	Energy efficiency measure

5. Approach to Development of Marginal Abatement Cost Curves

Marginal abatement cost curves (MACCs) have been developed for the industry key sector and subsectors for 2020, 2030 and 2050, presenting the annual technical mitigation potential relative to the reference WEM emissions projection.

Marginal abatement cost curves show the cost and emissions reduction potential for a group of mitigation measures or technologies. Relative to the reference WEM emissions projection, the MACC shows the GHG mitigation abatement potential for each abatement technology along the horizontal x-axis (in tonnes of CO_2e abated) and the cost of implementing the measures along the vertical y-axis (in rand (R) per tonne of CO_2e abated). The mitigation measures are shown in the order of their marginal abatement cost from left to right along the x-axis (from cheapest to most expensive).

A sectoral bottom-up approach has been taken in developing the MACCs and determining the industry sector level technical mitigation potential. Generally, the sectoral mitigation potential (for each year between 2010 and 2050) for each measure has been estimated compared to the reference WEM emissions projection for the industry subsector (and specified subsectors), based on an assessment of three key percentage factors:

- *Emissions reduction potential:* Percentage of process, direct fuel and/or indirect electricity emissions.
- *Applicability:* Percentage of the total reference sector emissions that the mitigation measure's reduction potential can be applied to.
- *Sector uptake/penetration:* Percentage of the sector that implements the measure.

The sector-wide mitigation potential is then simply estimated by multiplying the reference emissions by the three factors above for each measure and then adding the mitigation potential of all measures identified for the sector.

The approach taken and methodology applied in developing the MACCs for the industry sectors is described in detail in the Technical Appendix A: Approach and Methodology. A summary of the key methodological assumptions affecting GHG mitigation potential and the marginal abatement cost made are described below.

The project team adopted a capital discount rate of 11.3% when generating the MACCs, in accordance with guidelines provided by National Treasury.

In general, the theoretical methodological approach, which had to be adopted in the absence of comprehensive feasibility studies at site level, did not allow definitive statements to be made about the practical feasibility of these measures at site level.

Detailed abatement and marginal abatement costs for all measures identified in this study are shown in Table 53. Marginal abatement cost curves for individual sectors and subsectors are shown in Sections 6, 7, 8, 9, 10 and11.

5.1 Estimating Mitigation Potential

The GHG mitigation abatement potential for each abatement technology is displayed along the horizontal x-axis of the MACC (in tonnes of CO_2e abated).

The annual technical mitigation potential for each measure is calculated on a sectoral basis for each year between 2010 and 2050. The mitigation potential is measured based on the WEM reference emissions projection (for fugitive emissions, process emissions, direct fuel emissions and/or indirect electricity related emissions, as defined by the emissions sources of each key sector).

The mitigation potential for each identified mitigation measure has been estimated based on data parameters gathered (as described in Table 8 in Section 4.1), and the formulas defined below, according to the emissions sources of each sector. The data parameters stipulate the emissions reduction potential and applicability (that is process, direct fuel and/or indirect related), fuel saving potential and applicability, and/or electricity saving potential and applicability, and the assumed sector uptake.

Sector mitigation potential (tCO_2e/year) = *process emissions reduction (tCO_2e/year) +*
direct fuel emissions reduction (tCO_2e/year) +
indirect electricity emissions reduction (tCO_2e/year)

First, the process emissions reduction potential for a given mitigation measure is calculated using the following formula:

Process emissions reduction (tCO_2e/year) = reference process emissions (tCO_2e/year) × process emissions reduction potential (%) × applicability (%) × sector uptake (%)

Second, the fuel emissions reduction potential for a given mitigation measure is calculated using the following formula:

Direct fuel emissions reduction (tCO_2e/year) = reference direct fuel emissions (tCO_2e/year) × fuel energy saving potential (%) × applicability (%) × sector uptake (%)

Finally, the indirect electricity emissions reduction potential of a given mitigation measure is calculated using the following formula:

Indirect emissions reduction (tCO_2e/year) = reference indirect electricity emissions (tCO_2e/year) × electricity saving potential (%) × applicability (%) × sector uptake (%)

The emissions reduction potential and applicability, fuel saving potential and applicability, and electrical saving potential and applicability for each measure have been selected based upon benchmark information and/or in consultation with the TWG sector experts. The selected parameters for all mitigation measures identified in each industry sector are presented in the following sections, together with relevant assumptions.

Importantly, the selected level of sector uptake for each measure determines the extent to which a measure is available and implemented across the sector and impacts the overall mitigation potential.

5.1.1 Mitigation Measures Availability

A MACC may include a wide range of abatement measures, including established existing technologies, and less well established emerging technologies. Certain emerging technologies might not be available for application until some point in the future. This is reflected in the assumptions that are made about the availability of technology, at a given point in time.

Drawing on published research, the availability of each of the technologies over the assessment period has been defined. For each technology the availability has been allocated to the beginning of one of the following 10 year periods: 2010, 2020, 2030 and 2050.

5.1.2 Sector Uptake and Market Penetration

The extent to which a specific abatement measure can be implemented at a given point in time in the future is influenced by the measure's availability and its market penetration rate. The penetration rate essentially describes the rate at which the measure could realistically penetrate the market. It therefore provides a limit on the abatement potential that can be delivered by a specific measure. For new technologies, this rate is typically assumed to follow existing investment cycles.

In the energy (excluding electricity generation) sectors and industrial sectors, for example, the selected level of implementation of a mitigation measure in a given year is defined by three parameters outlined below:

- *Starting point:* When additional mitigation action is implemented.
- *Penetration rate:* At what rate a measure is implemented over the 2010–2050 time period (that is the penetration rate).
- *Uptake:* The extent to which a measure is implemented and deployed across the sector at a point in time (for example 25%, 50% or 100% by 2050).

To determine the starting point, penetration rate and uptake of each measure, a pragmatic approach is applied, guided by the principle of what is technically possible (and not limited by economic and other non-technical limitations). These parameters have been decided based on two factors:

- *Technology availability:* As defined above, the availability of each measure is allocated to the beginning of one of the following 10 year periods: 2010, 2020, 2030, 2040 or 2050.
- *Marginal abatement cost:* Defined as the cost of achieving incremental levels of emissions reduction (that is, cost per tonne of CO_2e abated).

Additionally, the following straightforward assumptions have been made:

- Measures are implemented between 2010 and 2050, from 0% to 100% additional uptake.
- Measures are implemented starting from when they are deemed to be technically available.
- Measures are typically implemented sector-wide at a rate from 0 to 100% over a period of 10 years, if a measure is a smaller retrofit project (that is a lifetime of between 10 and 15 years). If measures are deemed to be locked-in technology (that is a lifetime of between 25 and 40 years), then they are assumed to be implemented over 20 years.
- Where a set of measures is mutually exclusive, it is assumed that they will be implemented equally and the total summed uptake of these measures cannot exceed 100% (for example post combustion and oxyfuel CCS).

Where a measure is deemed to be too costly in comparison to other options or not feasible due to the prior implementation of another measure, then the uptake has been set to zero and the measure has been removed from the MACC.

The selected levels of uptake for each measure are presented in the following sections for each industry sector. These levels of uptake have been selected in consultation with the TWG industry experts.

The above approach and selected abatement, marginal abatement cost and technically possible levels of uptake result in the creation of the 'with additional measures' (WAM) emissions projection.

In the case of mitigation of emissions from the residential, commercial and institutional buildings sectors, the starting point, penetration rate and uptake of each measure, is based on the technology share proposed by the South African TIMES model (SATIM) model 'upper bound' scenario (ERC, 2013).

5.2 Estimating the Marginal Abatement Cost

The marginal abatement cost (MAC) is an indicator of the cost required to implement a given technical measure to abate a unit of CO_2e. The MAC describes the net cost of implementing a measure by comparing the capital and operational costs against potential energy cost savings (or additional energy overheads) per tonne of abatement. The MAC is shown along the vertical y-axis of the MACC (in cost per tonne of CO_2e abated).

The marginal abatement costs for a measure in a given year are defined as follows:

$$\text{MAC (ZAR/tCO}_2\text{e)} = \text{net annual cost (ZAR/year) / total emissions reduction (tCO}_2\text{e/year)}$$

The net annual cost (NAC) for a measure in a given year is the sum of the equivalent annual cost (EAC) and the annual operation and maintenance cost (Opex) minus the energy cost saving. The NAC is defined as follows:

$$\begin{aligned}\text{NAC (ZAR/year)} = \; & \text{equivalent annual cost (ZAR/year)} + \\ & \text{annual operation \& maintenance cost (ZAR/year)} - \\ & \text{energy cost saving (ZAR/year)}\end{aligned}$$

The EAC for a given measure is defined as the capital investment cost (Capex) of the technical measures annualised over the measure's lifetime, applying a discount rate.

The Capex is annualised because the measures within the MACC may have different lifetimes. Annualising the Capex allows the marginal abatement costs of different measures to be compared and ranked accordingly. The Capex is based on the estimated 'overnight' capital cost for the measure in 2010. The Capex, Opex and lifetime have mostly been based on benchmark information, then cross-checked with the Sector Task Team representatives. In cases where more accurate costing information has been made available by the TWG-M or Sector Task Team, this has been used instead. The selected Capex, Opex and lifetimes for all of the mitigation measures identified in each industry sector are displayed in the following sections. The discount rate is assumed to be 11.3% (as set by the TWG-M).

5.2.1 Other Cost Assumptions

The energy cost saving (R/year) for a given measure in a given year is based upon the estimated annual fuel and/or electricity saving (GJ/year) multiplied by the assumed price for that year (in R/GJ). The assumed fuel and electricity prices for the period 2010 to 2050 are presented and explained in Box 1.

Box 1: Energy Price Assumptions

The assumed fuel prices for 2010, 2020, 2030 and 2050 used in the mitigation analysis and the development of the non-power energy, industry and transport sector MACCs are presented in Table 21. The prices are based on the supply costs of various indigenous production of primary fossil and renewable energy and imports prices from the "Appendix I. Primary Energy Supply Sector - Reference Case Assumptions" of version 3.2 of the SATIM Energy Model Methodology Appendices (ERC, 2013) provided in R/GJ (with the exception of metallurgical coke, petcoke and refinery fuel gas which are not specified in the SATIM model). This source was considered to be the most comprehensive, up-to-date and consistent data source for South African fuel prices on which to base the fuel prices assumptions. The assumed prices are net prices and do not include tax or additional local distribution charges.

Exceptionally, the 2010 base year price for metallurgical coke and petcoke is based on average market price information (Resource-Net, 2011). The refinery fuel gas (RFG) production cost is based on the SATIM energy model crude oil cost and the assumption that 5% of crude feed stock is converted into RFG, and RFG production costs are 2.5% of total refinery product energy. The 2020, 2030 and 2050 prices are all extrapolated based upon the SATIM growth trend for crude oil.

In reality, the fuel prices paid by different businesses and industry subsectors may vary depending on several factors (for example amount of fuel purchased, supply contract terms etc.). As no other single and consistent information source was available for fuel prices paid in the non-power energy and industry subsectors, the SATIM energy model and DoE energy prices were applied.

The electricity price for 2010 and projection up to 2050 is based upon the anticipated average electricity price path included in the Integrated Resource Plan (IRP) For Electricity 2010–2030 (DoE, 2011, Figure 4). This was considered to be the most appropriate data source on which to base the electricity price assumption and projection and is consistent with the power sector mitigation analysis assumptions.

Table 21: Assumed energy prices for 2010 base year and projected prices up to 2050

Item	Units	Source	Note	2010	2020	2030	2040	2050
Coking coal	R/GJ	(ERC, 2013) DoE	Imports of coking coal	55	60	66	70	75
Bituminous coal	R/GJ	(ERC, 2013)	Extraction of coal	27	30	33	35	37
Metallurgical coke	R/GJ	(Resource-Net, 2011)	Projection linked to coal trend, SATIM model 2013	112	123	134	143	152
Petcoke	R/GJ	(Resource-Net, 2011)	Projection linked to crude oil trend, SATIM model 2013	111	137	170	192	213
Natural gas	R/GJ	(ERC, 2013)	Imports of gas southern Mozambique piped	44	55	68	77	85
Crude oil	R/GJ	(ERC, 2013)	Imports of oil crude	97	121	150	168	187
Natural gas liquids (NGL)	R/GJ	(ERC, 2013)	Imports of gas international LNG	72	88	108	121	133
Liquid petroleum gas (LPG)	R/GJ	(ERC, 2013)	Imports of oil LPG	276	300	329	348	367
Motor gasoline	R/GJ	(ERC, 2013)	Imports of oil gasoline	124	153	188	211	234
Gas diesel oil	R/GJ	(ERC, 2013)	Imports of oil diesel	117	145	180	203	226
Heavy fuel oil	R/GJ	(ERC, 2013)	Imports of oil HFO	97	121	150	168	187
Kerosene	R/GJ	(ERC, 2013)	Imports of oil kerosene	127	154	189	211	232
Biomass bagasse	R/GJ	(ERC, 2013)	Renewable resource: biomass bagasse	20	20	20	20	20
Biomass wood	R/GJ	(ERC, 2013)	Renewable resource: biomass wood	20	20	20	20	20
Biodiesel	R/GJ	(ERC, 2013)	Imports of biodiesel	123	152	189	213	237
Electricity	R/GJ	(DoE, 2011)	IRP projection, Figure 4. Breakdown of anticipated average electricity price path	117	264	264	264	264
Bioethanol	R/GJ	(ERC, 2013)	Imports of bioethanol	131	160	198	222	246
Refinery fuel gas	R/GJ	Specific assumption	Linked to imported crude oil projection	8	10	13	14	16

While a specific set of energy prices were assumed for the study, it is recognised that when developing sector specific feasible mitigation options, prices that are applicable to the specific activity will need to be applied.

6. Mitigation Potential for the Metals Sector

The metals sector includes iron and steel, ferroalloys and primary aluminium production. Mitigation measures have been identified and MACCs developed for these three metal subsectors.

6.1 Summary MACCs

The summary MACCs combining all of the mitigation measures identified and quantified for iron and steel, ferroalloys and primary aluminium production, for 2020, 2030 and 2050 are displayed below in Figure 3, Figure 4 and Figure 5, respectively. Detailed abatement and marginal abatement costs for all measures are shown in Table 53. Identification numbers shown in the legends of the figures below may be used to look up details in Table 53.

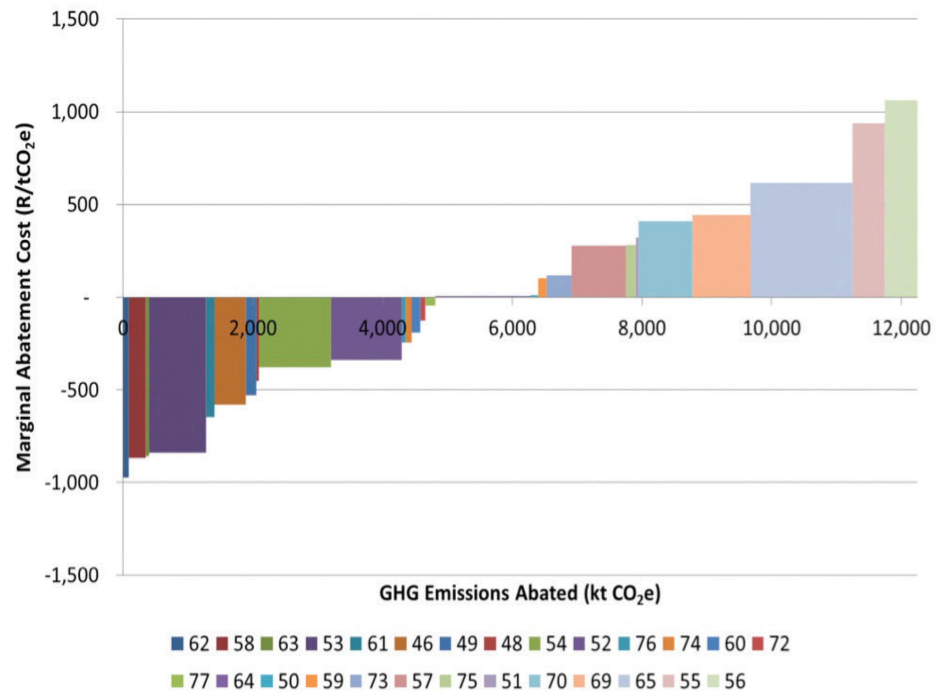


Figure 3: Metals sector MACC for 2020

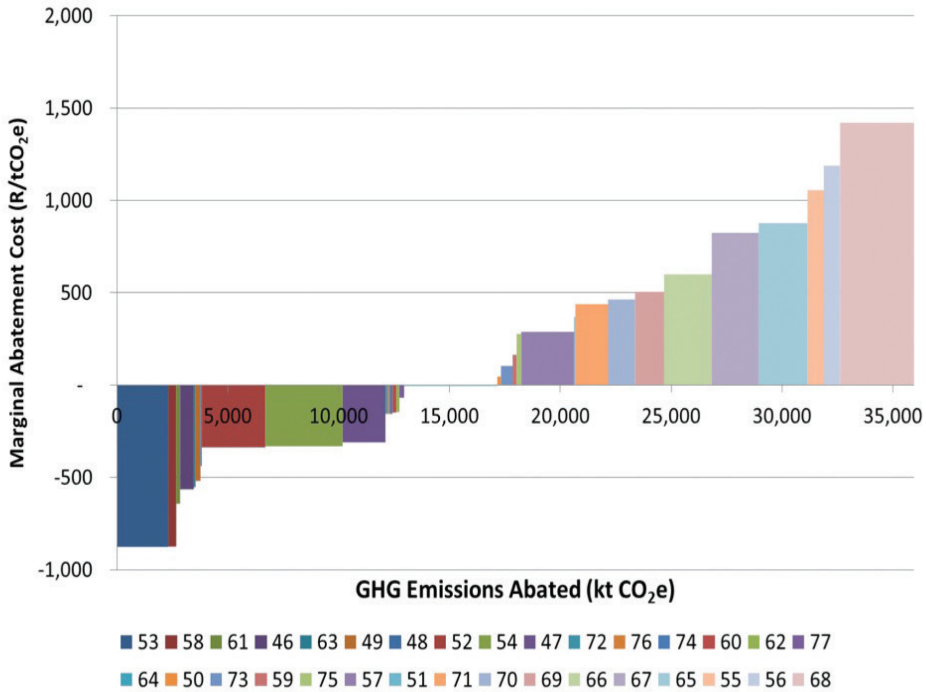


Figure 4: Metals sector MACC for 2030

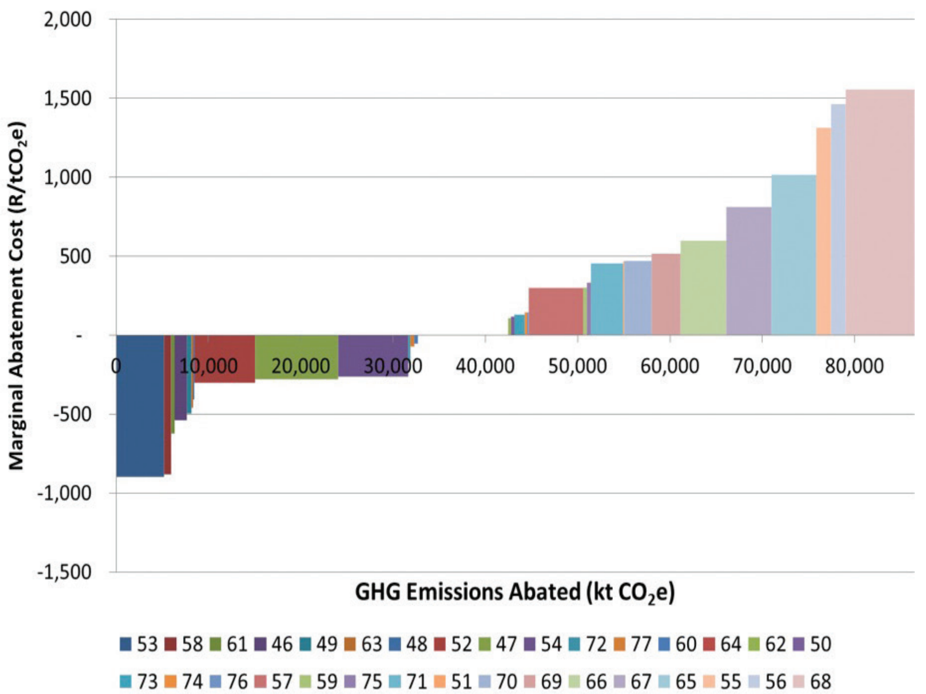


Figure 5: Metals sector MACC for 2050

6.2 Primary Aluminium Production

6.2.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the aluminium production MACC, together with references, are presented in Table 22. The assumed cost, technology availability and lifetime are listed in Table 23. The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 24.

For the objective of reducing energy consumption and GHG emissions, the mitigation analysis assumes a 20% production switch from primary operations to secondary production techniques is possible by 2030 by increasing recycling.

The process emission factors applied for prebake production technology are based upon IPCC guidelines and are in line with the assumptions in the GHGI for South Africa. It is noted that these are higher than the emission factors proposed by the TWG members representing the primary aluminium sector.

Sector growth is assumed to be 4.2% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

Table 22: Emissions reduction potential and energy saving potential of mitigation measures and references in primary aluminium production

Abatement measure		Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	
1	Best process selection for primary aluminium smelting	5%	100%	5%	90%	(EC, 2009b)
2	Switch to secondary production and increase recycling	90%	100%	90%	100%	(IAI, 2011a) (EC, 2008)
3	Energy monitoring & management system			1%	100%	(EC, 2009b)
4	Improved process control			2%	100%	(EC, 2009b)
5	Improved electric motor system controls and variable speed drives			10%	8%	(EC, 2009a)
6	Energy-efficient utility systems			10%	2.5%	(EC, 2009a)

Table 23: Costs, availability and lifetime of primary aluminium production mitigation measures

Abatement measure		Capital cost	Additional annual costs	Site production capacity	Availability	Lifetime
		Million R/site	Million R/year	Million tonnes/ year	Year	Years
1	Best process selection for primary aluminium smelting	60	3	0.1	2010	40
2	Switch to secondary production and increase recycling	600	30	0.1	2010	40
3	Energy monitoring & management system	18	0	0.1	2010	15
4	Improved process control	60	2	0.1	2010	15
5	Improved electric motor system controls and variable speed drives	54	1	0.1	2010	15
6	Energy-efficient utility systems	24	1	0.1	2010	15

Table 24 Mitigation technology sector uptake and other assumptions in primary aluminium production

	Abatement measure	% Sector uptake				Other assumptions
		2010	2020	2030	2050	
1	Best process selection for primary aluminium smelting	50%	100%	100%	100%	The industry has set a target of using electricity inputs of 11 megawatt hours (MWh) to produce one ton of aluminium by 2020, down from 15.7 MWh in 2010. Since energy consumption in US smelters (15 MWh/t average) is more than twice the theoretical minimum requirement, the US Department of Energy estimates current R&D efforts could reduce smelting energy needs by up to 30%. Assumes 50% already implemented by 2010 in terms of total sector uptake.
2	Switch to secondary production and increase recycling	0%	0%	50%	100%	Primary production total electrical power – 13.6–15.7 kWh/kg Al. The specific energy consumption of secondary aluminium products ranges from 2 to 9 GJ/tonne. Potential uptake limited by scrap availability. Costs estimated for new secondary production site at €50 million per site with 100,000 t Al/year with 5% additional annual cost.
3	Energy monitoring & management system	50%	100%	100%	100%	Assumes 50% already implemented by 2010 in terms of total sector uptake.
4	Improved process control	50%	100%	100%	100%	Assumes 50% already implemented by 2010 in terms of total sector uptake.
5	Improved electric motor system controls and VSDs	0%	100%	100%	100%	Assumes 50% already implemented by 2010 in terms of total sector uptake.
6	Energy-efficient utility systems	0%	100%	100%	100%	Assumes 50% already implemented by 2010 in terms of total sector uptake.

6.2.2 Marginal Abatement Cost Curve

The scope for emissions reductions in aluminium primary production is not as extensive as in the steel and ferroalloy industries. This is largely due to the fact that 100% of the industry in South Africa uses centre worked prebake (CWPB) technology with point feeding – the most energy efficient option available. Further, significant measures have already been taken to reduce process emissions caused by the 'anode effect'. In addition, a large proportion of production facilities already use best available production techniques and advanced process controls. In 2020, the total abatement potential amounts to just over 844 ktCO_2e (4% of the WEM emissions projection) with best process selection for primary aluminium smelting and advanced process control techniques offering the best scope for mitigation at the least marginal abatement cost, as shown in Figure 6.

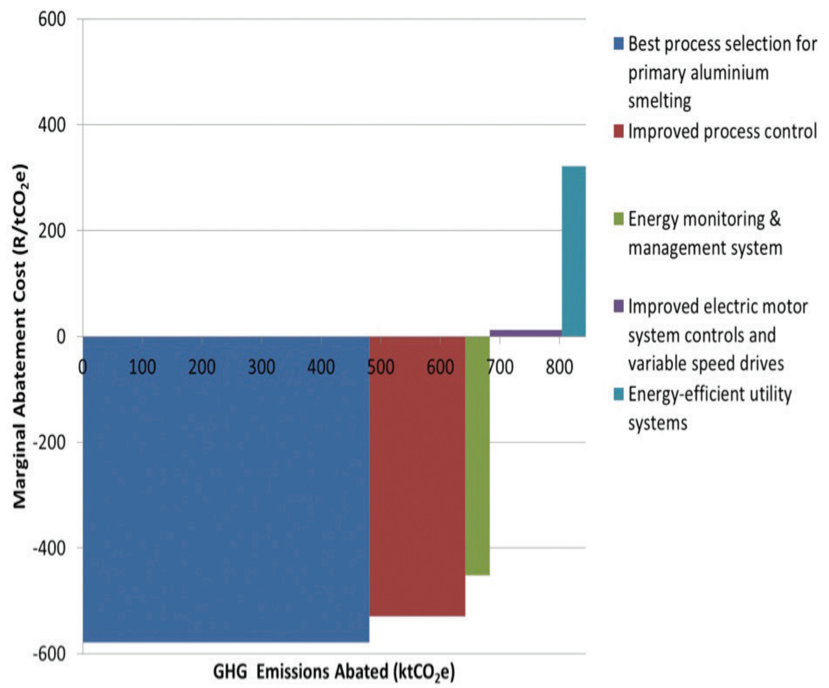


Figure 6: Primary aluminium production MACC for 2020

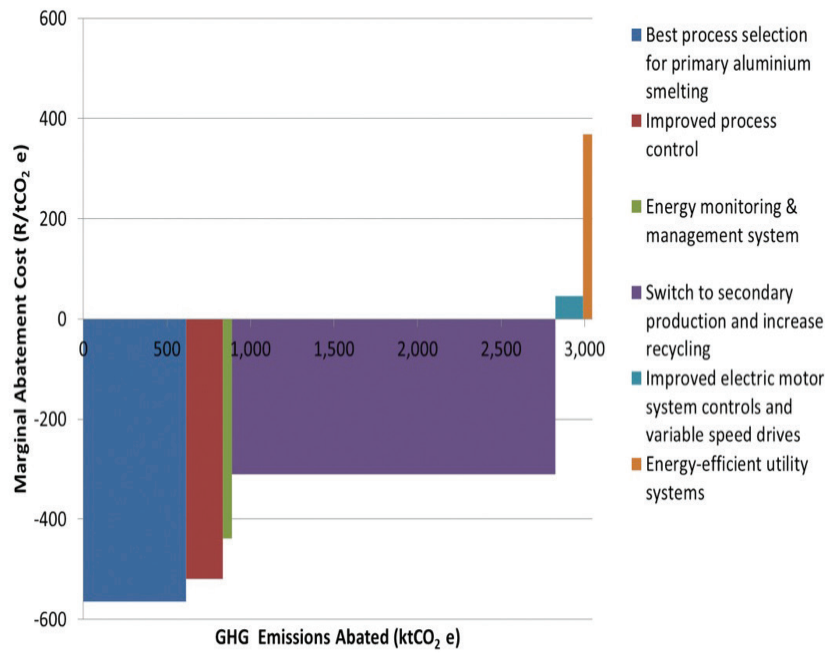


Figure 7: Primary aluminium production MACC for 2030

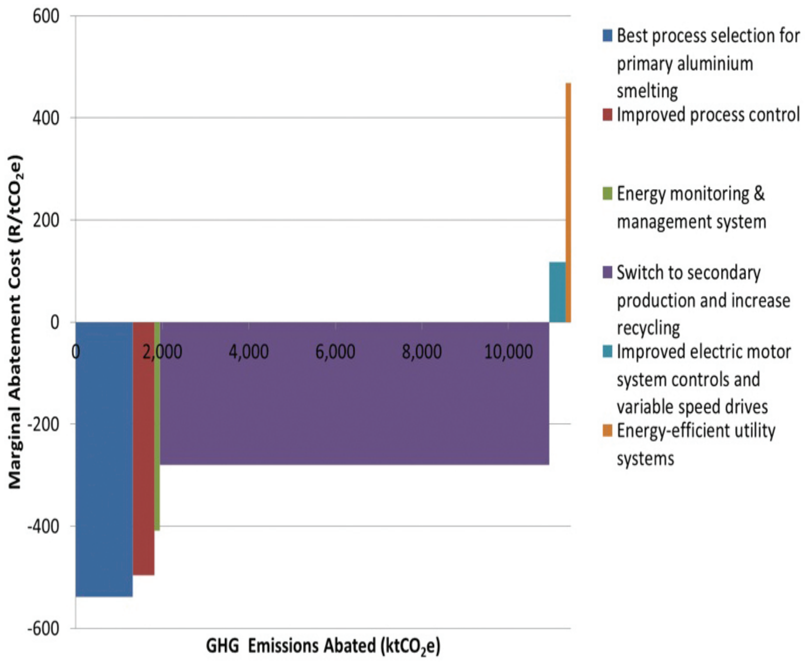


Figure 8: Primary aluminium production MACC for 2050

In 2030, the progressive switch from primary production techniques and replacement with secondary production contributes to total abatement potential of 3,045 $ktCO_2e$/year (11% of the reference WEM emissions projection), as shown in Figure 7. Secondary aluminium production using recycled scrap raw material requires significantly less energy compared to primary aluminium production and offers mitigation potential of 1,935 $ktCO_2e$/year at a negative marginal abatement cost of -R311/tCO_2e.

Figure 8 shows the benefit in terms of mitigation potential of switching to less electricity intensive secondary production techniques in 2050. Of course, shifting from the primary to the secondary production pathway is limited by access to scrap aluminium and would take place gradually as production facilities reach the end of their lives and are replaced.

The total mitigation potential which is deemed to be technically possible from 2010 to 2050 compared to the WEM is 169 million tCO_2e. This is equivalent to 13% of the reference WEM emissions.

6.3 Iron and Steel Production

6.3.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the iron and steel production MACC, together with references, are presented in Table 25. The assumed costs, technology availability and lifetime are listed in Table 26. The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 27.

To reduce sector emissions, it is assumed that 40% of crude steel can be produced from the secondary production route of electric arc furnaces (EAF) and scrap material by 2030 (an increase of 11% from 29% in 2010). This measure assumes a gradual shift from the primary production pathway of blast furnace (BF) and basic oxygen furnace (BOF) over a 20 year period starting in 2010. It is also assumed that the increased demand for scrap metal can be met. Again for the purposes of abatement, it is assumed that 40% of crude steel is produced using the direct reduced iron (DRI) smelting process in EAFs by 2030 (an increase of 27% from 13% in 2010). The increase in DRI production assumes that the necessary additional supplies of gas are available. The remaining 20% of production in 2030 is assumed to come from the BF and BOF route (a reduction of 38% from 58% of total production in 2010).

Sector growth is assumed to be 3.9% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

Table 25: Emissions reduction potential and energy saving potential of iron and steel production mitigation measures and references

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	
1	BOF waste heat and gas recovery			3%	100%	(EC, 2013c) (ArcelorMittal, 2013)
2	Top gas pressure recovery turbine			2%	97%	
3	Electric arc furnaces (EAF) and secondary production route	96%	100%	72%	100%	(EC, 2013c) (JRC I&S, 2012)
4	State-of-the-art power plant	5%	100%	15%	100%	(EC, 2013c)
5	Top gas-recycling blast furnace (with CCS)	48%	100%	-1%	100%	(EC, 2013c) (ULCOS, 2008) (ETSAP, 2010b)
6	CCS - blast furnace (post-combustion)	48%	100%	-16%	97%	(EC, 2013c) (ETSAP, 2010b)
7	State-of-the-art power plant (with CCS)	10%	100%	-1%	65%	
8	DRI – Midrex	54%*	100%	11%	100%	(IPCC, 2006)
9	DRI – HYL	54%*	100%	7%	100%	**
10	DRI – ULCORED	54%*	100%	20%	100%	(EC, 2013c) (Voestalpine, 2013)
11	Energy monitoring and management system			1%	100%	(ArcelorMittal, 2013) (EC, 2009a)
12	Improved process control			3%	100%	
13	Improved electric motor system controls and variable speed drives			10%	6%	
14	Energy efficient boiler systems and kilns			10%	10%	
15	Energy-efficient utility systems			10%	4%	
16	Improved heat exchanger efficiencies			10%	10%	

* *In the opinion of the sector expert, the 54% process emission abatement potential for direct reduction processes (Midrex, HYL and Ulcored) is overstated. The estimate is derived from an EU benchmark that is currently being contested in that region.*

** *IPCC, 2006: Guidelines for National Greenhouse Gas Inventories, Chapter 4: Metal Industry Emissions (Table 4.1: Tier 1 default CO2 emission factors for coke production and iron & steel product, Page 4.25)*





Table 26: Costs, availability and lifetime of iron and steel production mitigation measures

	Abatement measure	Capital cost	Additional annual costs	Site production capacity	Availability	Lifetime
		Million R/site	Million R/year	Million tonnes/ year	Year	Years
1	BOF waste heat and gas recovery	450	23	2.8	2010	25
2	Top gas pressure recovery turbine	108	5	3	2010	25
3	Electric arc furnaces (EAFs) and secondary production route	1,440	72	0.8	2010	40
4	State-of-the-art power plant	5,850	293	3.0	2010	40
5	Top gas-recycling blast furnace (with CCS)	864	308	1.0	2020	40
6	CCS - blast furnace (post-combustion)	913	304	1.0	2020	40
7	State-of-the-art power plant (with CCS)	8,424	812	3.0	2020	40
8	DRI – Midrex	6,600	330	2	2010	40
9	DRI – HYL	5,400	270	2	2010	40
10	DRI – ULCORED	3,600	180	1	2020	40
11	Energy monitoring and management system	30	2	2	2010	15
12	Improved process control	240	12	2	2010	15
13	Improved electric motor system controls and variable speed drives	180	9	2	2010	15
14	Energy-efficient boiler systems and kilns	120	6	2	2010	15
15	Energy-efficient utility systems	120	6	2	2010	15
16	Improved heat exchanger efficiencies	72	4	2	2010	15

Table 27 Iron and steel production mitigation technology sector uptake and other assumptions

	Abatement measure	% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
1	BOF waste heat and gas recovery	0%	50%	100%	100%	BF and BOF production route: • Energy intensity –18.74 GJ/t Liquid Steel (based upon EU average (EC, 2013c) • Process emissions intensity – 1.82 tCO_2/t crude steel, including coke, sinter and iron making (IPCC, 2006) • When BOF gas is recovered, energy savings amount to 0.35–0.7 GJ/t LS, compared to flaring. A leak-free system, which was developed by Nippon Steel Corporation, leads to energy savings of 0.98–1.08 GJ/t LS and increased molten steel production of 0.4 % compared to flaring. (EC, 2013c, p412) • 0.6 GJ/t LS selected after consultation with industry task-team members. Assumes BOF gas is combusted in the converter gas duct, and subsequently the sensible heat is recovered in a waste heat boiler. Costs do not include power generation which is included in state-of-the-art power plant below. Assumes implementation in parallel.
2	Top gas pressure recovery turbine	0%	50%	100%	100%	Energy savings are estimated at up to 0.4 GJ/t hot metal (HM) for a 15 MW turbine. The savings amount to 2% of the gross blast furnace energy demand. Application of top gas pressure recovery at blast furnaces is common in furnaces with high top pressure. EC, 2013c, p351)
3	Electric arc furnaces (EAFs) and secondary production route	0%	50%	100%	100%	• EAF cost assumed to be R1,800/t installed capacity. Total cost assumes reference plant capacity of 0.8 million tonnes steel per year. EAF and scrap production route: • Energy intensity – 5.2GJ/t Liquid Steel (LS) (primary energy, assuming grid efficiency of 35%) • Process emissions intensity – 0.08 tCO2/t crude steel (IPCC, 2006).
4	State-of-the-art power plant	0%	50%	50%	50%	• Power plant size is 260MWe based upon ArcelorMittal Vanderbijlpark works electricity demand of 6.28 GWh per day. • Capex of US$2500/kW assumed after consultation with industry task-team members. • Cost includes power generation equipment. Gas storage equipment is included in BOF waste heat and gas recovery. Assumes implementation in parallel. • Assumes replacement of all imported power for energy saving. Indirect emissions reduction not included. • There are no advanced or fully integrated-scale power plants in South Africa. The counterfactual technology is assumed to be imported power. • 50% of state-of-the-art power plants are built without CCS and 50% with CCS.

Abatement measure		% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
5	Top gas-recycling blast furnace (with CCS)	0%	0%	50%	50%	Test results at LKAB's experimental blast furnace (EBF) under the ULCOS programme, claim that in comparison with the conventional blast furnace process, a carbon saving ratio of about 24% could be achieved, corresponding to a reduction of the CO_2 emission of up to 76% when assuming the underground storage of the corresponding captured CO_2. The top gas recycling ratio could be up to 90% with CO recovery of about 88%. Assumptions: • 24% carbon-reductants saving t/HM at the blast furnace (BF) should be feasible • Overall equivalent energy saving from reduction in coke consumption assumed to be 15% t/LS. • -16% total GJ/t steel energy/power overhead for capture and compression of CO_2 based on compression costs at Corex plant in South Africa (Voestalpine, 2013) • Assuming coke reductants is reduced, this is equivalent to a 5% reduction in process emissions from coke consumption at the BF t/HM and 4% overall CO_2/t LS (not including storage). • 76% overall emissions capture and storage efficiency. • Assumes additional annual costs of 10 US$/t$CO_2$e transport (pipeline 300km) and 20US$/t$CO_2$e offshore storage cost. Assumes even 50% of BFs are built with top gas-recycling blast furnace technology and 50% are retrofitted with post-combustion technology.
6	CCS - blast furnace (post-combustion)	0%	0%	50%	50%	Assumption as above, except 75% reduction efficiency in overall CO_2 capture & storage efficiency from process. Assumes even 50% of BFs are built with top gas-recycling blast furnace technology and 50% are retrofitted with post-combustion technology.
7	State-of-the-art power plant (with CCS)	0%	0%	50%	50%	Assumptions as above, except 85% reduction efficiency in overall CO_2 capture & storage efficiency from power plant. Additional annual costs of 5% of Capex plus 10US$/t$CO_2$ transport and 20US$/t$CO_2$ offshore storage cost. 50% of state-of-the-art power plants are built without CCS and 50% with CCS.
8	DRI - Midrex	0%	33%	33%	33%	Midrex and EAF production route: • Energy intensity– 16.6 GJ/t liquid steel • Process emissions intensity - 0.84 tCO_2/t crude steel (IPCC, 2006) The process shift to DRI from BF and BOF is assumed to be an even 1/3 split between the three DRI technologies - Midrex, HYL and ULCORED.
9	DRI - HYL	0%	33%	33%	33%	HYL and EAF production route: • Energy intensity– 17.47 GJ/t liquid steel • Process emissions intensity - 0.84 tCO_2/t crude steel (IPCC, 2006).

Abatement measure		% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
10	DRI - ULCORED	0%	0%	33%	33%	ULCORED and EAF production route: • Energy intensity– 14.97 GJ/t Liquid Steel • Process emissions intensity - 0.84 tCO2/t crude steel (IPCC, 2006)
11	Energy monitoring and management system	0%	100%	100%	100%	Energy saving potential and costs estimated and cross-checked with TWG members.
12	Improved process control	0%	100%	100%	100%	
13	Improved electric motor system controls and VSDs	0%	100%	100%	100%	
14	Energy-efficient boiler systems and kilns	0%	100%	100%	100%	
15	Energy-efficient utility systems	0%	100%	100%	100%	
16	Improved heat exchanger efficiencies	0%	100%	100%	100%	

6.3.2 Marginal Abatement Cost Curve

The iron and steel production MACC indicates that all of the mitigation opportunities identified have a combined GHG emissions abatement potential of 5,825 ktCO_2e in 2020 compared to the WEM reference scenario or 18% of total projected emissions, as shown in Figure 9. Energy efficiency measures, such as implementation of BOF waste heat and gas recovery, energy monitoring and management system and top gas pressure recovery turbine, have negative marginal abatement costs due to their significant energy cost saving potential and relatively low capital cost. The most significant abatement option is to shift from traditional energy-intensive primary production processes of iron ore reduction using blast furnaces to secondary techniques using EAFs and maximising scrap raw material. This has the potential to mitigate some 1,465 ktCO_2e in 2020 (although the uptake of this measure is limited by the availability and price of scrap metal). Replacing further production from the counterfactual BF and BOF route by switching to DRI and EAF could mitigate over 1,700 ktCO_2e in 2020 (for example by implementing Midrex and HYL technologies that produce DRI from pellets by gas-based direct reduction in a shaft furnace). However, this has an abatement cost of over R410/tCO_2e and uptake maybe limited by access to natural gas or coke oven gas. Building state-of-the-art power plants has significant abatement potential (by installing advanced, high-efficiency power generation equipment using waste process gas to generate electricity and thus replace grid power). However, this also has a positive abatement cost of over R600/tCO_2e.

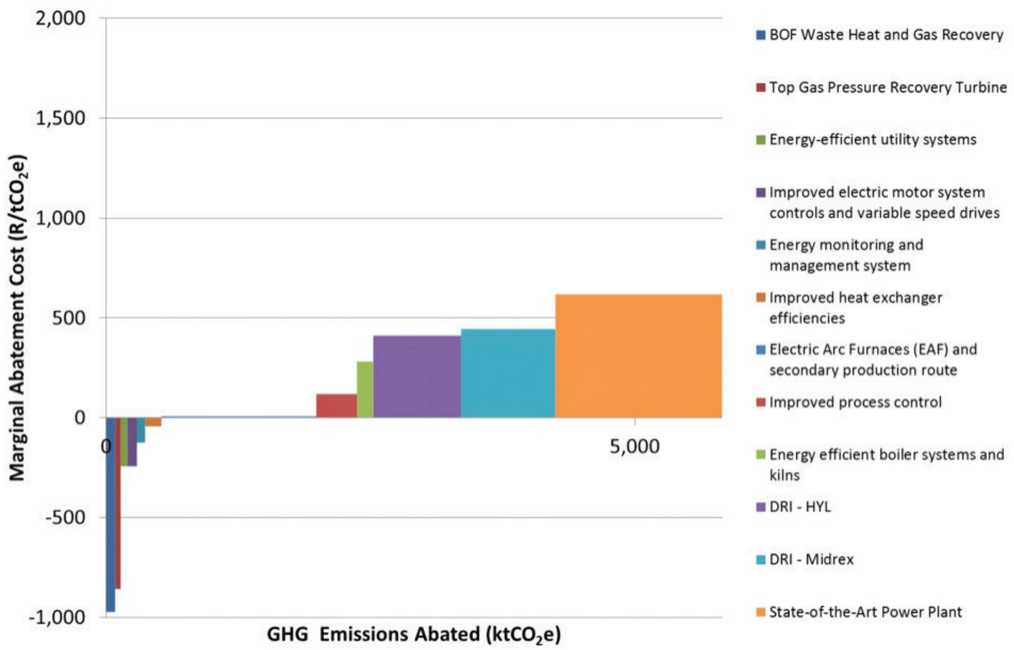


Figure 9: Iron and steel production MACC for 2020

The portfolio of available mitigation technologies in 2030 widens with the introduction of DRI-ULCORED (a more cost effective DRI production technique) and CCS technologies (capable of capturing and storing process and fuel combustion CO_2 emissions) on the right hand side of the horizontal axis in Figure 10. The total mitigation potential of 19,500 $ktCO_2e$ in 2030 or 41% of total projected emissions is considered to be technically achievable. The DRI and EAF alternative to the BF and BOF steelmaking pathway has a combined abatement potential of almost 8,200 $ktCO_2e$ in 2030 at marginal abatement costs of less than R505 and -R4/tCO_2e, respectively. Capturing CO_2 at the blast furnace (for example by implementing top gas-recycling blast furnace and post-combustion technologies has the potential to abate over 4,260 $ktCO_2e$ in 2030, at costs of R600 and R825/tCO_2e, respectively (top gas-recycling blast furnace also saves energy and is therefore the cheaper option). Implementing state-of-the-art power plant with CCS is the most expensive mitigation option at over R1,400/tCO_2e.

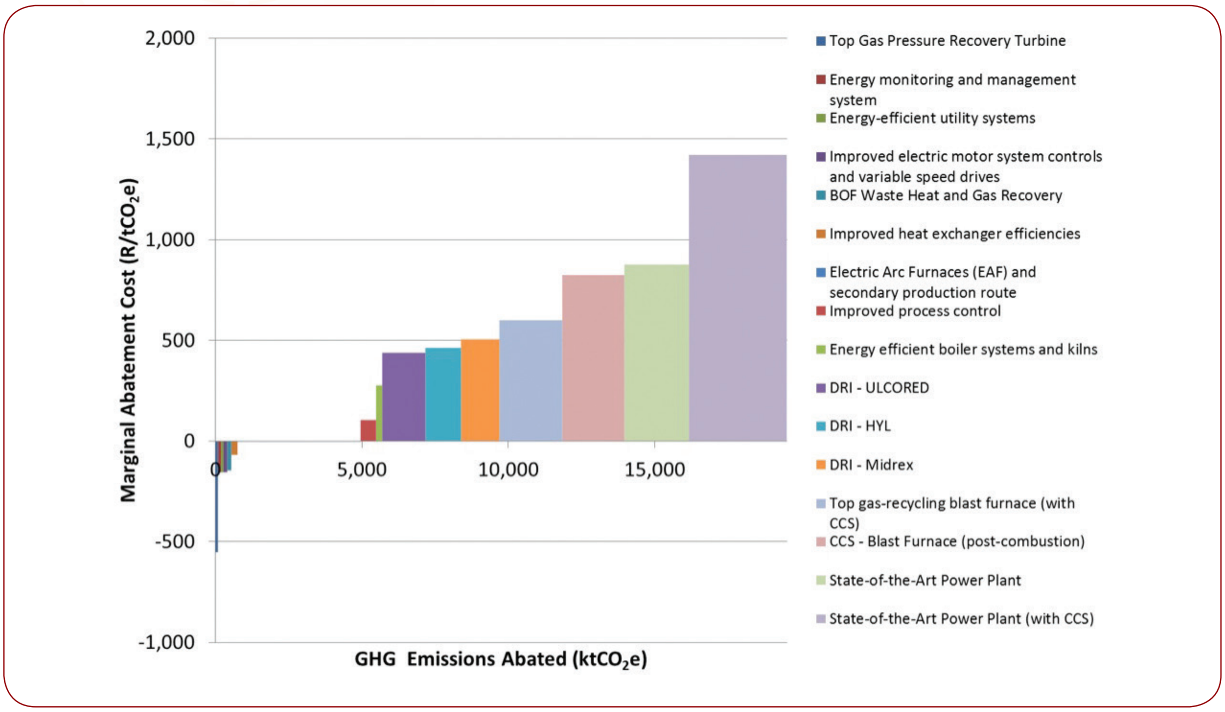


Figure 10: Iron and steel production MACC for 2030

By 2050, the uptake of all available mitigation options offers a combined mitigation potential of 44.6 million tCO_2e or 41% of total WEM emissions. Retrofitting CCS to blast furnaces combined with top gas-recycling blast furnace offers a realistic solution for maximising energy efficiency whilst minimising emissions from the blast furnace primary production pathway with marginal abatement costs of R600/ tCO_2e. However, CCS for power plants is more costly and emphasises the high investments costs associated with this technology. The clear leaders in terms of abatement potential are shifting away from energy-intensive primary techniques to more energy-efficient secondary techniques (EAFs and use of scrap metal) and increasing production using DRI. The option with the highest marginal abatement cost is implementing state-of-the-art power plants (with and without CCS).

The total mitigation potential which is deemed to be technically possible is 758 million tonnes of CO_2e in absolute terms over the 2010 to 2050 period or 34% of the reference emissions.

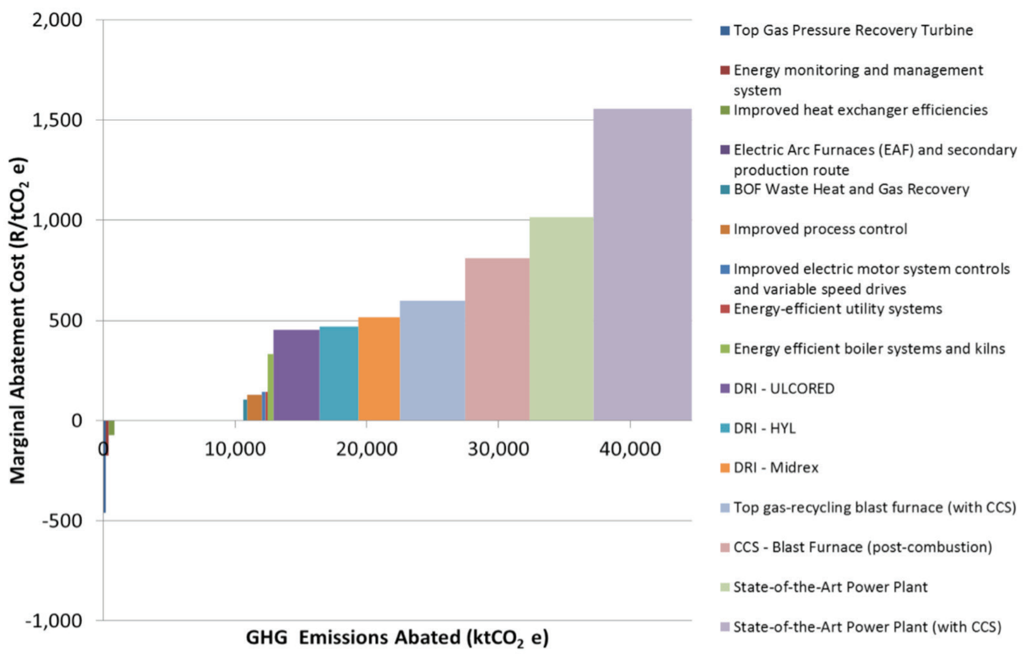


Figure 11: Iron and steel production MACC for 2050

6.4 Ferroalloys Production

6.4.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the ferroalloys production MACC, together with references, are presented in Table 28. The assumed costs, technology availability and lifetime are listed in Table 29. The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 30.

The share of furnace technology in operation across the sector is assumed to be 40% semi-closed and 60% closed type in 2010. For the objective of increasing energy efficiency and GHG abatement, the analysis assumes a production switch of 25% of semi-closed to the more energy efficient closed furnace type is technically possible by 2030, giving a split of 15% semi-closed and 85% closed. The mitigation analysis also assumes a 20% switch from carbon reductants (for example coke and coal) to biocarbon sources (for example charcoal and woodchips) is possible by 2030. Sector growth is assumed to be 4.2% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

Table 28: Emissions reduction potential and energy saving potential of mitigation measures and references in ferroalloys production

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Energy saving potential	Applicability		Reference
		%	%	%	%	%	%	Note	
1	Implementing best available production techniques	10%	100%	5%	100%	5%	100%	100% of all electric use	(Xstrata, 2012) (EC, 2009b)
2	Replace submerged arc furnace semi-closed with closed type	16%	88%	16%	100%	20%	95%	95% of electricity used by semi closed furnaces	(EC, 2009b) (Riekkola-Vanhanen, 1999) (Holappa, 2010)
3	Waste gas recovery and power generation – CO from closed furnace					13%	95%	95% of electricity used by closed furnaces	(Xstrata, 2012) (EC, 2009b) (Riekkola-Vanhanen, 1999)
4	Waste heat recovery and power generation from semi-closed furnace – Rankine Cycle					13%	95%	95% of electricity used by semi closed furnaces	
5	Waste heat recovery and power generation from semi-closed furnace – Organic Rankine Cycle					13%	95%	95% of electricity used by semi closed furnaces	
6	Use biocarbon reductants instead of coal/coke	100%	88%						(Riekkola-Vanhanen, 1999) (EC, 2009b)
7	Energy monitoring and management system			1%	100%	1%	100%	of all electricity use	(EC, 2009b) (EC, 2009a)
8	Improved electric motor system controls and variable speed drives					10%	5%	of all electricity use	(EC, 2009a)
9	Energy-efficient utility systems					10%	5%	of all electricity use	
10	Improved heat exchanger efficiencies			10%	5%	10%	5%	of all electricity use	

Table 29: Costs, availability and lifetime of ferroalloys production mitigation measures

Abatement measure		Capital cost	Additional annual costs	Site production capacity	Availability	Lifetime
		Million ZAR/site	Million ZAR/year	Million Tonnes/ year	Year	Years
1	Implementing best available production techniques	240	12	0.4	2010	25
2	Replace submerged arc furnace semi-closed with closed type	720	36	0.4	2010	25
3	Waste gas recovery and power generation – CO from closed furnace	472.5	23.625	0.4	2010	25
4	Waste heat recovery and power generation from semi-closed furnace – Rankine cycle	945	47.25	0.4	2010	25
5	Waste heat recovery and power generation from semi-closed furnace – organic Rankine cycle	1008	50.4	0.4	2014	25
6	Use biocarbon reductants instead of coal/coke	60	3	0.4	2010	25
7	Energy monitoring and management system	12	0.6	0.4	2010	15
8	Improved electric motor system controls and variable speed drives	42	2.1	0.4	2010	15
9	Energy-efficient utility systems	30	1.5	0.4	2010	15
10	Improved heat exchanger efficiencies	18	0.9	0.4	2010	15

Table 30 Mitigation technology sector uptake and other assumptions in ferroalloys production

	Abatement measure	% Sector uptake 2010	2020	2030	2050	Other Assumptions
1	Implementing best available production techniques	20%	50%	100%	100%	Cost depends on extent of retrofit projects installed. €20 million assumes plant revamp (not including replacement of furnace).
2	Replace submerged arc furnace semi-closed with closed type	20%	50%	100%	100%	Cost assumed new closed electric arc furnace is R1,800/t installed capacity (US$200/tonne)
3	Waste gas recovery and power generation – CO from closed furnace	0%	50%	100%	100%	Assumes 15–20% of electric energy consumed by the electric arc furnace can be recovered by an energy recovery system. Percentage is considerably higher for a system that produces electricity and uses the thermal energy of the furnace cooling and the off-gas volume. Assumes site can sell electricity over the fence. Assumes 35MW installed capacity with internal combustion technology with annual availability of 95% and 70% capacity utilisation.
4	Waste heat recovery and power generation from semi-closed furnace – Rankine cycle	0%	50%	100%	100%	Has been considered for general application to the ferroalloy industry. Typical capital cost US$2500/kW to US$3300/kW. Assumes site can sell electricity over the fence. Assumes 35MW installed capacity with Rankine cycle steam turbine technology with an annual availability of 95% and 70% capacity utilisation.
5	Waste heat recovery and power generation from semi-closed furnace – organic Rankine cycle (ORC)	0%	50%	100%	100%	Assuming a 35MW gross installed capacity ORC with an annual availability of 95% and 70% capacity utilisation.
6	Use biocarbon reductants instead of coal/coke	0%	50%	100%	100%	Assumes fossil fuel reductants replaced by zero process emissions sources (e.g. biomass). Cost savings depend on fuel price. Assumes no cost saving. Estimated €5m Capex for new storage and conversion per site. Assumes maximum of 20% switch from coke and coal.
7	Energy monitoring and management system	20%	100%	100%	100%	Energy saving potential and costs estimated and cross-checked with TWG member.
8	Improved electric motor system controls and variable speed drives	20%	100%	100%	100%	
9	Energy-efficient utility systems	0%	100%	100%	100%	
10	Improved heat exchanger efficiencies	0%	100%	100%	100%	

6.4.2 *Marginal Abatement Cost Curve*

The identified technical mitigation potential in ferroalloy production in 2020 is estimated at almost 5,580 ktCO_2e/year or 16% when compared to the WEM emissions projection, as shown in Figure 12. Several mitigation options provide negative marginal abatement costs and are available. The replacement of submerged arc semi-closed furnaces with closed type offers the lowest marginal abatement cost to reduce emissions by 877 ktCO_2e/year at a marginal abatement cost of -R840/tCO_2e. Implementation of best available production techniques and waste gas recovery and power generation (on closed furnace types) also offer negative marginal abatement cost options to reduce carbon intensity.

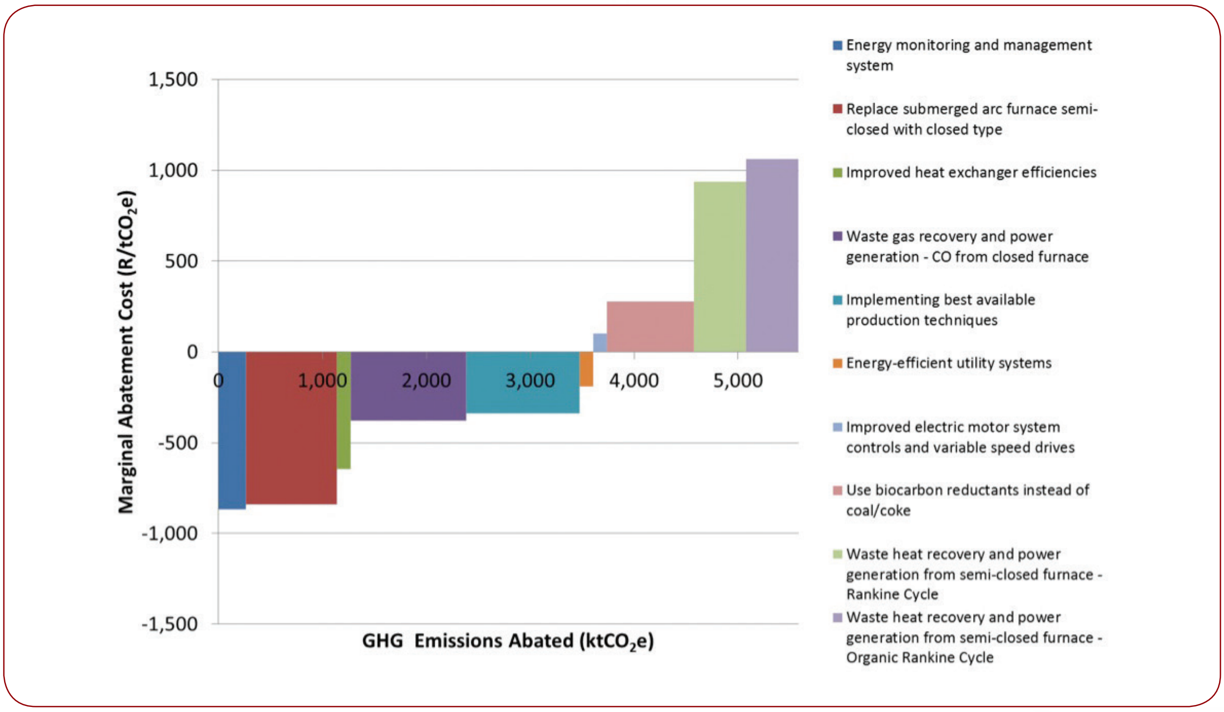


Figure 12: Ferroalloy production MACC for 2020

In 2030, the technical abatement potential is estimated at 13,400 ktCO_2e or 28% of the reference WEM emissions projection, as shown in Figure 13. The deployment of waste heat recovery and power generation projects adopting Rankine cycle and organic Rankine cycle technologies is unlikely as lower marginal abatement cost energy efficiency options are available. The option to use biocarbon reductants instead of coal/coke offers a zero-carbon solution capable of abating almost 2,400 ktCO_2e/year at a relatively modest marginal cost of R290/tCO_2e. It is important to note that the extent of mitigation achieved through the use of biocarbon reductants depends on the nature of the ore and the type of biocarbon used. As this technology has not been tested in South Africa, the feasibility of implementation will require further investigation on the basis of specific biocarbons.

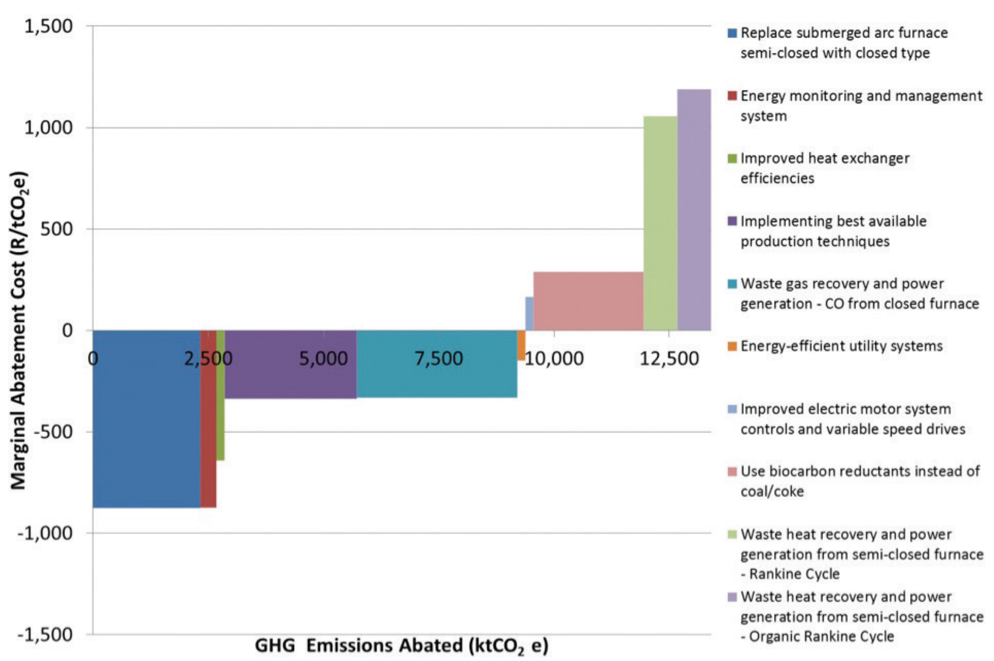


Figure 13: Ferroalloy production MACC for 2030

By 2050, the total annual mitigation potential has increased to over 30 million tCO_2e/year or 28% of the reference WEM emissions projection with the notable options being the replacement of submerged arc semi-closed furnaces with closed type, implementation of best available production techniques and using CO gas from closed furnaces to generate power onsite and reduce electricity imports (and associated indirect emissions), as shown in Figure 14.

The total mitigation potential which is deemed to be technically possible from 2010 to 2050 compared to the WEM is over 539 million tCO_2e equivalent to 24% of projected emissions.

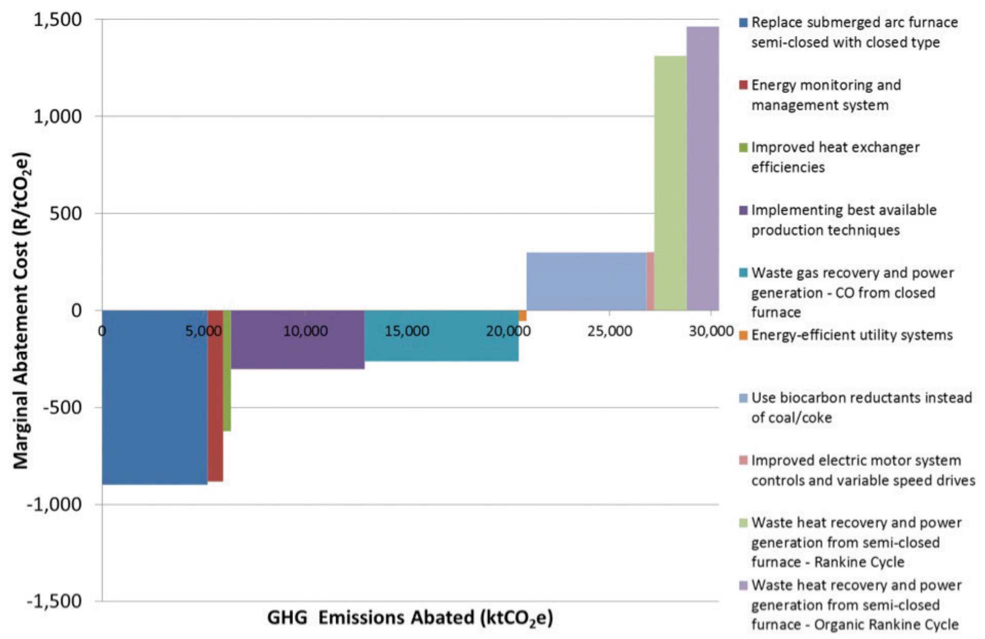


Figure 14: Ferroalloy production MACC for 2050

7. Mitigation Potential for the Minerals Sector

The minerals sector includes cement and lime production. Mitigation measures have been identified and MACCs developed for the two subsectors.

The summary MACCs combining all of the mitigation measures identified and quantified for cement and lime production, for 2020, 2030 and 2050 are displayed below in Figure 15, Figure 16 and Figure 17, respectively. Detailed abatement and marginal abatement costs for all measures are shown in Table 53. Identification numbers shown in the legends of the figures below may be used to look up details in Table 53.

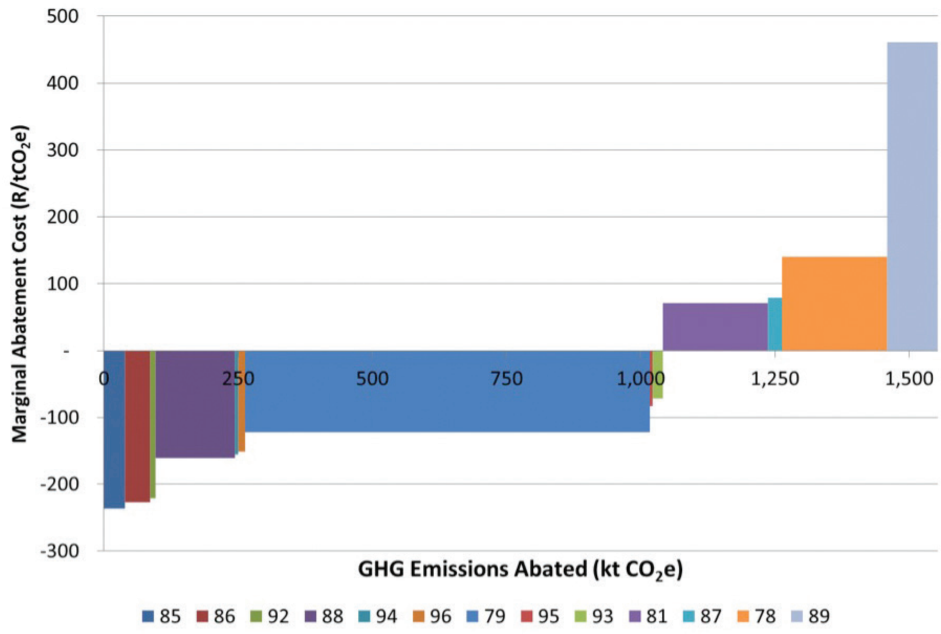


Figure 15: Minerals sector MACC for 2020

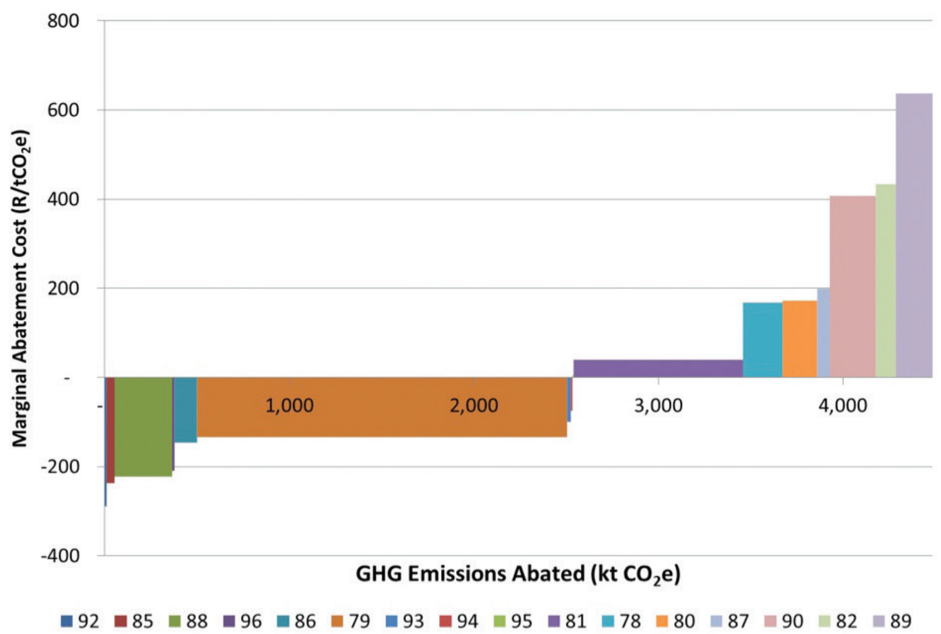


Figure 16: Minerals sector MACC for 2030

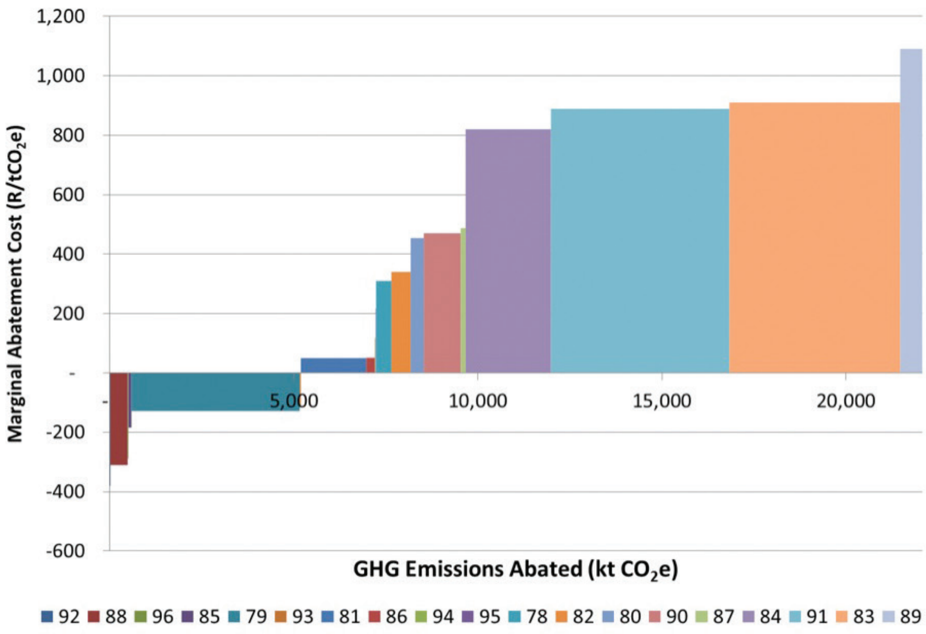


Figure 17: Minerals sector MACC for 2050

7.1 Cement Production

7.1.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the cement production MACC, together with references, are presented in Table 31. The assumed costs, technology availability and lifetime are listed in Table 32. The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 33.

For the objective of reducing emissions, the analysis assumes that a 25% fuel switch from fossil fuels to zero-carbon waste and biomass fuels is technically possible by 2030 (the proportional split of fuel is assumed to be 99% fossil and 1% waste/biomass in 2010). The analysis assumes a reduction in clinker content of cement is possible from 69% on average in 2010 down to 60% on average by 2030. The MACCs also assume that 2.5% of total cement production can be supplied by geopolymer production techniques by 2040.

Sector growth is assumed to be 4.2% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

Table 31: Emissions reduction potential and energy saving potential of mitigation measures and references in cement production

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	%	%	
1	Implement kiln systems with multistage cyclone preheaters and precalciners			13%	100%	5%	100%	(EC, 2013a) (IEA, 2010) (ETSAP, 2010)
2	Improved process control			5%	100%	5%	100%	(EC, 2013a)
3	Reduction of clinker content of cement products	100%	100%	100%	100%			(EC, 2013a) (ERC, 2007)
4	Waste heat recovery from kilns and coolers/cogeneration					28%	100%	(EC, 2013a)
5	Use waste material as fuel			100%	100%			(EC, 2013a) (ERC, 2007)
6	Geopolymer cement production	80%	100%	80%	100%	80%	100%	(IEA, 2010) (ETSAP, 2010)
7	CCS – back-end chemical absorption	95%	100%	-38%	100%	-51%	100%	(IEA, 2010) (ETSAP, 2010) (CSI/ECRA, 2009)
8	CCS – oxyfuelling	95%	100%	-38%	100%	-51%	100%	(IEA, 2010) (ETSAP, 2010) (CSI/ECRA, 2009)
9	Energy monitoring and management system			1.0%	100%	1.0%	100%	(EC, 2009a)
10	Improved electric motor system controls and variable speed drives					9%	100%	(EC, 2009a)
11	Energy-efficient utility systems					5%	100%	(EC, 2009a)

Table 32: Costs, availability and lifetime of cement production mitigation measures

	Abatement measure	Capital cost	Additional annual costs	Site production capacity	Abatement cost	Availability	Lifetime
		Million R/site	Million R/year	Million tonnes/ year	R/t CO_2e	Year	Years
1	Implement kiln systems with multistage cyclone preheaters and precalciners	3,156	348.0	1		2010	40
2	Improved process control	60	3.0	1		2010	10
3	Reduction of clinker content of cement products	150	2.5	1		2010	20
4	Waste heat recovery from kilns and coolers/cogeneration	175	8.8	1		2010	25
5	Use waste material as fuel	50	5.0	1		2010	25
6	Geopolymer cement production	1,800	90.0	1		2020	40
7	CCS - back-end chemical absorption				630	2030	40
8	CCS - oxyfuelling				540	2030	40
9	Energy monitoring and management system	6	0	1		2010	15
10	Improved electric motor system controls and variable speed drives	30	2	1		2010	15
11	Energy-efficient utility systems	24	1	1		2010	15

Table 33 Mitigation technology sector uptake and other assumptions in cement production

	Abatement measure	% Sector uptake 2010	2020	2030	2050	Other assumptions
1	Implement kiln systems with multistage cyclone preheaters and precalciners	0%	0%	0%	0%	
2	Improved process control	0%	100%	100%	100%	The costs of process control optimisation techniques vary widely, up to €5 million. Assumes €5 million and 2Mt/year plant capacity.
3	Reduction of clinker content of cement products	0%	50%	100%	100%	Costs for additional filler handling, storage and equipment conversion. Assumes no cost saving on clinker reduction. Assumes energy and emissions depend largely on clinker content.
4	Waste heat recovery from kilns and coolers/ cogeneration	0%	0%	50%	50%	Assumes 5MW power output installed with capacity factor of 80% at investment cost of R35 m/MW. Assume reduction in electrical imports and indirect emissions. May possibly be lower than 50% maximum due to more efficient kiln technology.
5	Use waste material as fuel	0%	50%	100%	100%	Costs for additional fuel handling, storage, moisture content control and equipment conversion. Assumes no cost saving on fuel. Assumes fossil fuel replaced by 80% zero emissions fuel (e.g. biomass) and 20% other wastes. Also assumes moisture content controlled so no additional heat required. Capex assumed to be R50 million and Opex = 10% of Capex.
6	Geopolymer cement production	0%	0%	50%	100%	Assumes 2.5% maximum uptake and switch from standard Portland cement production due to product requirements.

Abatement measure		% Sector uptake				Other assumptions
		2010	2020	2030	2050	
7	CCS - back-end chemical absorption	0%	0%	0%	50%	Assumes 95% of process emissions could be captured by chemical absorption using 1.5 GJ heat and 0.2 GJ electricity (CO_2 compression) per tonne of clinker (ETSAP, 2010a). Capex cost assumes US$40/t$CO_2$e avoided (ETSAP, 2010a) Retrofitted to 50% of existing plant from 2030 onwards.
8	CCS - oxyfuelling	0%	0%	0%	25%	Assumes 95% of these emissions could be captured by chemical absorption using 1.5 GJ heat and 0.2 GJ electricity (CO_2 compression) per tonne of clinker. Capex cost assumes US$35/t$CO_2$e avoided (ETSAP, 2010a) Additional annual costs of 5% of Capex plus US$10/t$CO_2$e transport and US$20/tCO_2e offshore storage cost. Included in 25% of production from 2030 onwards.
9	Energy monitoring and management system	0%	100%	100%	100%	
10	Improved electric motor system controls and variable speed drives	0%	50%	100%	100%	
11	Energy-efficient utility systems	0%	50%	100%	100%	

7.1.2 Marginal Abatement Cost Curve

The mitigation potential in the South African cement sector in 2020 is estimated at 1,258 $ktCO_2e$/year compared to the reference WEM scenario (or 12% of total emission). The MACC displayed in Figure 18 shows that the lower marginal abatement cost option is the reduction of clinker content of cement products to 66% on average capable of mitigating 754 $ktCO_2e$/year at a negative marginal abatement cost of -R122/tCO_2e in 2020. Improved electric motor system controls and VSDs and advanced energy management systems are also options with negative abatements costs of -R227 and -R237/tCO_2e, respectively.

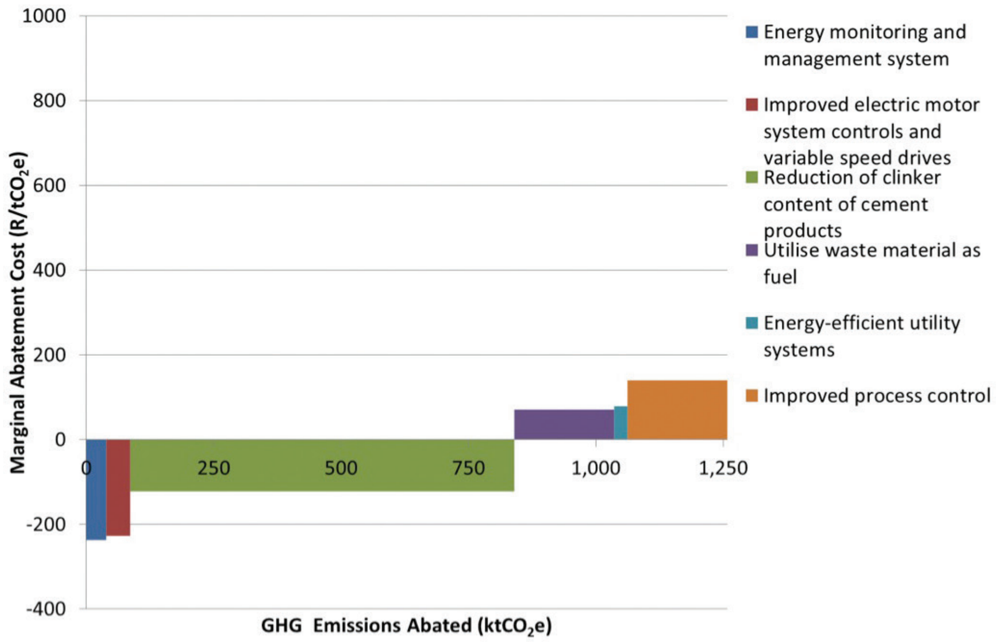


Figure 18: Cement production MACC for 2020

By 2030, more technology options become available increasing the total annual mitigation potential to over 3,650 $ktCO_2e$/year for the cement sector, as indicated by Figure 19, or 25% of total reference emissions. These include the implementation of waste heat recovery from kilns and coolers and the production of geopolymer cement (replacing standard Portland cement), with marginal abatements costs of R172 to over R434/tCO_2e, respectively. Using waste materials as fuel also shows good potential as an option and has a lower marginal abatement cost when compared to 2020.

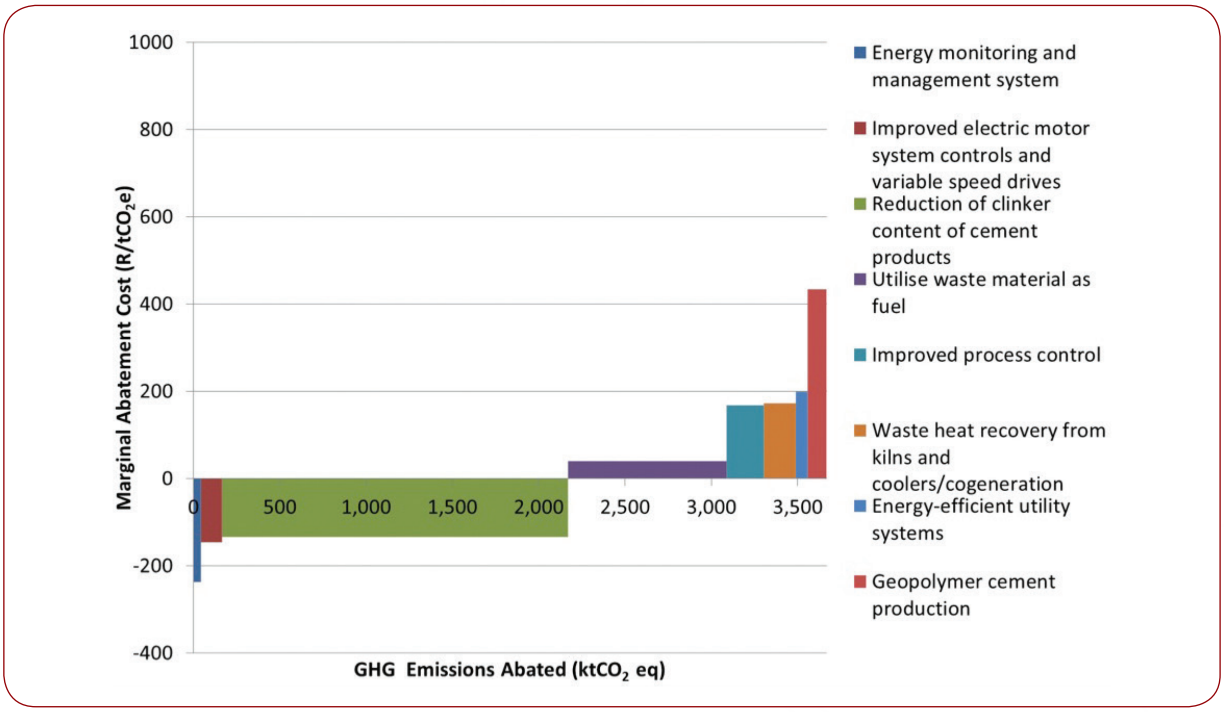


Figure 19: Cement production MACC for 2030

By 2050, the availability of CCS technologies including back-end chemical absorption and oxyfuel (with a marginal abatement cost of 910 and R820/tCO_2e,respectively) offers a much wider opportunity to reduce emissions of over 15 million tCO_2e/year in total compared to the WEM scenario or 46% of projected annual emissions, as shown in Figure 20.

The total mitigation potential for cement production from 2010 to 2050 is estimated at 230 million tCO_2e compared to the WEM reference scenario, equivalent to 34% of total emissions for the period.

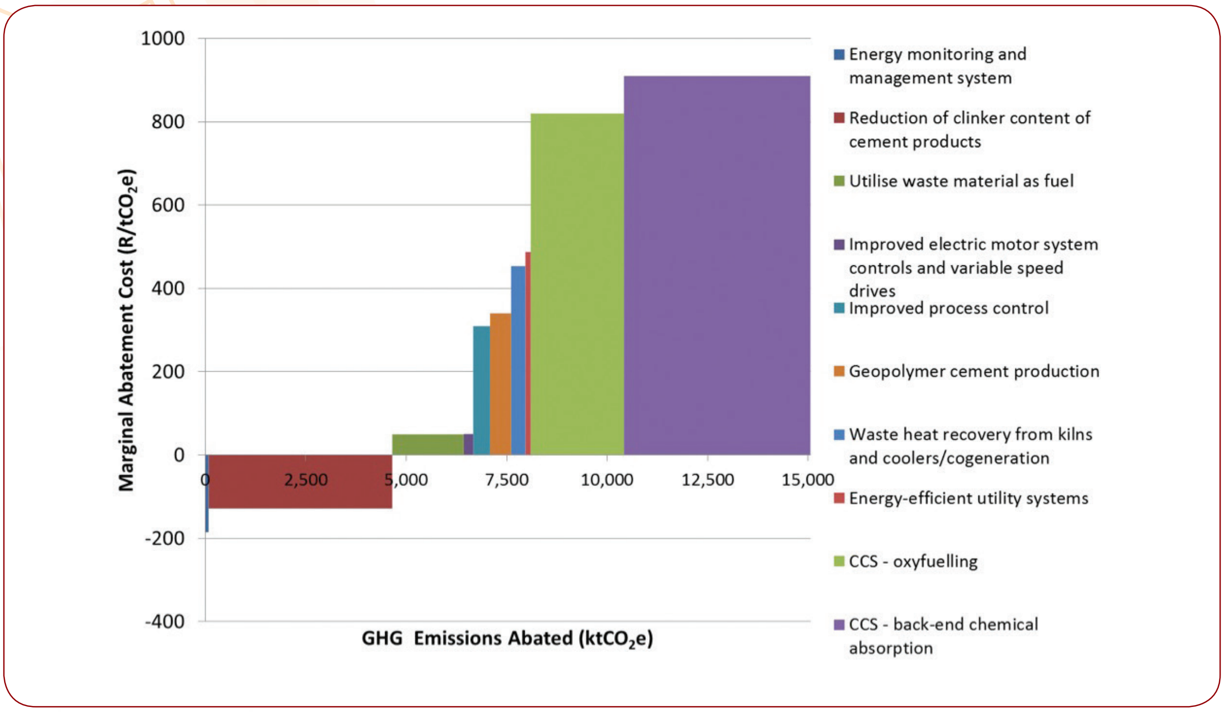


Figure 20: Cement production MACC for 2050

7.2 Lime Production

7.2.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the lime production MACC (including quick and hydrated lime), together with references, are presented in Table 34. The assumed costs, technology availability and lifetime are listed in Table 35. The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 36.

For the objective of reducing emissions, the analysis assumes that 90% of fuel consumed in 2010 is from fossil sources and 10% is waste/biomass fuel. By 2040, a 40% fuel switch from fossil fuel to zero-carbon waste and biomass fuels is assumed to be technically possible (that is by 2040, 50% of fuel is from fossil sources and 50% from waste/biomass). The MACCs also assume that by 2050, 80% of all kilns are vertical/parallel flow regenerative kiln (PFRK) type and the remaining 20% are rotary/other type (in 2010, it is assumed that 100% are of rotary or other non-vertical kiln types).

Sector growth is assumed to be 4.2% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

Table 34: Emissions reduction potential and energy saving potential of mitigation measures and references in lime production

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	%	%	
1	Installation of shaft preheaters			46%	100%			(EC, 2013a) (PPC, 2013)
2	Replace rotary kilns with vertical kilns or PFRK			30%	100%			(EC, 2013a) (PPC, 2013)
3	Use alternative fuels including waste and biomass	60%	100%	-10%	100%	-5%	50%	(EC, 2013a) (PPC, 2013)
4	CCS for lime production	95%	100%	-29%	100%	-100%	100%	(ETSAP, 2010b) (PPC, 2013)
5	Energy monitoring and management system			1%	100%	1.0%	100%	(EC, 2013a) (PPC, 2013) (EC, 2009a)
6	Improved process control			3%	100%		100%	
7	Improved electric motor system controls and VSDs					5%	100%	
8	Energy-efficient utility systems					4%	100%	
9	Improved heat exchanger efficiencies			1%	100%			

Table 35: Costs, availability and lifetime of lime production mitigation measures

	Abatement measure	Capital cost	Additional annual costs	Site production capacity	Abatement cost	Availability	Lifetime
		Million ZAR/site	Million ZAR/year	Million Tonnes/ year	ZAR/t CO_2e	Year	Years
1	Installation of shaft preheaters	200	1	0.4		2010	25
2	Replace rotary kilns with vertical kilns or PFRK	300	15	0.3		2010	40
3	Use alternative fuels including waste and biomass	30	-	0.7		2020	25
4	CCS for lime production				630	2040	40
5	Energy monitoring and management system	3.0	0.2	0.3		2010	15
6	Improved process control	12.0	0.6	0.3		2010	15
7	Improved electric motor system controls and VSDs	4.8	0.2	0.3		2010	15
8	Energy-efficient utility systems	4.2	0.2	0.3		2010	15
9	Improved heat exchanger efficiencies	3.0	0.2	0.3		2010	15

Table 36 Mitigation technology sector uptake and other assumptions in lime production

	Abatement measure	% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
1	Installation of shaft preheaters	60%	20%	40%	40%	Energy saving potential based upon information from TWG-M sector expert. R200 million Capex from sector expert.
2	Replace rotary kilns with vertical kilns or PFRK	20%	25%	50%	100%	There are two vertical shaft kilns being built at present in SA. It is unlikely that there will be any new rotary kilns. R300 million Capex from sector expert.
3	Use alternative fuels including waste and biomass	10%	0%	50%	100%	Investment costs for equipment required to use a particular fuel (e.g. storage handling, drying, milling, injection and safety). No additional fuel cost included here. MAC calculation assumes the price of alternative fuels including waste/biomass is 50% higher than the reference average fuel price. R 30 million Capex from sector expert.
4	CCS for lime production	0%	0%	0%	75%	Assumes additional 100% of current power use (e.g. for air separation, stripping, purification, CO_2 compression, etc.). Assumes 95% of process emissions could be captured by chemical absorption using 1.5 GJ heat and 0.2 GJ electricity (CO_2 compression) per tonne of lime based upon post-combustion CCS cement (ETSAP, 2010b). Assumes Capex cost of US\$100/tCO_2 captured (at the high end of the benchmark scale (ETSAP, 2010b).
5	Energy monitoring and management system	40%	60%	60%	60%	Electricity saving of measure 5, 7 and 8 add up to total of 10% of total electricity consumption, based upon information from TWG-M sector expert. Fuel saving of measure 5, 6 and 9 add up to total of 5% of total fuel consumption, based upon information from TWG-M sector expert.
6	Improved process control	60%	40%	40%	40%	Fuel saving of measure 5, 6 and 9 add up to total of 5% of total fuel consumption, based upon information from TWG-M sector expert.
7	Improved electric motor system controls and VSDs	20%	80%	80%	80%	Electricity saving of measure 5, 7 and 8 add up to total of 10%of total electricity consumption, based upon information from TWG-M sector expert.
8	Energy-efficient utility systems	20%	80%	80%	80%	Electricity saving of measure 5, 7 and 8 add up to total of 10%of total electricity consumption, based upon information from TWG-M sector expert.
9	Improved heat exchanger efficiencies	20%	80%	80%	80%	Fuel saving of measure 5, 6 and 9 add up to total of 5% of total fuel consumption, based upon information from TWG-M sector expert.

7.2.2 Marginal Abatement Cost Curve

In 2020, the identified technical mitigation potential for lime production is almost 295 ktCO_2e/year or 7% compared to the WEM emissions projection scenario. The MACC displayed in Figure 21, shows that implementing shaft preheater has a negative abatement cost of –R161/tCO_2e. The replacement of rotary kilns with vertical shaft kilns or parallel flow regenerative kilns (PFRK) also offers a significant abatement option, albeit, at much higher marginal abatement costs.

In 2030, the mitigation potential increases to 822 ktCO_2e/year equivalent to 15% of the WEM reference emissions projection, with the use of alternative fuels including waste and biomass increasing the opportunity for mitigation. The implementation of advanced energy monitoring and management systems, improved heat systems including heat exchanger efficiencies and improved electric motor system controls and VSDs are all mitigation options with low marginal abatement costs, although their impact is limited. The implementation of shaft preheaters is still the most significant mitigation option. The replacement of rotary kilns with vertical kilns or PFRK type also shows significant potential for abatement, albeit at a much higher cost.

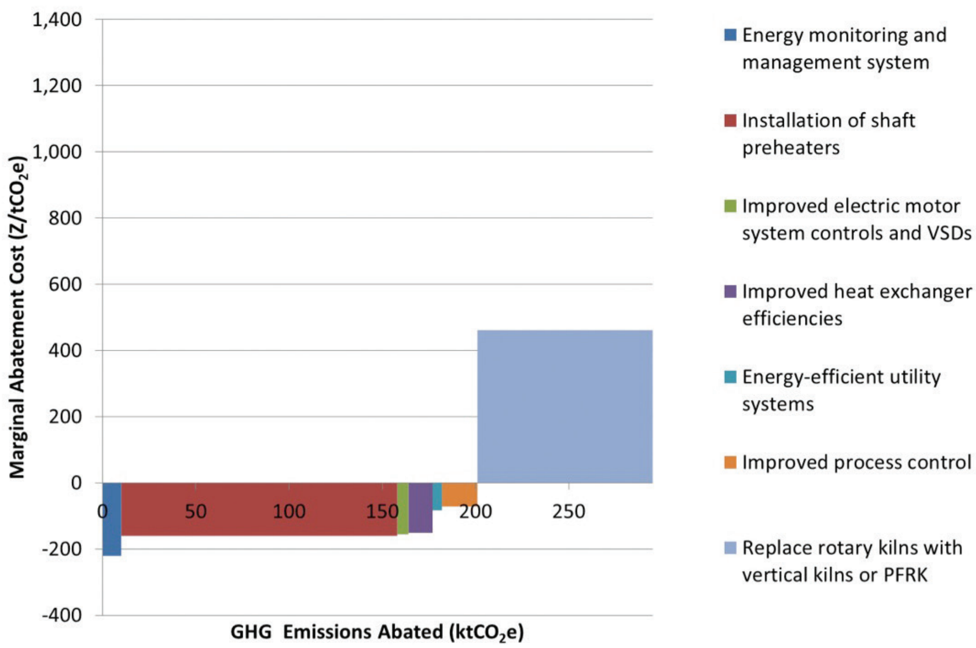


Figure 21: Lime production MACC for 2020

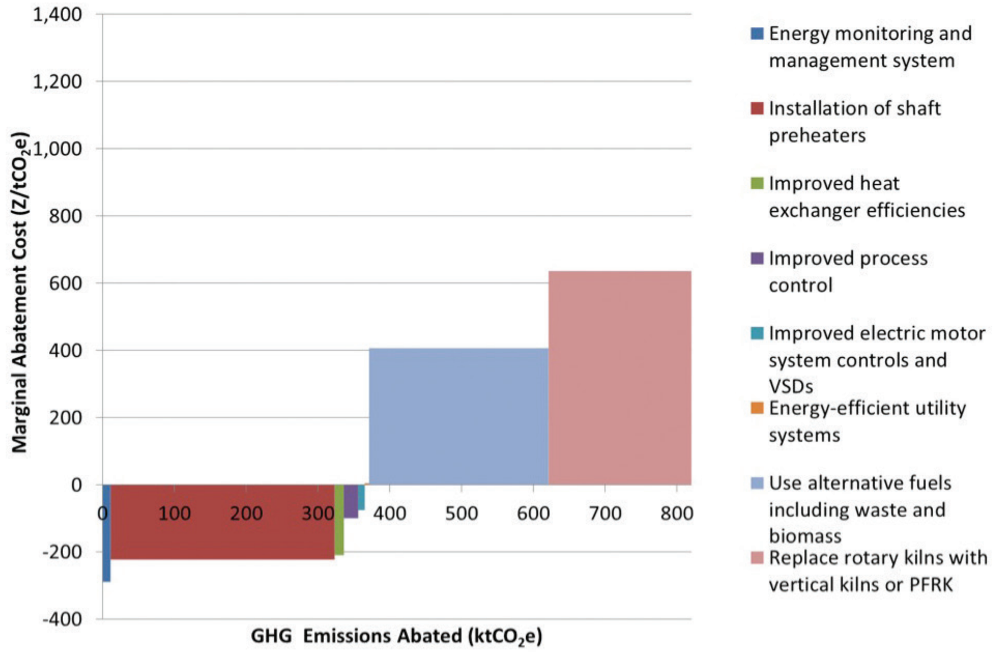


Figure 22: Lime production MACC for 2030

The MACC for 2050, displayed in Figure 23, shows the availability of CCS at a cost of over R800/tCO_2e significantly increases the mitigation potential to 7 million tCO_2e/year. This is equivalent to 56% of the WEM reference emissions projection. The marginal abatement cost of replacing rotary kilns with vertical kilns or PFRK increases from 800 in 2030 to over R1,300/tCO_2e in 2050. This is the result of an increased use of alternative fuels (including waste and biomass) in 2030 and 2050 which reduces the carbon intensity of lime production and therefore reduces the carbon reduction potential of other energy saving measures thereby increasing their marginal abatement cost.

The total mitigation potential from 2010 to 2050 is estimated at 74 million tCO_2e compared to the WEM reference scenario or 28% of total emissions.

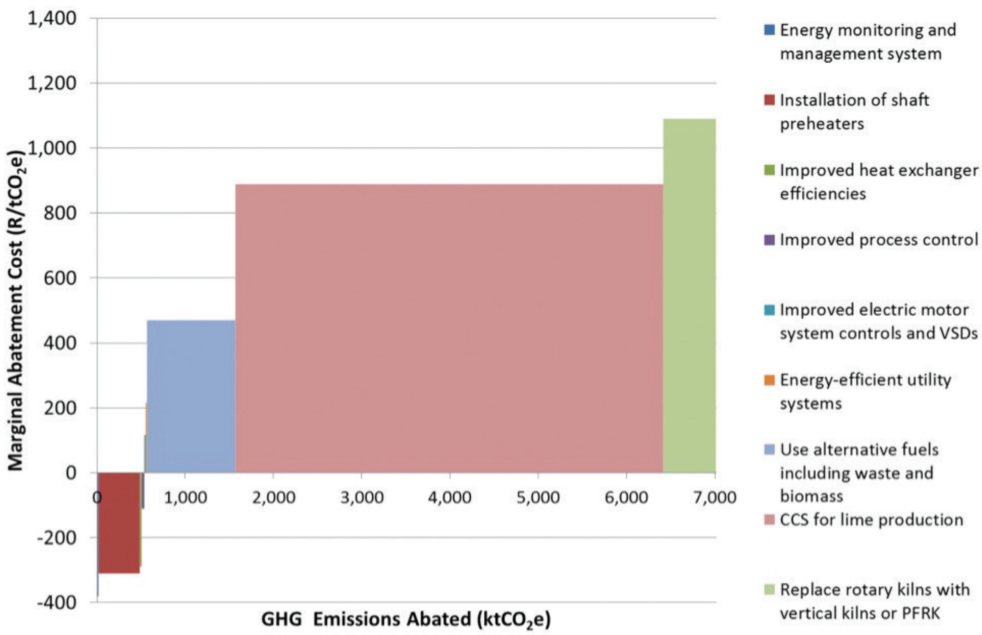


Figure 23: Lime production MACC for 2050

8. Mitigation Potential for the Chemicals Sector

The chemical sector as covered in this report includes the production of basic chemicals and other chemicals including ammonia, nitric acid, carbide, titanium dioxide, petrochemical and carbon black production. Disaggregated product data is only available for these chemicals, not for all chemicals produced in the basic and other chemicals subsectors. For the purposes of the study, energy efficiency measures have been assumed to apply equally to all production processes.

8.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the chemicals production MACC, together with references, are presented in Table 37. The assumed costs, technology availability and lifetime are listed in Table 38. The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 39.

Mitigation potential of product specific measures in the chemical sector was difficult to assess due to a lack of energy consumption and direct fuel/indirect electricity emissions data broken down by chemical product. In particular it was not possible to estimate the mitigation potential associated with the implementation of tail-gas energy recovery for combined heat and power plant within carbon black production. It should also be noted that ammonia production in South Africa is integrated with synthetic fuels and chemicals production and the majority of emissions and mitigation potential associated with ammonia production are captured in the other energy industries sector. Therefore, conventional measures used to assess mitigation potential for ammonia are not applicable to existing facilities but will be applicable to new facilities on the assumption that they adopt conventional technology.

The difficulties in projecting emissions for the chemicals sector mean that the current WEM projection is likely to underestimate total emissions and brings into question the integrity of the underlying data based on two difference sources (industry data reported to the Chemical and Allied Chemical Industries' Association (CAIA) and the DoE 2009 Energy Balance). Action should be taken to improve the quality, coverage and granularity of production, energy and emissions data where possible.

Sector growth is assumed to be 4.1% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

Table 37: Emissions reduction potential and energy saving potential of mitigation measures and references in the chemicals sector

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	%	%	
1	Replace coal-fired partial oxidation processes with natural gas-fired steam reforming production	42%	100%	33%	100%			(EC, 2007a, p37, 50) (ERC, 2007)
2	CCS for new ammonia production plants process emissions *	90%	100%					(ETSAP, 2010b, p19)
3	Revamp: increase capacity and energy efficiency (based on upgrade of an ammonia plant **)			15%	100%	10%	100%	(EC, 2007a, p64) (Prince, 2007) (IEA, 2009)
4	N_2O abatement for new production plants	90%	100%					(EC, 2007a p123, 127, 130) (EC, 2007a) (IPCC, 2007) (USEPA, 2010)
5	Tail-gas energy recovery for combined heat and power plant (CHP) and minimise flaring (only applicable to carbon black)			32%	100%			(EC, 2007a, p234)
6	Energy monitoring and management system			2.0%	100%	2.0%	100%	(EC, 2007a, p359) (EC, 2009a, p45, 83)
7	Advanced process control			5%	100%			(EC, 2007a p13) (EC, 2009a, p76)
8	Improved electric motor system controls and VSDs					10%	60%	(EC, 2009a p199, 214, 289)
9	Energy efficient boiler systems and kilns			20%	100%			(EC, 2009a, p116, 134) (EC, 2007b p24, 138)
10	Energy efficient utility systems					5%	40%	(EC, 2009a p206, 228, 235, 246)

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	%	%	
11	Increase process integration and improved heat systems			10%	100%			(EC, 2007a p70)
12	Waste heat and/or gas energy recovery and utilisation for cogeneration			20%	100%			(EC, 2009a p163)
13	Combined heat and power (CHP)			-49%	100%	15%	100%	(EC, 2006, p291) (EC, 2009a p176) (nPower, 2005)

* *The energy overhead associated with the implementation of CCS is included in the assumed marginal abatement cost (see Table 39)*

** *Although mitigation options for new plants are accepted as potentially feasible, in a carbon-constrained future it is assumed that they would be implemented as part of any new investment, and operation would not therefore result in further emissions.*

Table 38: Costs, availability and lifetime of the chemicals sector mitigation measures

	Abatement measure	Capital cost	Additional annual costs	Site production capacity	Abatement cost	Availability	Lifetime
		Million R/site	Million R/year	Million t/year	R/tCO_2e	Year	Years
1	Replace coal-fired partial oxidation processes with natural gas-fired steam reforming production	240	12.0	0.4		2010	25
2	CCS for new ammonia production plants process emissions				585	2030	25
3	Revamp: increase capacity and energy efficiency	120.0	6.0	0.4		2010	25
4	N2O abatement for new production plants	3.2	0.2	0.3		2010	25
5	Tail-gas energy recovery for combined heat and power plant (CHP) and minimise flaring	240	12.0	0.8		2010	25
6	Energy monitoring and management system	9.0	0.5	0.4		2010	15
7	Advanced process control	6.0	0.3	0.4		2010	15
8	Improved electric motor system controls and VSDs	36.0	1.8	0.4		2010	15
9	Energy-efficient boiler systems and kilns	36.0	1.8	0.4		2010	15
10	Energy-efficient utility systems	18.0	0.9	0.4		2010	15
11	Increase process integration and improved heat systems	9.0	0.5	0.4		2010	15
12	Waste heat and/or gas energy recovery and use for cogeneration	216	10.8	0.4		2010	25
13	Combined heat and power (CHP)	4,500	225.0	15.4		2010	25

Table 39 Mitigation technology sector uptake and other assumptions in the Chemicals sector

	Abatement measure	% Total sector uptake				Other assumptions
		2010	2020	2030	2050	
1	Replace coal-fired partial oxidation processes with natural gas-fired steam reforming production	50%	50%	50%	50%	Cost estimate assume €20 million to convert process and O&M assumed 5% of Capex. Assume 50% of production already switched process and feed/fuel.
2	CCS for new ammonia production plants process emissions	0%	0%	100%	100%	CO_2e already captured and used in ammonia production in South Africa recovering a considerable portion as a high purity stream and sold to end users, so uptake is limited to new plants. Capex estimate based on 40% of IEA costs for process CO_2 avoidance costs of US$30–35/t$CO_2$ (inc. Capex, Opex and other costs). Transport and storage costs assumed to be US$10/t$CO_2$ and US$20/t$CO_2$ respectively. Additional electrical energy costs for compression included in overall abatement cost. Storage assumed to begin in 2025.
3	Revamp: increase capacity and energy efficiency	50%	70%	90%	90%	Example of energy consumption reduction (before and after the revamp) from 36.0 to 31.1 GJ/tonne (fuel + feed). Total investment: €5.7 million. €10 million selected. Assume 50% of existing plant already revamped.
4	N_2O abatement for new production plants	90%	100%	100%	100%	Numbers based on N_2O destruction project based on estimate from SA plant. Up to 90% N_2O abatement already achieved in the sector on existing plant (e.g. CDM projects). Only applicable to new plant.
5	Tail-gas energy recovery for combined heat and power plant (CHP) and minimise flaring	0%	0%	0%	0%	Typical plant size 75 kt/year carbon black production. Total erection costs, including engineering, installing and additional equipment (stack, controls, foundations, etc.); tail-gas conveying system to combustion devices excluded. Gross investment cost €15–25 million. Assumed €20 million.
6	Energy monitoring and management system	20%	40%	60%	60%	Costs estimated.
7	Advanced process control	20%	40%	60%	60%	Costs estimated.
8	Improved electric motor system controls and VSDs	20%	40%	60%	60%	Assume 10% improvement is possible. Costs estimated.
9	Energy efficient boiler systems and kilns	20%	20%	20%	20%	Costs estimated.

	Abatement measure	% Total sector uptake				Other assumptions
		2010	2020	2030	2050	
10	Energy efficient utility systems	20%	40%	60%	60%	Assume 5% improvement is possible. Costs estimated.
11	Increase process integration and improved heat systems	20%	40%	60%	60%	Costs estimated.
12	Waste heat and/or gas energy recovery and utilisation for cogeneration	100%	100%	100%	100%	Already implemented/maximised in existing plant. Assumed to be included in new plant as standard.
13	Combined heat and power (CHP)	0%	25%	50%	50%	Assume 15% of total imported power can be replaced by installing 250MWe of CHP. Assumes fuel utilisation of 85% (45% heat/40% power) and capacity utilisation/ availability of 80%. Capex cost assumes US$/2000kW and Opex = 5% of Capex. Saving comes from fuel utilisation efficiency gain. Counter factual is imported grid power and steam generation boilers onsite combust fuel (without CHP) at fuel utilisation of 80%. Additional fuel required to meet existing heat demand and generate the additional power required is included in MAC curve.

8.2 Marginal Abatement Cost Curve

In 2020, the identified technical mitigation potential for the chemicals sector is 938 ktCO_2e/year compared to the WEM emissions projection or 6% of total emissions. There are a number of negative marginal abatement cost opportunities available to mitigate both process and fuel combustion emissions, as shown in Figure 24. The options with the lowest marginal abatement costs are energy efficiency measures to implement advanced energy monitoring and management systems, improve electric motor system controls and install variable speed drives (VSDs), increase process integration and revamping old facilities to improve overall production and energy efficiency, all with negative marginal abatement costs. Implementing onsite combined heat and power (CHP) generation systems also offers major scope for reductions at a positive abatement cost.

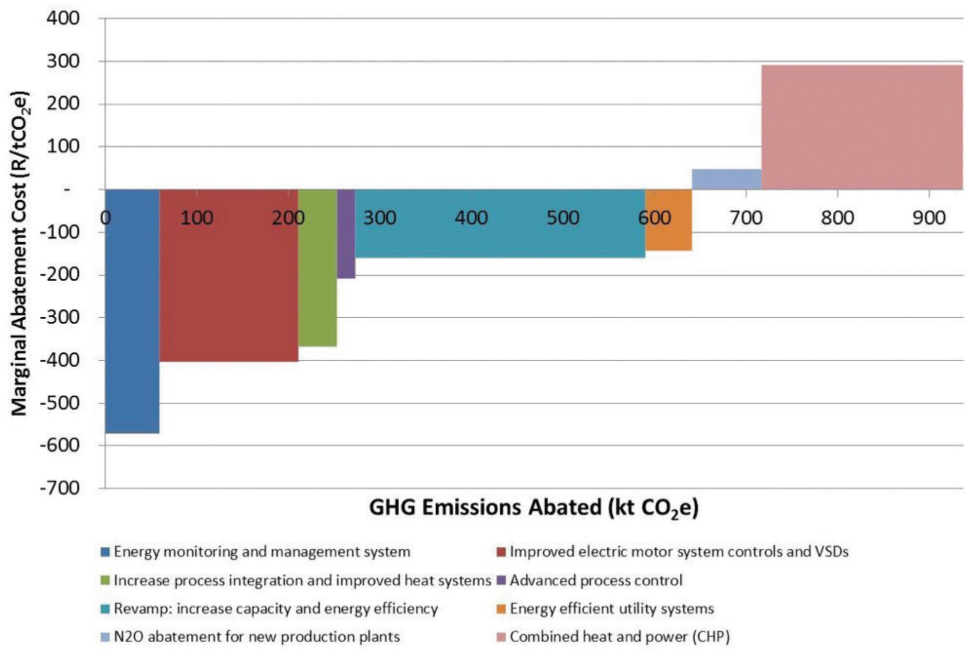


Figure 24: Chemicals production MACC for 2020

In 2030, the priority order of mitigation options in terms of marginal abatement cost remains similar to 2020, as shown in the 2030 MACC displayed in Figure 25. The identified technical mitigation potential increases to almost 2.6 million tCO_2e/year compared to the WEM emissions projection or 13% of total emissions due to wider uptake of technologies. Energy management systems and improved electric motor systems remain the options with the lowest marginal abatement costs while complete site revamps and CHP offer the biggest scope for mitigation. N_2O abatement is only applicable to new production facilities as most nitric acid production plants in South Africa have already implemented N_2O abatement projects partially financed under the UNFCCC's Clean Development Mechanism (CDM). CCS for ammonia becomes available and provides an option to reduce process emissions.

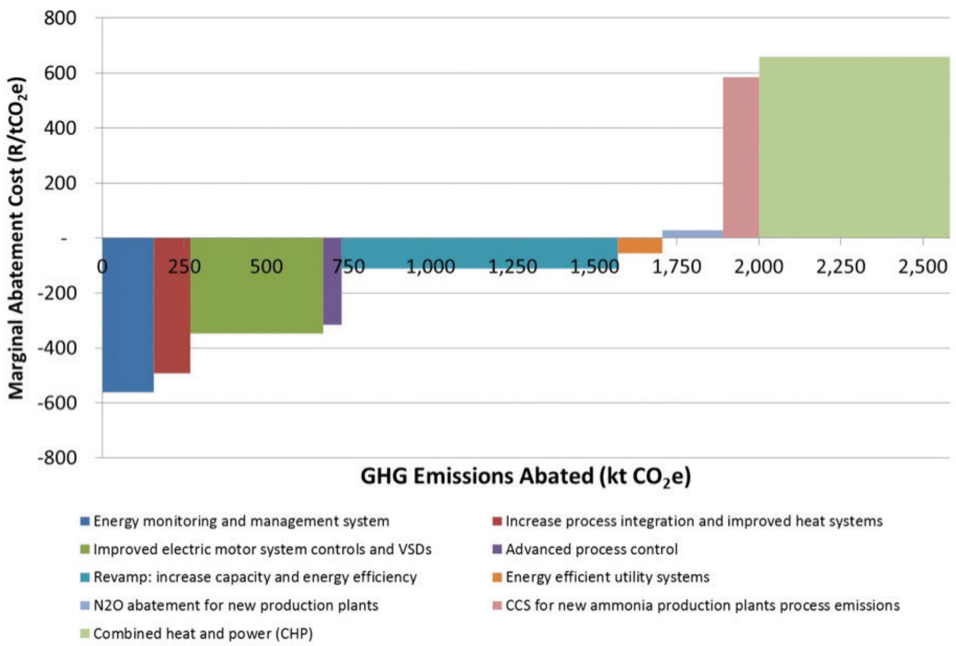


Figure 25: Chemicals production MACC for 2030

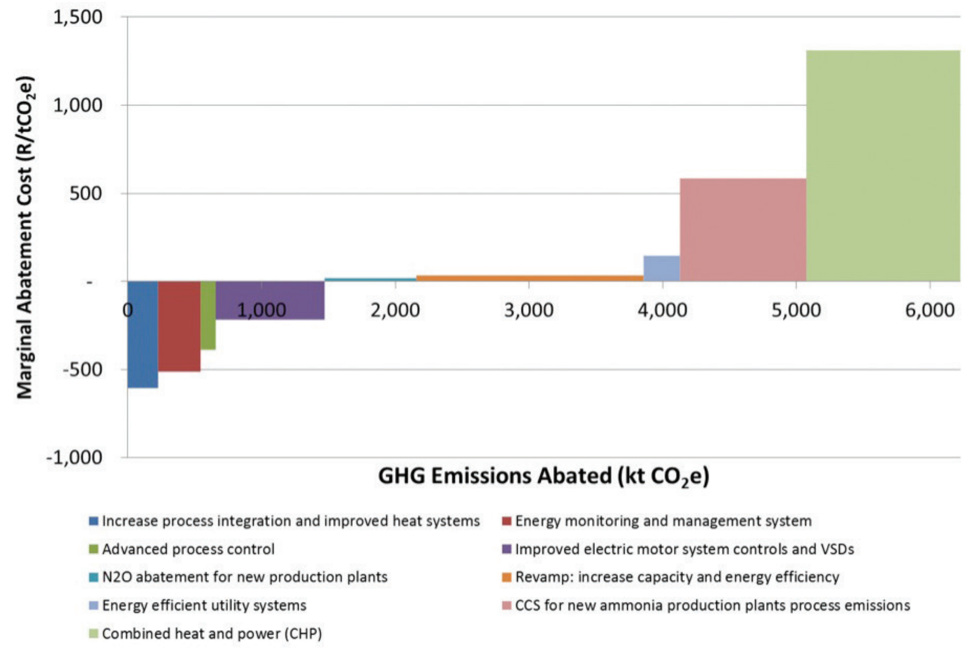


Figure 26: Chemicals production MACC for 2050

The mitigation potential in 2050 increases to over 6.2 million tCO_2e/year compared to the WEM emissions projection or 15% of total emissions. CCS is fully implemented across new production facilities and capable of reducing process emissions by 945 tCO_2e/year by 2050. Figure 26 shows that the mitigation cost at R585/tCO_2e is lower compared to the cost of CCS in other industries due to the high purity of the CO_2 in the process emissions resulting in lower capture and compression costs. The portfolio of energy efficiency measures available combined offer the largest mitigation opportunity at negative cost.

The total mitigation potential for the chemicals sector for 2010 to 2050 is estimated at 106 million tCO_2e compared to the WEM scenario or 11% of total emissions.

9. Mitigation Potential for the Mining Sector

The mining sector encompasses mined materials from surface and underground mines, including gold, platinum group metals (PGMs), diamonds, iron ore, chromite, manganese and other mined materials. This sector does not include coal mining. GHG emissions from coal mining and handling are included in the energy sector.

9.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the mining sector MACC (not including coal mining activity), together with references, are presented in Table 40. The assumed technology costs, availability and lifetime are listed in Table 41 The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 42.

For the implementation of biodiesel mitigation measures, the MACCs assume that a maximum of 50% of the mining fleet can be fuelled by biodiesel. This assumes that first generation biodiesel is available from 2010 and second generation biodiesel is available from 2020. In both cases, it is assumed that the infrastructure and planning is in place to ensure 50% of the fleet can be supplied.

Sector growth ranges from 3.8 to 4.3% per annum on average from 2010 to 2050 for various mined products, in line with the emissions projection assumptions and the underlying macroeconomic model.

Table 40: Emissions reduction potential and energy saving potential of mitigation measures and references in mining

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	%	%	
1	Use of 1st generation biodiesel (B5) for transport and handling equipment	5%	100%					(DRET, 2013)
2	Improve energy efficiency of mine haul and transport operations			15%	100%			(DRET, 2013)
3	Use of 2nd generation biodiesel (B50) for transport and handling equipment	50%	100%					
4	Use of 2nd generation biodiesel (B100) for transport and handling equipment	100%	100%					
5	Process, demand & energy management system					5.0%	100%	(DRET, 2010)
6	Energy efficient lighting					1%	100%	(DRET, 2010)
7	Install energy-efficient electric motor systems					20%	100%	(DRET, 2010)
8	Optimise existing electric motor systems (controls and VSDs)					10%	100%	(DRET, 2010)
9	Onsite clean power generation					10%	100%	(DRET, 2010)

Table 41: Costs, availability and lifetime of mining mitigation measures

	Abatement measure	Capex/unit electricity saved/year	Additional Opex/unit electricity saved/year	Capex/unit fuel energy saved/year	Additional Opex/unit fuel energy saved/year	Capex/unit CO_2e abated/year	Additional Opex/unit CO_2e abated/year	Availability	Lifetime
		R/TJ	R/TJ	R/TJ	R/TJ	R/ktCO_2	R/ktCO_2	Year	Years
1	Use of 1st generation biodiesel (B5) for transport and handling equipment					424,623	21,231	2010	15
2	Improve energy efficiency of mine haul and transport operations			283,925	141,963			2010	15
3	Use of 2nd generation biodiesel (B50) for transport and handling equipment					127,387	6,369	2020	15
4	Use of 2nd generation biodiesel (B100) for transport and handling equipment					84,925	4,246	2030	15
5	Process, demand & energy management system	43,554	2,178					2010	15
6	Energy-efficient lighting	217,771	4,355					2010	15
7	Install energy-efficient electric motor systems	536,800	26,840					2010	15
8	Optimise existing electric motor systems (controls and VSDs)	80,520	4,026					2010	15
9	Onsite clean power generation	3,856,048	192,802					2010	25

Table 42: Mining mitigation technology sector uptake and other assumptions

	Abatement measure	% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
1	Use of 1st generation biodiesel (B5) for transport and handling equipment	0%	25%	25%	0%	Abatement potential assumes 100% of fleet converted to 5% biodiesel (B5) and is applicable to 100% of fleet fuel emissions. Assumes biodiesel is 100% zero emissions and R50 million is the conversion costs. Based on mitigation data submitted by TWG-M member. Maximum implementation of biodiesel is 50% of fleet.
2	Improve energy efficiency of mine haul and transport operations	50%	50%	100%	100%	Technology and energy saving potential based on Australian benchmark data. No available benchmark Capex and Opex information, therefore this has been estimated. The costs difference between diesel and biofuels is included in the marginal abatement cost.
3	Use of 2nd generation biodiesel (B50) for transport and handling equipment	0%	0%	25%	25%	Abatement potential assumes 100% of fleet converted to 10% biodiesel (B10) and is applicable to 100% of fleet emissions. Assumes biodiesel is 100% zero emissions and 100million ZAR is the conversion costs. Maximum implementation of biodiesel is 50% of fleet.
4	Use of 2nd generation biodiesel (B100) for transport and handling equipment	0%	0%	0%	25%	Abatement potential assumes 100% of fleet converted to 10% biodiesel (B10) and is applicable to 100% of fleet emissions. Assumes biodiesel is 100% zero emissions and 100million ZAR is the conversion costs. Maximum implementation of biodiesel is 50% of fleet.
5	Process, demand & energy management system	50%	75%	100%	100%	Based on mitigation data submitted by TWG-M members. Assumes 50% already implemented. Additional 50% implement by 2030.
6	Energy efficient lighting	50%	75%	100%	100%	
7	Install energy-efficient electric motor systems	50%	75%	100%	100%	
8	Optimise existing electric motor systems (controls and VSDs)	50%	75%	100%	100%	
9	Onsite clean power generation	20%	60%	100%	100%	

9.2 Marginal Abatement Cost Curve

The technical mitigation potential for the mining sector (not including coal mining operations) in 2020 is estimated at 5,613 $ktCO_2e$/year compared to the reference WEM emissions projection (equivalent to 11% of total projected emissions). The mining MACC for 2020 is displayed in Figure 27. This shows that there are several energy efficiency measures available with negative abatement costs, including the implementation of process, demand and energy management system, installation of energy-efficient electric motor systems, optimisation of existing electric motor systems (controls and VSDs), installation of energy-efficient lighting and the improvement of mine haul and transport energy efficiency (via training, behaviour change and improved transport management and operation).

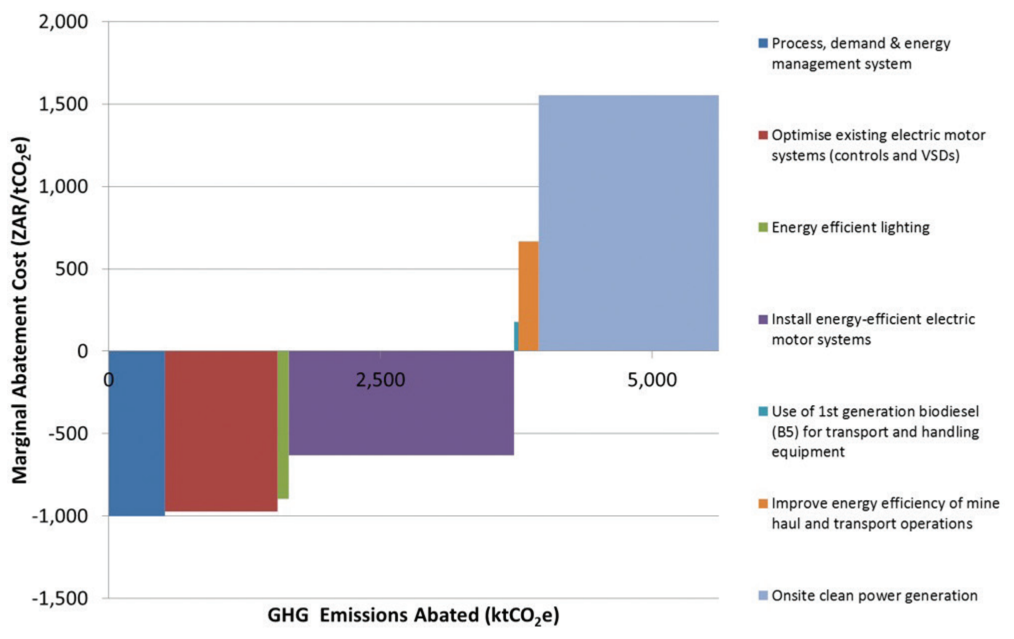


Figure 27: Mining MACC for 2020

In 2030, the mitigation potential increases to 16,807 $ktCO_2e$/year equivalent to 23% of the WEM reference emissions projection driven largely by cost effective energy-efficiency measures. The development of onsite clean power generation also contributes to GHG mitigation (for example solar PV) by replacing imported power and reducing indirect emissions. However, this measure has a high marginal abatement cost of over R1000/tCO_2e.

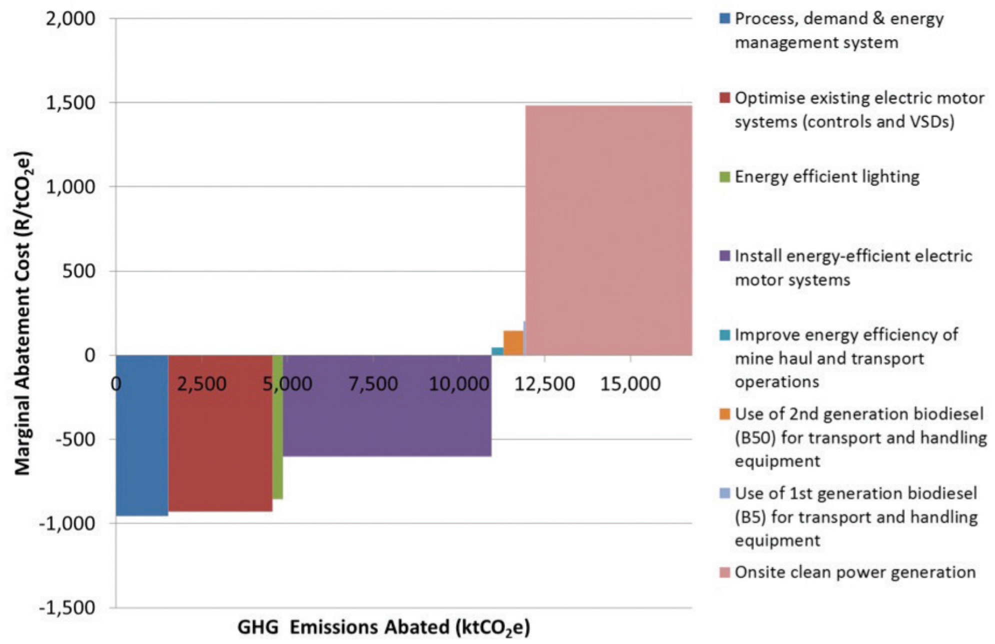


Figure 28: Mining MACC for 2030

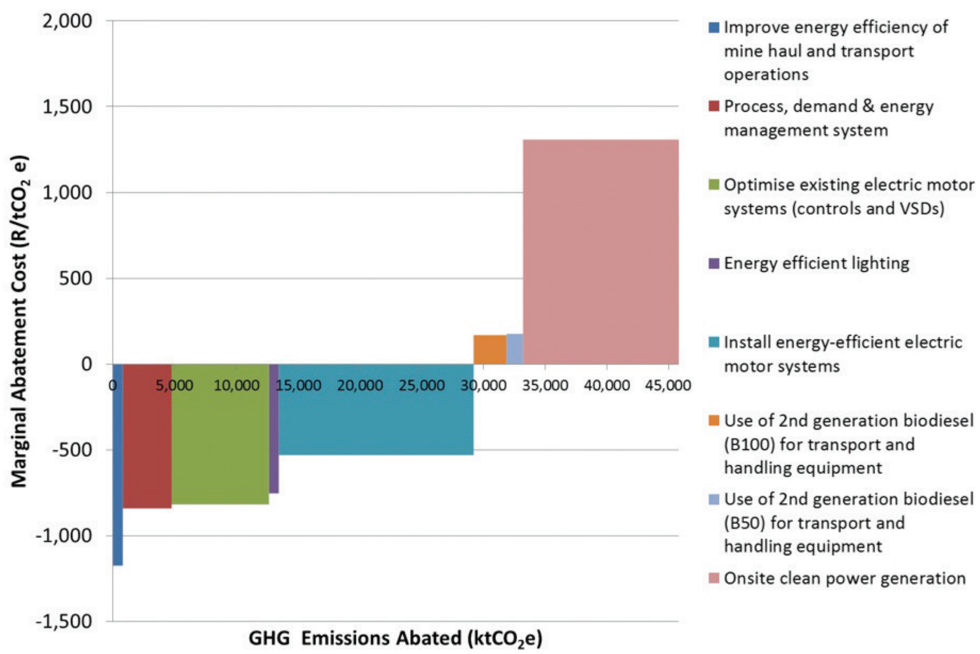


Figure 29: Mining MACC for 2050

The MACC for 2050, displayed in Figure 29, shows the overall abatement potential increases to 45,847 ktCO_2e/year; equivalent to 24% of the WEM reference emissions projection. The notably significant and cost effective mitigation options are the implementation of process, demand and energy management systems, installation of energy-efficient electric motor systems and optimisation of existing electric motor systems (controls and VSDs). These are all energy-efficiency measures which reduce electricity consumption and associated indirect emissions. The availability of biodiesel for reducing fleet emissions has a much smaller impact in comparison.

The total mitigation potential from 2010 to 2050 is estimated at 726 million tCO_2e compared to the WEM reference scenario or 21% of total GHG emissions.

10. Mitigation Potential for the Buildings Sector

The buildings sector includes commercial/institutional and residential buildings. GHG emissions mitigation measures have been identified and MACCs have been developed for both groups of buildings.

The summary MACCs combining all of the mitigation measures identified and quantified for commercial/institutional and residential buildings for 2020, 2030 and 2050 are displayed below in Figure 30, Figure 31 and Figure 32, respectively. Detailed abatement and marginal abatement costs for all measures are shown in Table 53. Identification numbers shown in the legends of the figures below may be used to look up details in Table 53.

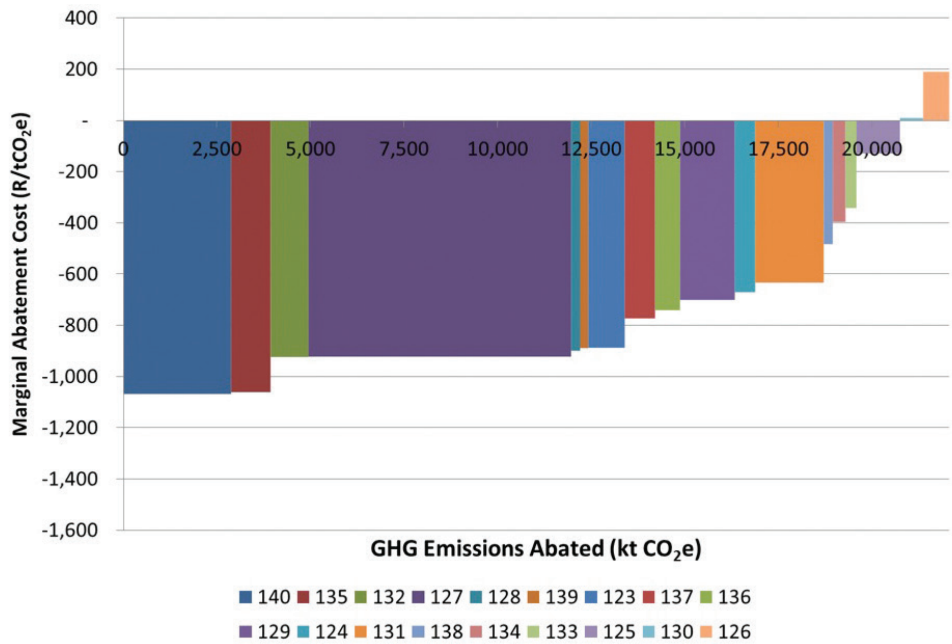


Figure 30: Buildings sector MACC for 2020

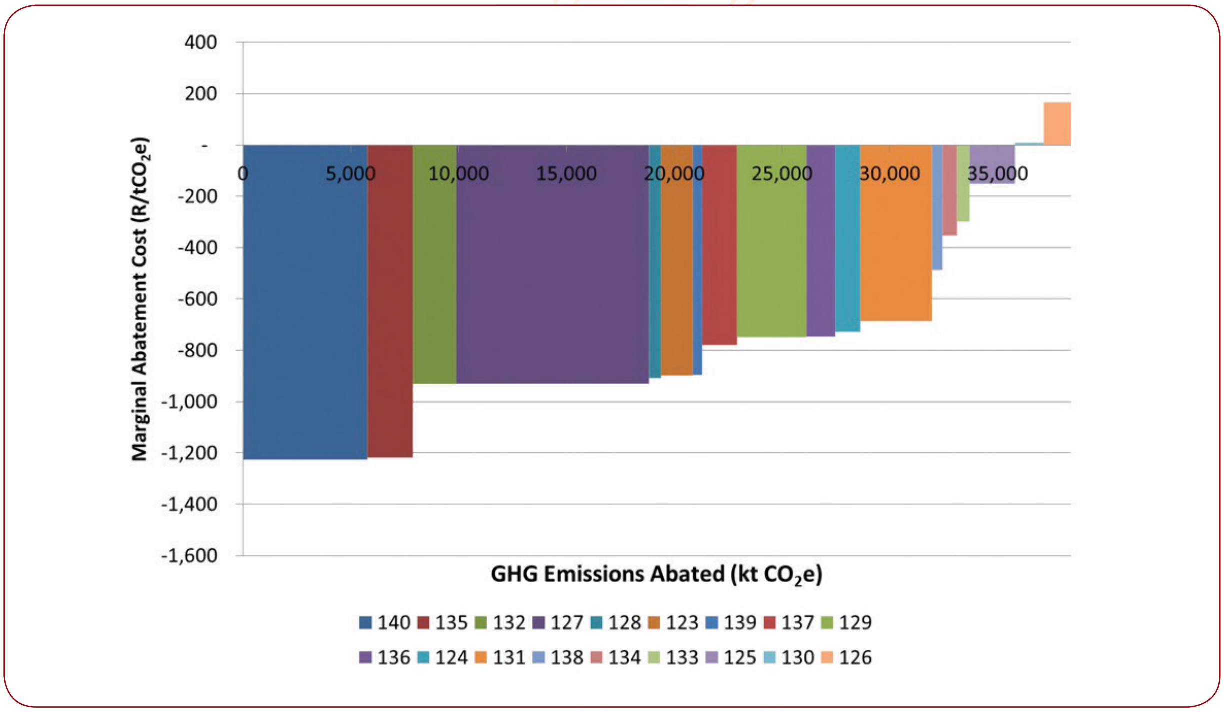


Figure 31: Buildings sector MACC for 2030

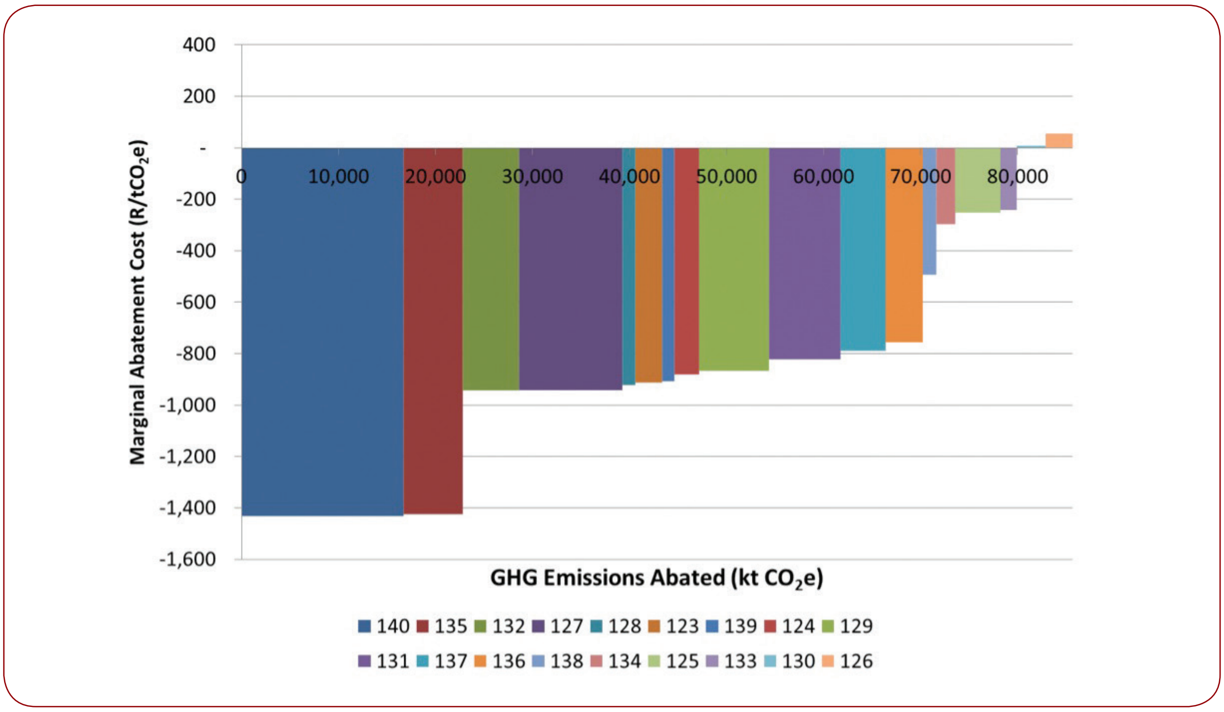


Figure 32: Buildings Sector MACC for 2050

10.1 Commercial/Institutional Buildings

10.1.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the commercial/institutional buildings MACC, together with references, are presented in Table 43. The assumed costs, technology availability and lifetime are listed in Table 44.

The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 45. In the case of mitigation of emissions from the residential, commercial and institutional buildings sectors, the starting point, penetration rate and uptake of each measure is based upon the technology share proposed by the South African TIMES model (SATIM) model 'upper bound' scenario.

10.1.2 Marginal Abatement Cost Curve

The identified mitigation potential for commercial and institutional buildings in South Africa is estimated at 7.5 million tCO_2e in 2020 compared to the reference WEM emissions projection (equivalent to 13% of total projected emission). Several negative marginal abatement cost mitigation options are available to reduce emissions from commercial and institutional buildings, as shown by the MACC in Figure 33. Installation of HVAC with heat recovery in new buildings offers the most cost effective abatement measure followed closely by efficient lighting, energy-efficient appliances and HVAC equipment with variable speed drives. Construction of passive buildings with improved thermal design offers the largest single mitigation potential with the lowest marginal abatement cost.

In 2030, the priority order of measures remains the same compared to 2020 as all the measures are implemented at the same rate, as shown by Figure 34. The overall mitigation potential increases to over 15 $MtCO_2e$/year, or 22% of the reference emissions projection.

Again, the order of marginal abatement costs in 2050 is the same as in 2030, as shown in Figure 35. Fuelled by both the growth in buildings and reference emissions, and by the increases in uptake of mitigation technologies, the overall mitigation potential increases to over 43 million tCO_2e/year or 45% of the reference emissions projection.

The total mitigation potential for residential buildings from 2010 to 2050 is estimated at 432 million tCO_2e compared to the WEM reference scenario or 15% of total emissions.

Table 43: Emissions reduction potential and energy saving potential of mitigation measures and references for the commercial/institutional buildings MACC

	Abatement measure	Energy saving potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	
1	Efficient lighting			46%	40%	(CIDB, 2009) (Bettgenhäuser et al., 2009) (Stats SA, 2010a) (Stats SA, 2010b) (Molemoeng, 2012) (ERC, 2013).
2	Heat pumps – existing buildings			18%	30%	
3	Heat pumps – new buildings			18%	35%	
4	HVAC: with heat recovery – new buildings	30%	54%	30%	35%	
5	HVAC: variable speed drives – existing buildings			35%	35%	
6	HVAC: variable speed drives – new buildings			43%	35%	
7	HVAC: central air conditioners – new buildings			13%	35%	
8	Energy-efficient appliances			56%	7%	
9	Passive building/improved thermal design – new buildings	71%	54%	71%	38%	

Table 44: Costs, availability and lifetime of the commercial/institutional buildings mitigation measures

	Abatement measure	Capital cost	Additional annual costs	Capital cost	Additional annual costs	Availability	Lifetime
		R/building	R/building	ZAR/m²	ZAR/m²	Year	Years
1	Efficient lighting	-288		-0.12		2010	5
2	Heat pumps – existing buildings			37	0.9	2010	15
3	Heat pumps – new buildings			37	0.9	2010	15
4	HVAC: with heat recovery –– new buildings	100,000	2,500	40.13	1.0	2010	15
5	HVAC: Variable speed drives – existing buildings	100,000	2,500	40.13	1.0	2010	15
6	HVAC: Variable speed drives – new buildings	100,000	2,500	40	1.0	2010	15
7	HVAC: Central air conditioners – new buildings			35	0.9	2010	15
8	Energy efficient appliances	7,160		2.87		2010	15
9	Passive building/improved thermal design - new buildings	12,458,635	311,466	5,000	125	2010	30

Table 45: Mitigation technology sector uptake and other assumptions in the commercial/institutional buildings MACC

	Abatement measure	% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
1	Efficient lighting	5%	15.0%	25%	50%	Uptake, energy saving, costs and applicability based on SATIM energy model. (ERC, 2013).
2	Heat pumps – existing buildings	5%	15.0%	25%	50%	Uptake, energy saving, costs and applicability based on SATIM energy model. (ERC, 2013).
3	Heat pumps – new buildings	5%	15.0%	25%	50%	Uptake, energy saving, costs and applicability based on SATIM energy model. (ERC, 2013).
4	HVAC: with heat recovery – new buildings	5%	15.0%	25%	50%	Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark, unless otherwise stated. Applicability based on SA Statistics. (Stats SA, 2010a).
5	HVAC: variable speed drives – existing buildings	5%	15.0%	25%	50%	The energy saving is a result of the reduced ventilation losses. Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark, unless otherwise stated. Applicability based on SA Statistics. (Stats SA, 2010a).
6	HVAC: variable speed drives – new buildings	5%	15.0%	25%	50%	Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark, unless otherwise stated (Bettgenhäuser et al., 2009). Applicability based on SATIM (ERC, 2013).
7	HVAC: central air conditioners – new buildings	5%	15.0%	25%	50%	Uptake, energy saving, costs and applicability based on SATIM energy model.
8	Energy efficient appliances	5%	15.0%	25%	50%	Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark, unless otherwise stated (Bettgenhäuser et al., 2009). Applicability based on SA Statistics (Stats SA, 2010a) and SATIM.(ERC, 2013).
9	Passive building/improved thermal design – new buildings	5%	15.0%	25%	50%	Energy saved for spatial heating/cooling. Fuel saving based on 54% of fuel use for spatial heating. Energy saving potential (based on spatial heating demand for passive building of 5 $kWh/m^2/yr$ compared to 28 $kWh/m^2/yr$ for reference service building in southern Europe) and energy saving benchmark. Electricity based on 35% of electricity use for spatial heating and cooling Applicability based on SA Statistics and SATIM energy model.

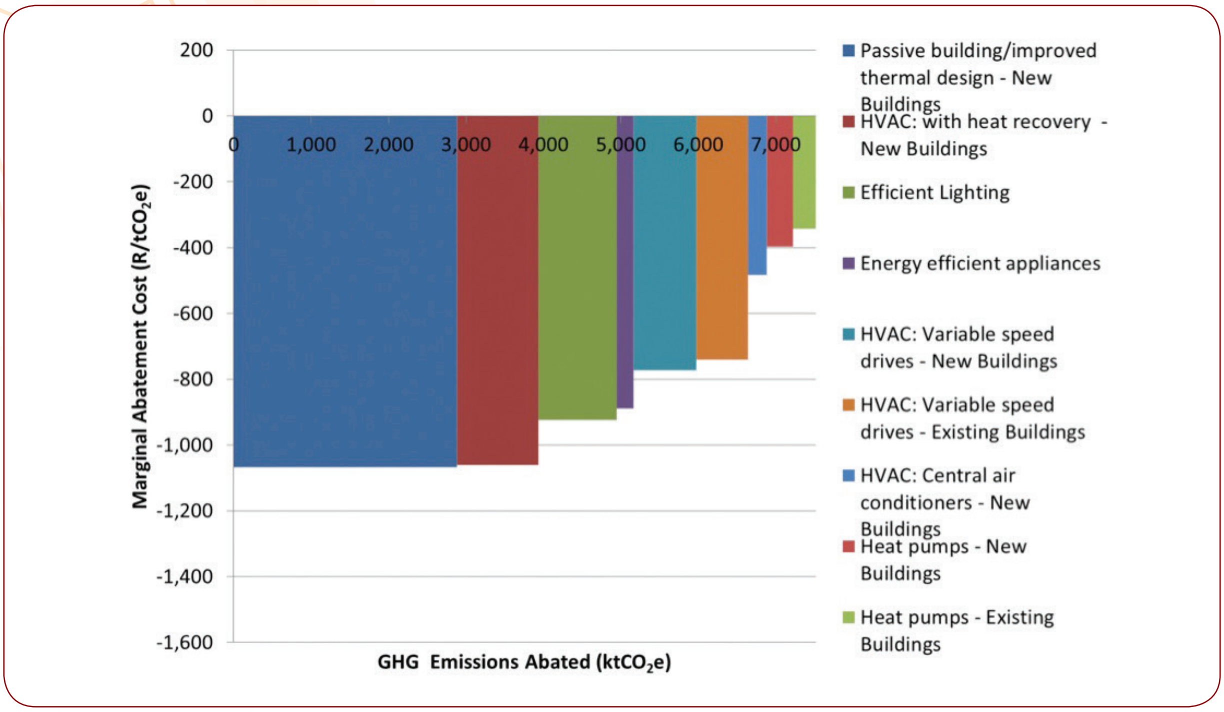


Figure 33: Commercial/institutional buildings MACC for 2020

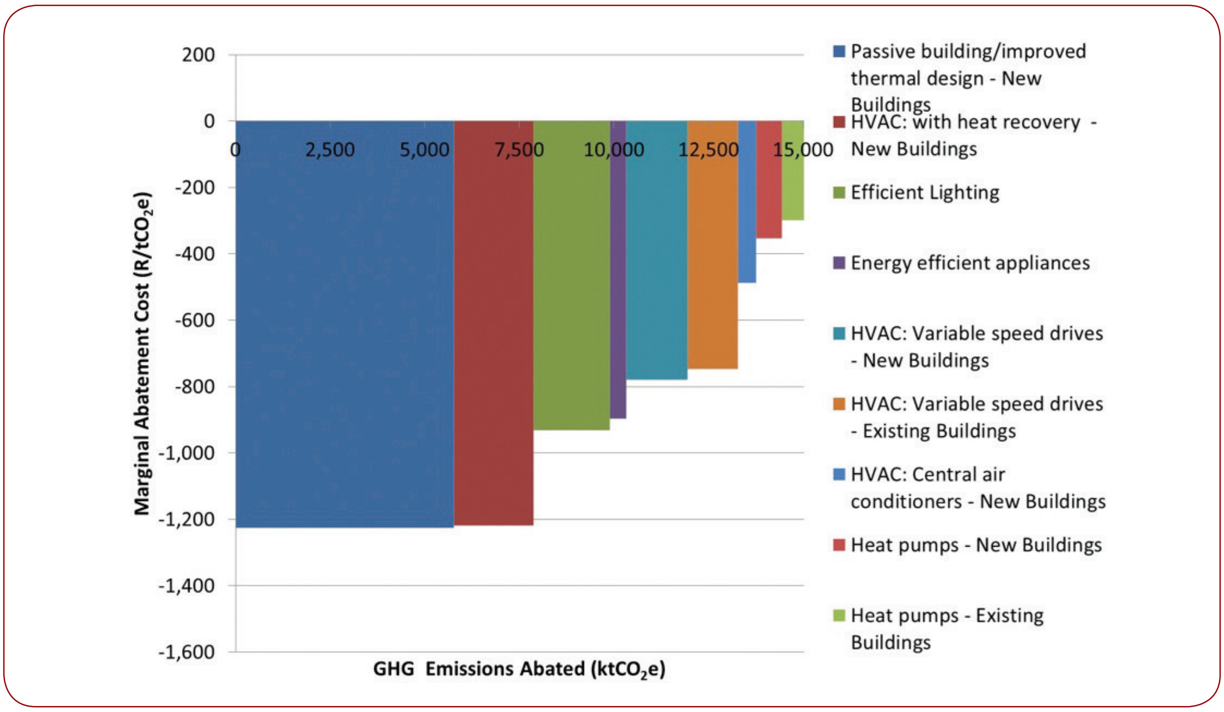


Figure 34: Commercial/institutional buildings MACC for 2030

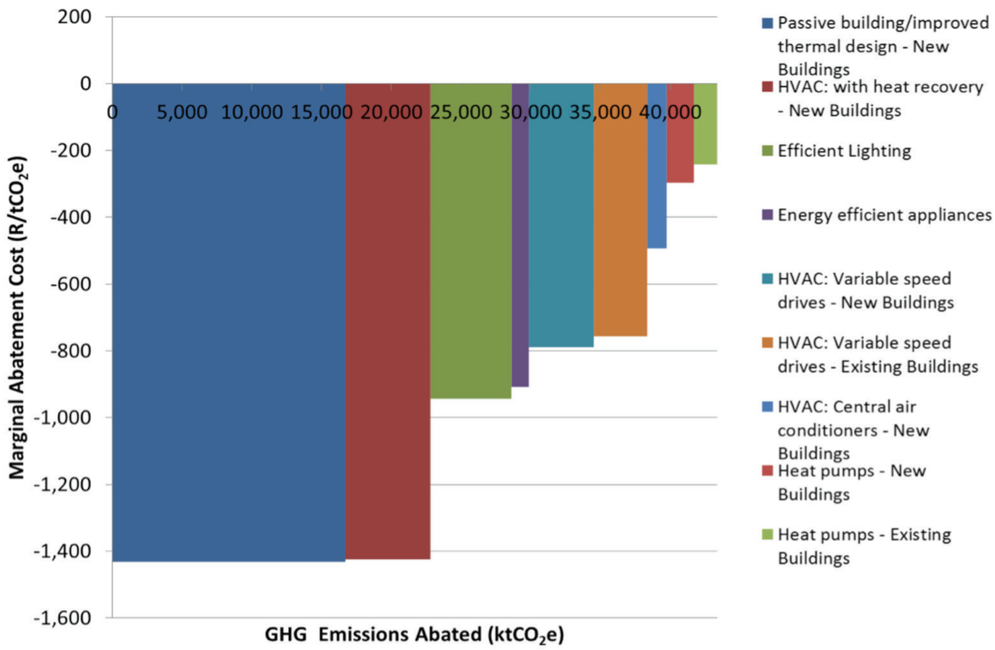


Figure 35: Commercial/institutional buildings MACC for 2050

10.2 Residential Buildings

10.2.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the residential buildings MACC, together with references, are presented in Table 46. The assumed costs, technology availability and lifetime are listed in Table 47.

The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 48. In the case of mitigation of emissions from the residential, commercial and institutional buildings sectors, the starting point, penetration rate and uptake of each measure, is based upon the technology share proposed by the South African TIMES model (SATIM) model 'upper bound' scenario.

Table 46: Emissions reduction potential and energy saving potential of mitigation measures and references for the residential buildings MACC

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	%	%	
1	Energy efficient appliances					40%	15%	(CIDB, 2009) (Bettgenhäuser et al., 2009) (Stats SA, 2010a) (Stats SA, 2010b) (Molemoeng, 2012) (ERC, 2013).
2	Geyser blankets			14%	72%	14%	28%	
3	Improved insulation – new buildings			50%	31%	50%	16%	
4	Improved insulation – existing buildings			30%	31%	30%	16%	
5	Efficient lighting – FLs					80%	20%	
6	Efficient lighting – LEDs					20%	20%	
7	Solar water heating			50%	41%	50%	28%	
8	LPG for cooking	24%	27%					
9	Passive building/improved thermal design – new buildings			74%	31%		16%	

Table 47: Costs, availability and lifetime of the residential buildings mitigation measures

	Abatement measure	Capital cost	Additional annual costs	Capital cost	Additional annual costs	Availability	Lifetime
		R/building	ZAR/building	ZAR/m^2	ZAR/m^2	Year	Years
1	Energy efficient appliances	4,961		39		2010	15
2	Geyser blankets	300		2		2010	10
3	Improved insulation – new buildings	221,402		1,750		2010	50
4	Improved insulation – existing buildings	221,402		1,750		2010	50
5	Efficient lighting – FLs	39		0.3		2010	5
6	Efficient lighting – LEDs	1,825		14		2020	10
7	Solar water heating	16,800	420	132.79	3.32	2010	10
8	LPG for cooking	2,000		16		2010	10
9	Passive building/improved thermal design – new buildings	632,577	15,814	5,000	125	2010	30

Table 48 Mitigation technology sector uptake and other assumptions in the residential buildings MACC

	Abatement measure	% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
1	Energy efficient appliances	23%	33.0%	43%	68%	Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark. Applicability based on residential electricity usage (%) for residential sector (CIDB, 2009).
2	Geyser blankets	5%	12.5%	25%	50%	Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark Applicability based on residential electricity usage (%) for residential sector (CIDB, 2009).
3	Improved Insulation – new buildings	5%	15.0%	25%	50%	Including floor, wall, roof and window surfaces. The energy saving is a result of the reduced losses. Average floor area for new and existing houses assumed to be 127 m^2 (Stats SA, 2010a) and average surface area (e.g. walls, windows, walls and roof) 380 m^2 (based on 3 x floor area). Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark (Bettgenhäuser et al., 2009). Applicability based on residential fuel energy use balance for urban high-medium income; electrified (CIDB, 2009).
4	Improved insulation – existing buildings	5%	15.0%	25%	50%	Including floor, wall, roof and window surfaces. The energy saving is a result of the reduced losses. Average floor area for new and existing houses assumed to be 127 m^2 (Stats SA, 2010a) and average surface area (e.g. walls, windows, walls and roof) 380 m^2 (based on 3 x floor area). Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark (Bettgenhäuser et al., 2009). Applicability based on residential fuel energy use balance for urban high-medium income; electrified (CIDB, 2009).
5	Efficient lighting – FLs	87%	91.0%	100%	100%	Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark. Applicability based on residential electricity usage (%) for residential sector (CIDB, 2009). Kilolumens hours per building for new and existing household – 14.6 klm/building (assuming 10 x 60W bulbs at 730 lumen/bulb).

Abatement measure		% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
6	Efficient lighting – LEDs	5%	12.5%	25%	50%	Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark. Applicability based on residential electricity usage (%) for residential sector (CIDB, 2009). Kilolumens hours per building for new and existing household – 14.6 klm/building (assuming 10 x 60W bulbs at 730 lumen/bulb).
7	Solar water heating	5%	12.5%	25%	50%	Energy saving and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark. Applicability based on residential fuel energy use balance for Urban High-Medium Income; Electrified (CIDB, 2009).
8	LPG for cooking	6%	13.5%	26%	51%	Emissions saving assume replaces fossil fuel use (mostly paraffin). No cost data per household. Cost of conversion not available. Applicability based upon fossil fuel use for cooking taken from the main source of energy used for cooking by year, 2002–2010 (Stats SA, 2010b).
9	Passive building/improved thermal design – new buildings	5%	15.0%	25%	50%	Energy saved for spatial heating/cooling. Fuel saving based on 31% of fuel use for spatial heating. Energy saving (based on spatial heating demand for passive house 10 kWh/m2/yr compared to 38 kWh/m2/yr for reference house in southern Europe) and cost based on EU benchmarks for buildings in Southern Europe and energy saving benchmark. Electricity based on 16% of electricity use for spatial heating and cooling. Applicability based on SA statistics.

10.2.2 Marginal Abatement Cost Curve

The identified mitigation potential in the residential building sector is 14.5 $MtCO_2e$/year in 2020 compared to the reference WEM emissions projection (equivalent to 20% of total projected emission). Figure 36 shows there are a number of mitigation options available to reduce emissions from residential buildings in South Africa. The lowest marginal abatement cost option is the installation of high-efficiency lighting and energy-efficient appliances in new and old buildings. The implementation of solar water heating, geyser blankets and improved insulation in new buildings also offer large potential savings at negative marginal abatement costs. Constructing passive buildings with improved thermal design has the largest abatement potential and the lowest marginal cost over a lifetime of 30 years.

The priority order of measures remains the same in 2030, as shown by Figure 37. The overall mitigation potential increases to over 23 million tCO_2e/year compared to the reference WEM emissions projection (equivalent to 29% of total projected emission.

Figure 38 shows that again, the order of marginal abatement costs in 2050 remain the same. With the continued uptake of mitigation technologies, the overall mitigation potential increases to over 42 million tCO_2e/year or 46% of the reference emissions projection.

The total mitigation potential for residential buildings from 2010 to 2050 is estimated at 703 million tCO_2e compared to the WEM reference scenario or 22% of total emissions.

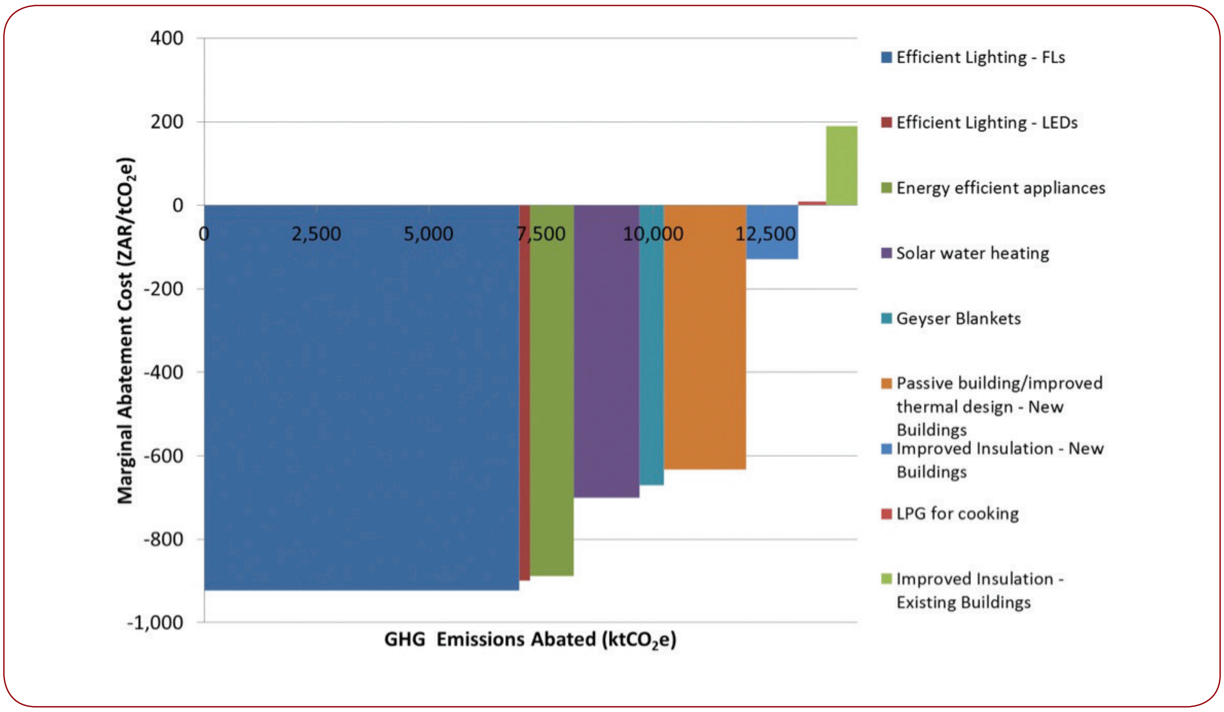


Figure 36: Residential buildings MACC for 2020

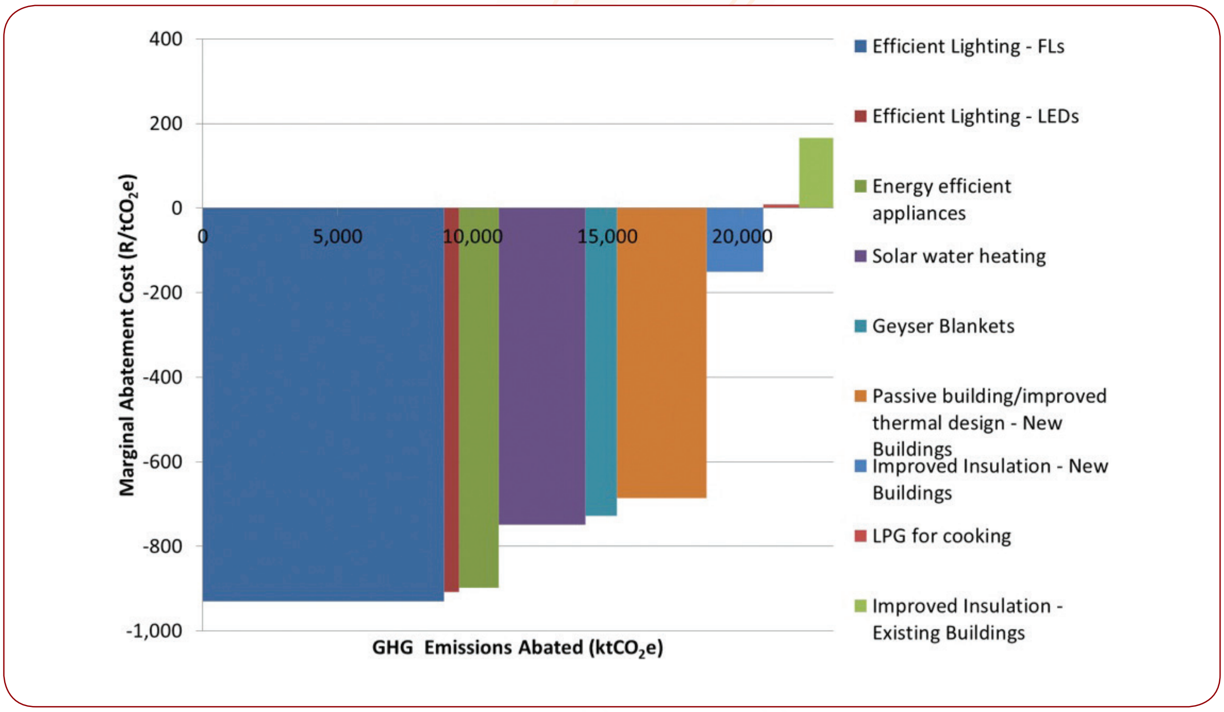


Figure 37: Residential buildings MACC for 2030

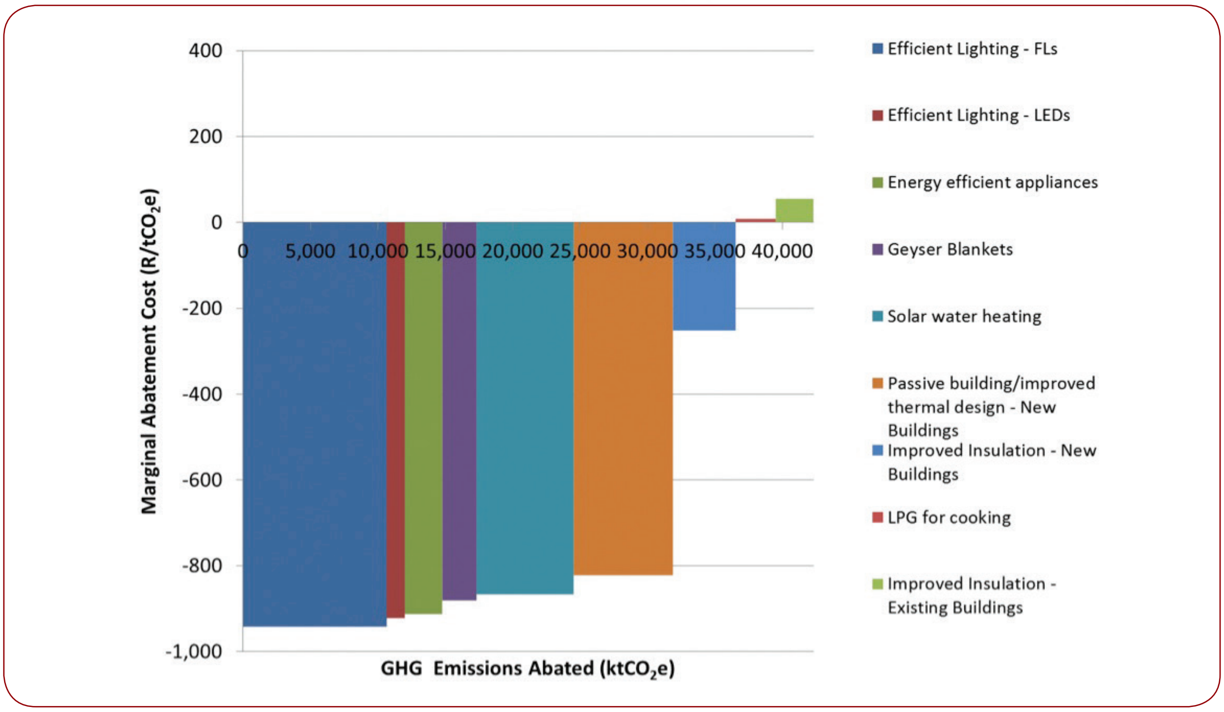


Figure 38: Residential buildings MACC for 2050

11. Mitigation Potential from Other Sectors

The other sectors include the pulp and paper production industry. MACCs have been development for pulp and paper production in 2020, 2030 and 2050.

11.1 Pulp and Paper

11.1.1 Key Assumptions

The assumed emissions reduction and energy saving potential for each mitigation measure included in the pulp and paper production MACC together with references are presented in Table 49. The assumed costs, technology availability and lifetime are listed in Table 50. The assumed technology uptake in 2010, 2020, 2030 and 2050 and other key assumptions are shown in Table 51.

For the objective of reducing emissions, the analysis assumes that a 45% switch from fossil fuels to zero-carbon residual wood waste and biomass fuels is technically possible by 2030 (that is by 2030, 55% of fuel is from fossil sources and 45% is waste/biomass). The MACCs also assume that 300 MW of CHP is installed by 2030 (with 85% fuel utilisation/ efficiency).

Sector growth is assumed to be 3.8% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

11.1.2 Marginal Abatement Cost Curve

The technical mitigation potential for the South African pulp and paper sector in 2020 is 2,423 ktCO_2e/year or 32% compared to the reference WEM emission projection. There are several mitigation options available, as shown in the 2020 MACC in Figure 39. The implementation of advanced energy management system and energy efficient electric motors, improved controls and variable speed drives have negative abatement costs. However, their overall abatement potential is small. The most significant abatement measures available to the pulp and paper industry is the conversion of fuel from coal to biomass/residual wood waste in conjunction with the implementation of combined heat and power (CHP) systems to replace imported grid power. Both options have positive abatement costs with CHP the most expensive at over 1,400 ZAR/tCO_2e.

In 2030, the continued switching from coal to biomass and residual wood waste fuels and uptake of CHP increases mitigation potential 5,618 ktCO_2e/year or 54% compared to the reference WEM emission projection, as shown in Figure 40.

The mitigation potential increases in absolute terms to over 12 million tCO_2e/year (influenced by the sector growth and increasing reference emissions), as shown by the 2050 MACC in Figure 41. However, in percentage terms, the mitigation drops slightly to 54% compared to the reference WEM emission projection. The fuel switch option from coal to biomass remains the largest mitigation opportunity.

The total mitigation potential for pulp and paper production for 2010 to 2050 is estimated at 222 million tCO_2e or 47% compared to the reference WEM emissions projection.

Table 49: Emissions reduction potential and energy saving potential of mitigation measures and references in the Pulp and Paper Production MACC

	Abatement measure	Process emissions abatement potential	Applicability	Energy saving potential	Applicability	Energy saving potential	Applicability	Reference
		%	%	%	%	%	%	
1	Convert fuel from coal to biomass/residual wood waste	100%	100%					(EC, 2010)
2	Application of Co-generation of Heat and Power (CHP)			-24%	100%	74%	100%	(EC, 2010)
3	Energy recovery system			10%	100%			(EC, 2010)
4	Energy monitoring and management system			1%	100%	1%	100%	
6	Energy efficient electric motors, improved controls and variable speed drives					10%	70%	(EC, 2010)
6	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)					10%	30%	(EC, 2009)
7	Improved process control			5%	100%			
8	Energy efficient boiler systems and kilns and Improved heat systems			10%	100%			

Table 50: Costs, availability and lifetime of pulp and paper production mitigation measures

	Abatement measure	Capital cost	Additional annual costs	Site production capacity	Availability	Lifetime
		Million R/site	Million R/yr	Million t/yr	Year	Years
1	Convert fuel from coal to biomass/residual wood waste	180	4.8	0.60	2010	25
2	Application of Co-generation of Heat and Power (CHP)	1,080.0	54.0	0.60	2010	25
3	Energy recovery system	96.0	7.2	0.60	2010	25
4	Energy monitoring and management system	12.0	0.6	0.60	2010	15
6	Energy efficient electric motors, improved controls and variable speed drives	60.0	3.0	0.60	2010	15
6	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)	30.0	3.0	0.60	2010	15
7	Improved process control	48.0	6.0	0.60	2010	15
8	Energy efficient boiler systems and kilns and Improved heat systems	120.0	3.0	0.60	2010	15

Table 51 Mitigation technology sector uptake and other assumptions in the Pulp and Paper Production MACC

Abatement measure		% Sector uptake				Other Assumptions
		2010	2020	2030	2050	
1	Convert fuel from coal to biomass/residual wood waste	20%	25%	45%	45%	Assumes fossil fuel replaced by zero emissions fuel (e.g. biomass). Sector Capex cost assumes R6 million per site for investment costs for equipment required for using a particular fuel, e.g. storage handling, drying, milling, injection and safety. Grate-fired boiler retrofit to a fluidised-bed boiler would cost approximately €10–15 million, and operating costs would be €0.3–0.4 million /a. Sector costs assume 8 integrated mills in SA.
2	Application of co-generation of heat and power (CHP)	20%	50%	100%	100%	Assume 300 MW installed CHP output with 85% fuel use efficiency (40% power, 45% heat) supplying 4,335 TJ and reduction in imported power, at 95% availability. Assuming sector-level maximum potential of 300MW installed capacity at cost of US$3200 per KW power output combined capacity co-generation power plant. Abatement reduction 100% applicable to emissions from onsite generation from conventional coal power plants.
3	Energy recovery system	20%	100%	100%	100%	Investment costs for a new sludge and reject incinerator are about €5–7m and operating costs €0.5–0.6m /a corresponding to pulp production of 700 anaerobic digestion t/d. Power plant and boiler conversion costs included in No 1 above. Sector costs assume 8 integrated mills in SA.
4	Energy monitoring and management system	20%	50%	100%	100%	Energy saving potential and costs estimated and cross-checked with TWG members.
6	Energy efficient electric motors, improved controls and variable speed drives	20%	50%	100%	100%	
6	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)	20%	50%	100%	100%	
7	Improved process control	20%	50%	100%	100%	
8	Energy efficient boiler systems and kilns and Improved heat systems	0%	50%	100%	100%	

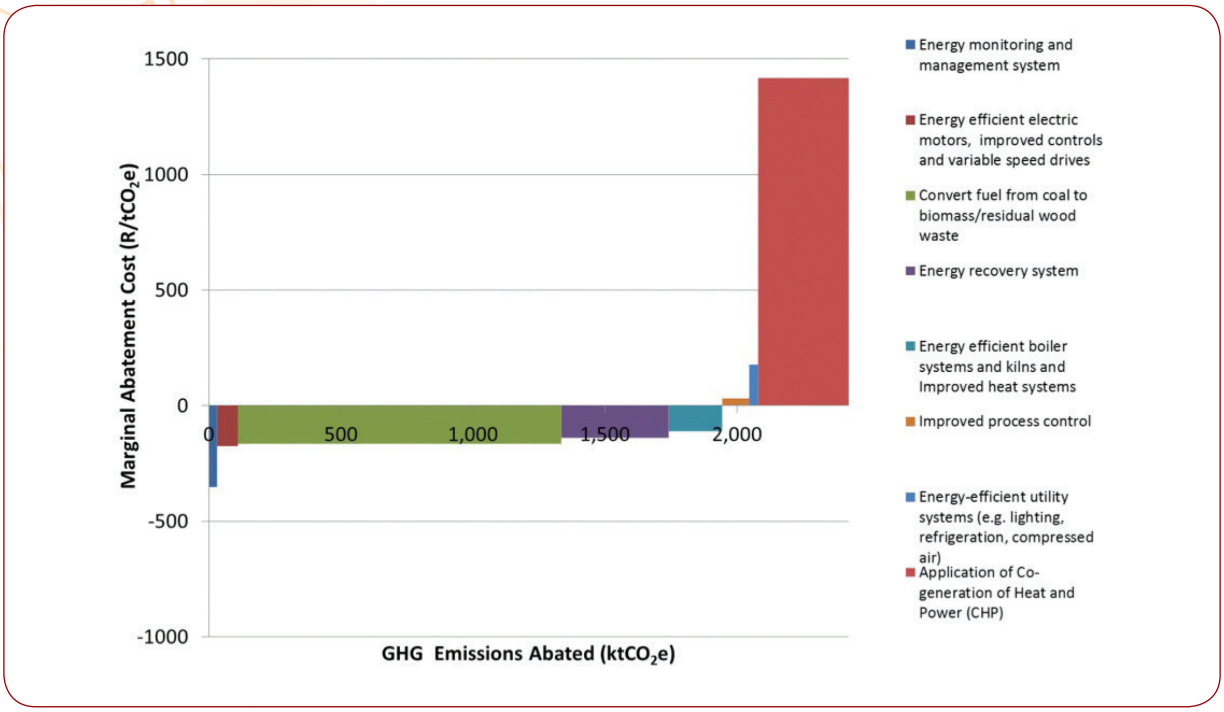


Figure 39: Pulp and paper production MACC for 2020

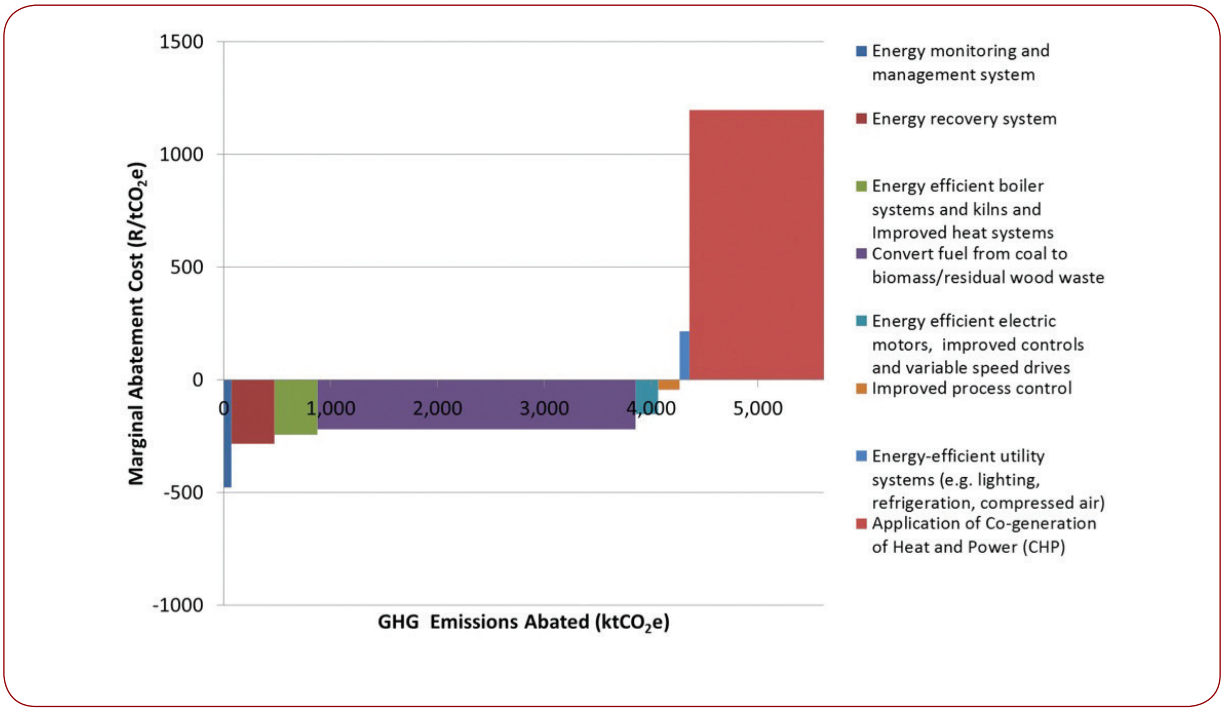


Figure 40: Pulp and paper production MACC for 2030

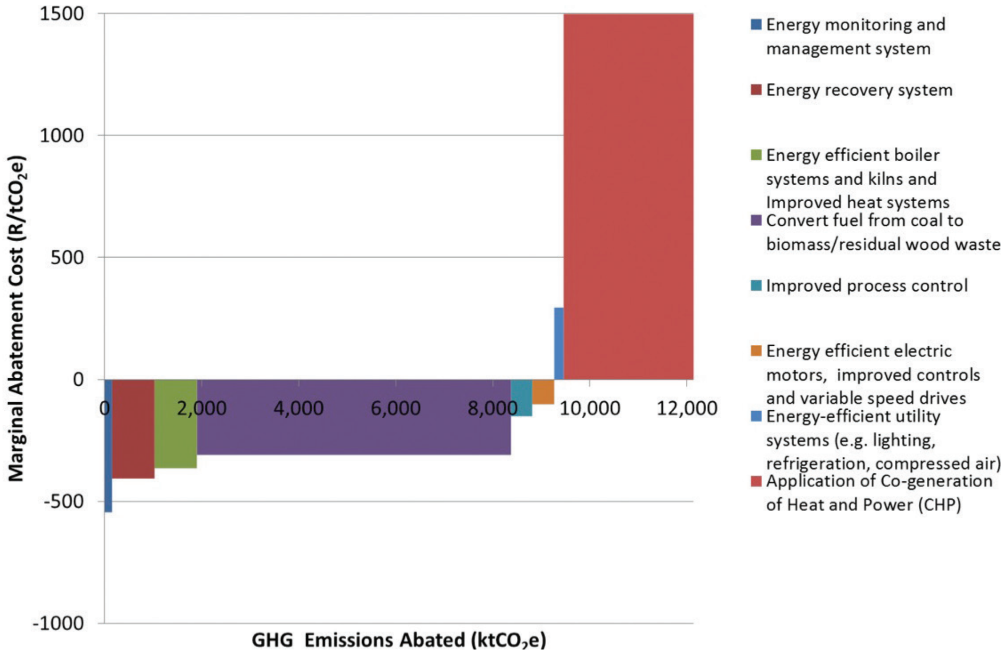


Figure 41: Pulp and paper production MACC for 2050

Chapter IV: Summary

11.2 Marginal Abatement Cost Curves

Marginal abatement cost curves for the industry sector are summarised in Figure 42, Figure 43 and Figure 44 for 2020, 2030 and 2050, respectively. Detailed abatement and marginal abatement costs for all measures are shown in Table 53. Identification numbers shown in the legends of the figures below may be used to look up details in Table 53.

In 2020, a total of 44,842 ktCO_2e of abatement potential has been identified in the industry sector (Figure 42). The MACC curve illustrates that slightly more than 73% of the available mitigation potential (32.913 ktCO_2e) can be achieved through measures which have negative marginal abatement costs (that is their marginal abatement cost, in R/tCO_2e is negative).

In 2030, a total of 103,850 ktCO_2e of abatement potential has been identified in the industry sector (Figure 43). The MACC curve illustrates that slightly more than 65% of the available mitigation potential (68,017 ktCO_2e) can be achieved through measures which have negative marginal abatement costs.

In 2050, a total of 258,453 ktCO_2e of abatement potential has been identified in the industry sector (Figure 44). The MACC curve illustrates that slightly more than 67% of the available mitigation potential (174,663 MtCO_2e) can be achieved through measures which have negative marginal abatement costs.

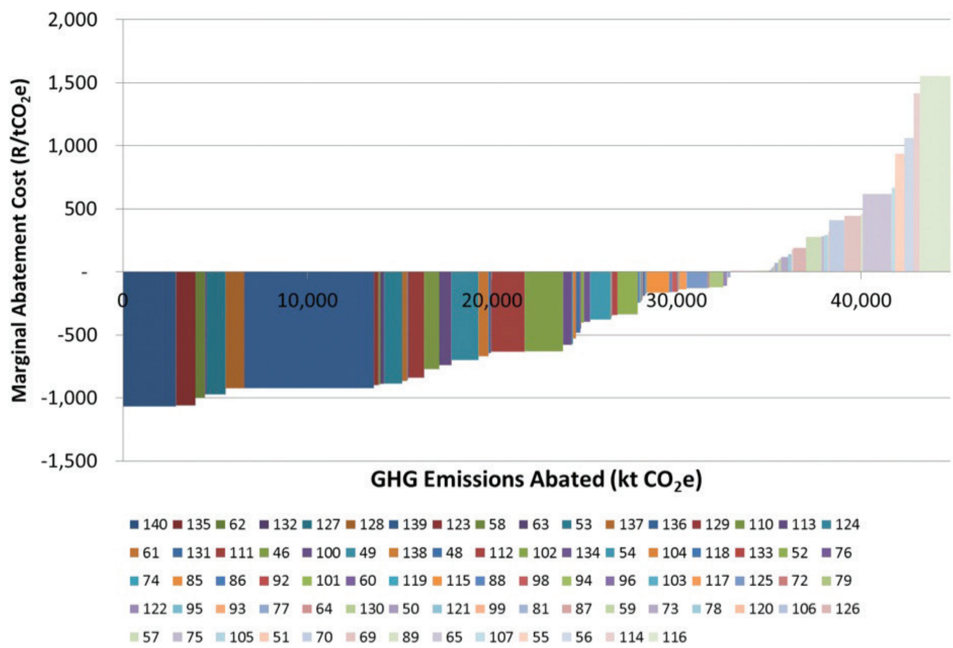


Figure 42: Marginal abatement cost curve for the industry sector in 2020

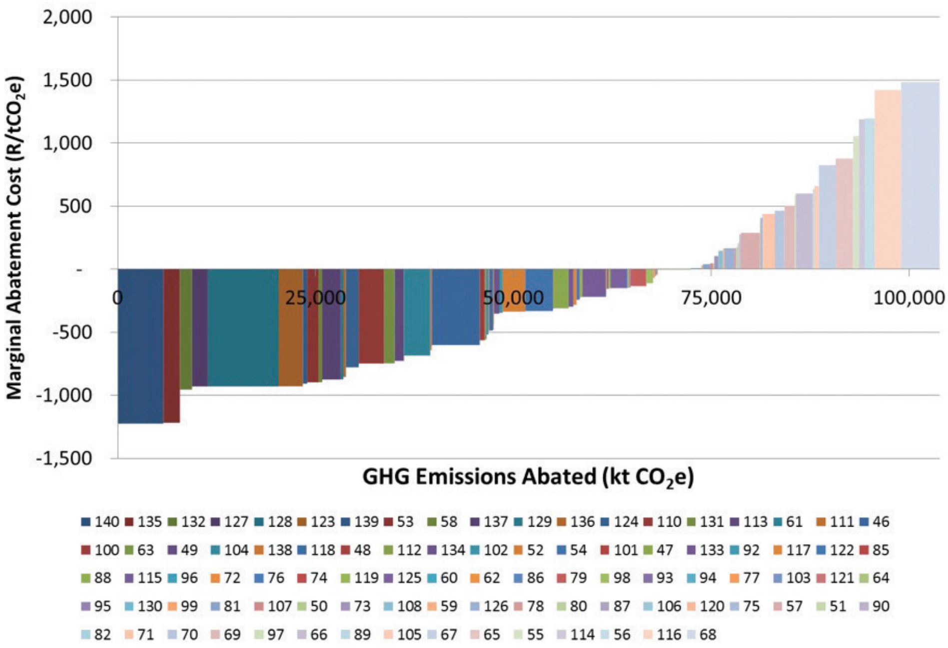


Figure 43: Marginal abatement cost curve for the industry sector in 2030

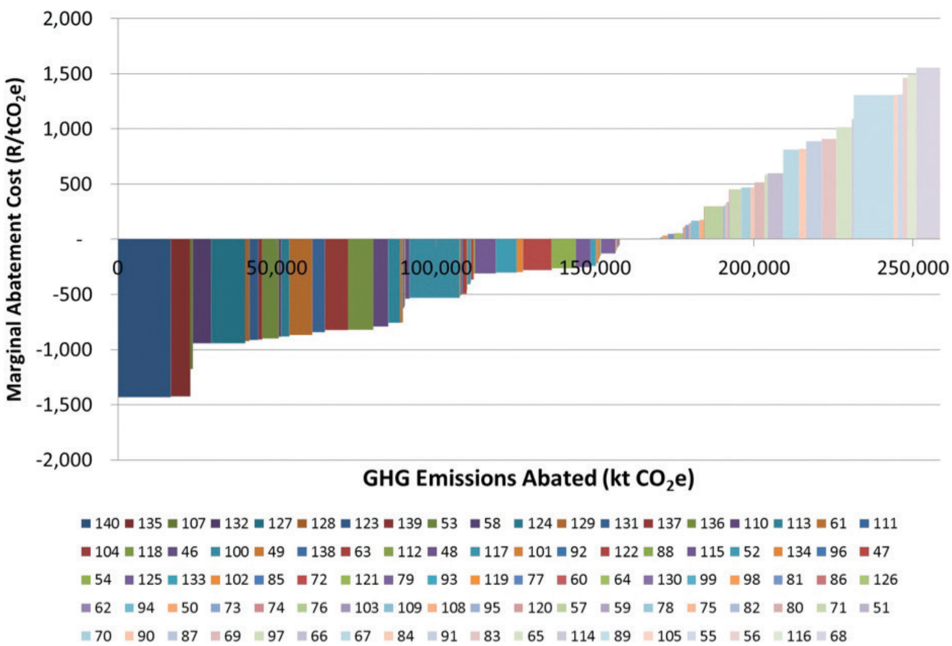


Figure 44: Marginal abatement cost curve for the industry sector in 2050

11.3 Technical Mitigation Potential

A summary of technical mitigation potential in 2020, 2030 and 2050 for all sectors and subsectors covered in the assessment of the industry sector is shown in Table 52 below.

Estimates of mitigation potential for the industry sector have been calculated independently of changes in other sectors. In 2020, the metals sector accounts for just over one quarter of mitigation potential for the industry sector (12,249 ktCO_2e, 27%). This rises to 86,502 ktCO_2e (33%) in 2050.

The proportion of total mitigation potential accounted for by the minerals sector rises from 3.5% in 2020 (1,553 ktCO_2e) to 8.5% (22,066 ktCO_2e) in 2050. By comparison, the buildings sector contribution to total mitigation potential drops from 49% (22 MtCO_2e) in 2020 to 30% (85,668 ktCO_2e) in 2050. The mining sector contribution to total mitigation potential is relatively stable, rising slightly from 12.5% (5,613 ktCO_2e) in 2020 to 17.7% (45,847 ktCO_2e) in 2050.

Table 52: Summary of technical mitigation potential for the industry sector, including a breakdown by sector and subsector and showing results for 2020, 2030 and 2050 (ktCO_2e)

Sector	Subsector	2020	2030	2050
Metals	Aluminium production	844	3,045	11,445
	Ferroalloys	5,579	13,407	30,392
	Iron and steel	5,825	19,507	44,665
	Subtotal	**12,249**	**35,959**	**86,502**
	% Total	**27.32%**	**34.63%**	**33.47%**
Minerals	Cement	1,258	3,666	15,059
	Lime	295	820	7,014
	Subtotal	**1,553**	**4,486**	**22,072**
	% Total	**3.46%**	**4.32%**	**8.54%**
Chemicals	Chemicals production	938	2,582	6,226
	% Total	**2.09%**	**2.49%**	**2.41%**
Pulp and paper	Pulp and paper	2,423	5,618	12,137
	% Total	**5.40%**	**5.41%**	**4.70%**
Other mining	Surface and underground mining	5,613	16,807	45,847
	% Total	**12.52%**	**16.18%**	**17.74%**
Buildings	Residential	14,551	23,375	42,303
	Commercial	7,515	15,023	43,365
	Subtotal	**22,066**	**38,398**	**85,668**
	% Total	**49.21%**	**34.70%**	**30.30%**
Total		**44,842**	**103,850**	**258,453**

11.4 "With Additional Measures" Projection

Assuming that all available mitigation measures are implemented, the resulting 'with additional measures' abatement projection is shown in Figure 45. Note that emissions from the power sector have been reallocated to end-users and electricity-related emissions savings have been adjusted for the progressive reduction of carbon intensity of the electricity supply over time. The total projected emissions savings in 2020, 2030 and 2050 (44.8, 103.9 and 258.5 $MtCO_2e$) represent a reduction of the reference WEM emissions of 30%, 52% and 63%, respectively.

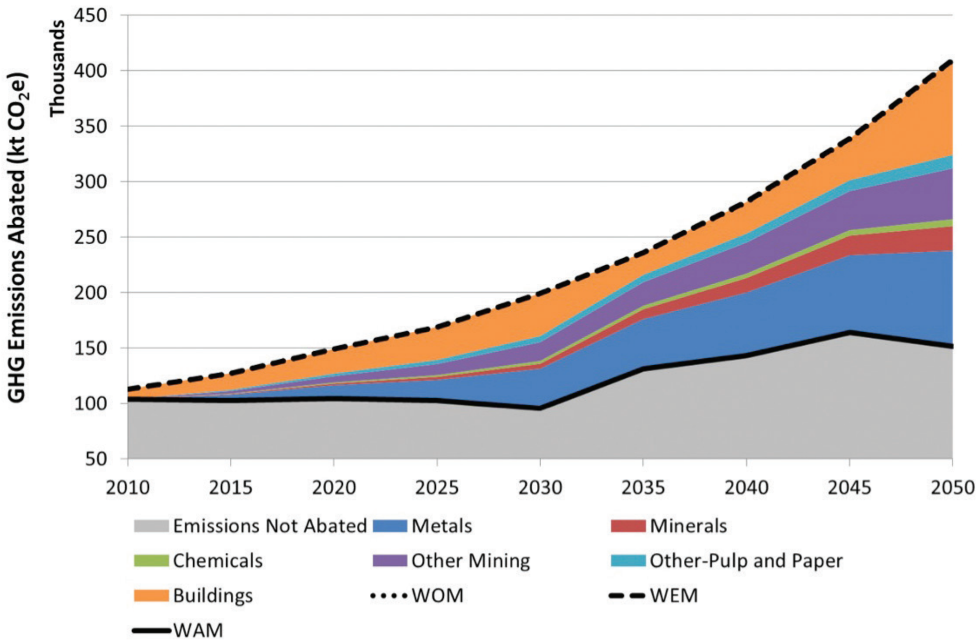


Figure 45: 'With additional measures' scenario for the industry sector, showing a breakdown per sector. Emissions from the power sector have been reallocated to end-users and electricity-related emissions savings have been adjusted accordingly. Reference case WOM and WEM emission projections, which coincide, are also shown.

12. Impact Assessment of Individual Mitigation Measures

The impact assessment is undertaken using the multi-criteria analysis approach described in the main report.

12.1 Scoring of Each Measure in Relation to Agreed Criteria

The criteria for assessing each measure are applied consistently across all sectors with the scoring and weighting options described in the main the report. Two methods have been applied for scoring:

A quantitative assessment using the costs estimated for each measure and the economic models which provide figures for gross value added (the economic criterion) and jobs (part of the social criterion).

A qualitative assessment based on scoring by the Sector Task Team.

Taking both quantitative and qualitative scores into consideration for each criterion, points are allocated to each measure with the results for the 'balanced weighting' scenario shown in Table 54 below (zero is the worst result and 100 the best).

Measures in the buildings sector score highest due to the deemed relative low cost associated with their implementation compared to their high GHG abatement potential. This results in high positive economic and social impacts as well as non-GHG environmental benefits and relative ease of imple-

mentability compared to other more complex technologies. These measures are followed in the main by cross-sector energy efficiency measures interspersed by measures which switch fuel or improve or replace production processes. One would expect that similar mitigation measures from different sectors, such as industrial energy-efficiency retrofits and equipment replacement projects, would have similar scores across all categories (for example not just for abatement potential and cost, but also for social impact, non-GHG environmental benefits and implementability). However, in practice some generic measures score differently across sectors. This may be a result of the multiple input sources contributing to the overall MCA scoring process and of opposing individual opinions expressed in certain sectors.

Generally, those measures with a high positive marginal abatement cost and a low score for implementability score worst under the MCA scoring criteria (for example CCS measures and cost intensive changes or replacements of locked in production processes). This could be due to uncertainty about future technologies which are commercially unproven in South Africa and their perceived level of installation and operational complexity. As many proposed mitigation technologies are being led by research and development programmes elsewhere in Europe, Asia or North America, they might appear to score low in terms of social benefits as the mitigation technologies and the required skills are expected to be imported. However, several South African multinational companies are involved in global initiatives that could have local technology and skill benefits in mining, metals, chemicals and minerals, and, as a result, could nurture social benefits not included in the analysis.

12.2 Net Benefit Curve

The concept of net benefit is described in the main body of the report. In the case of the 'balanced weighting' scenario the net benefit curve is shown in Figure 46 below.

The amount of CO_2e which can be mitigated for each measure, for the full period from 2010 to 2050, is shown on the horizontal axis. According to the graph, slightly less than 4.2 $GtCO_2e$ of abatement potential is available from the industry sector over the next 40 years. In order to maximise the net benefit (as determined by the MCA analysis), the measures should be implemented in order from left to right as they appear in Figure 46. Please refer to Table 54 for details on each measure. The measures are listed in the table in order of their identification number with the overall scores assigned under the 'balanced weighting' option indicated (among other variables from the MCA model).

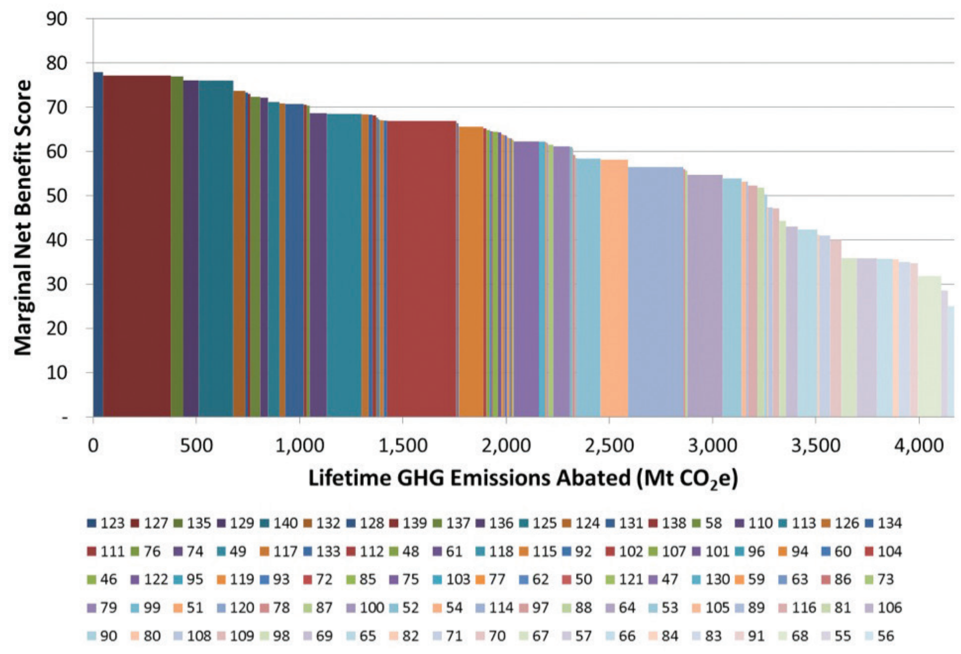


Figure 46: Net benefit curve for the Balanced Criteria scenario for the Industry sector.

Table 53: Abatement (kt CO_2e) and Marginal Abatement Cost (MAC, R/tCO_2e) for all measures in the Industry sector in 2020, 2030 and 2050

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
46	Industry	Metals	Primary Aluminium Production	Best process selection for primary aluminium smelting	481	-579	614	-564	1,315	-538
47	Industry	Metals	Primary Aluminium Production	Switch to secondary production and increase recycling	0	0	1,935	-311	9,000	-280
48	Industry	Metals	Primary Aluminium Production	Energy monitoring & management system	40	-452	55	-439	126	-408
49	Industry	Metals	Primary Aluminium Production	Improved process control	161	-529	220	-519	502	-496
50	Industry	Metals	Primary Aluminium Production	Improved electric motor system controls and variable speed drives	121	12	165	46	377	118
51	Industry	Metals	Primary Aluminium Production	Energy-efficient utility systems	40	322	55	369	126	468
52	Industry	Metals	Ferroalloys Production	Implementing best available production techniques	1,091	-338	2,871	-337	6,588	-302
53	Industry	Metals	Ferroalloys Production	Replace submerged arc furnace semi-closed with closed type	877	-840	2,325	-876	5,199	-898
54	Industry	Metals	Ferroalloys Production	Waste gas recovery and power generation - CO from closed furnace	1,112	-378	3,481	-332	7,591	-262
55	Industry	Metals	Ferroalloys Production	Waste heat recovery and power generation from semi-closed furnace - Rankine Cycle	502	938	731	1,056	1,595	1,313
56	Industry	Metals	Ferroalloys Production	Waste heat recovery and power generation from semi-closed furnace - Organic Rankine Cycle	502	1,062	731	1,188	1,595	1,463
57	Industry	Metals	Ferroalloys Production	Use biocarbon reductants instead of coal/coke	838	278	2,388	289	5,911	299
58	Industry	Metals	Ferroalloys Production	Energy monitoring and management system	263	-867	351	-874	766	-882
59	Industry	Metals	Ferroalloys Production	Improved electric motor system controls and variable speed drives	132	103	176	164	383	301
60	Industry	Metals	Ferroalloys Production	Energy-efficient utility systems	132	-190	176	-148	383	-54

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
61	Industry	Metals	Ferroalloys Production	Improved heat exchanger efficiencies	132	-646	176	-642	383	-623
62	Industry	Metals	Iron and Steel Production	BOF Waste Heat and Gas Recovery	85	-973	138	-146	297	107
63	Industry	Metals	Iron and Steel Production	Top Gas Pressure Recovery Turbine	52	-858	84	-553	180	-460
64	Industry	Metals	Iron and Steel Production	Electric Arc Furnaces (EAF) and secondary production route	1,465	7	4,201	-4	9,779	-1
65	Industry	Metals	Iron and Steel Production	State-of-the-Art Power Plant	1,576	618	2,205	877	4,848	1,016
66	Industry	Metals	Iron and Steel Production	Top gas-recycling blast furnace (with CCS)	0	0	2,148	600	4,956	599
67	Industry	Metals	Iron and Steel Production	CCS - Blast Furnace (post-combustion)	0	0	2,120	825	4,891	812
68	Industry	Metals	Iron and Steel Production	State-of-the-Art Power Plant (with CCS)	0	0	3,341	1,421	7,465	1,556
69	Industry	Metals	Iron and Steel Production	DRI - Midrex	893	444	1,308	505	3,140	516
70	Industry	Metals	Iron and Steel Production	DRI - HYL	830	410	1,219	463	2,949	470
71	Industry	Metals	Iron and Steel Production	DRI - ULCORED	0	0	1,474	438	3,499	454
72	Industry	Metals	Iron and Steel Production	Energy monitoring and management system	77	-126	106	-155	222	-174
73	Industry	Metals	Iron and Steel Production	Improved process control	385	118	530	104	1,109	130
74	Industry	Metals	Iron and Steel Production	Improved electric motor system controls and variable speed drives	92	-244	127	-155	266	145

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
75	Industry	Metals	Iron and Steel Production	Energy efficient boiler systems and kilns	154	281	212	277	443	333
76	Industry	Metals	Iron and Steel Production	Energy-efficient utility systems	62	-244	85	-155	177	145
77	Industry	Metals	Iron and Steel Production	Improved heat exchanger efficiencies	154	-45	212	-69	443	-73
78	Industry	Minerals	Cement Production	Improved process control	196	140	215	168	420	310
79	Industry	Minerals	Cement Production	Reduction of clinker content of cement products	754	-122	2,005	-134	4,570	-128
80	Industry	Minerals	Cement Production	Waste heat recovery from kilns and coolers/cogeneration	0	0	187	172	357	454
81	Industry	Minerals	Cement Production	Utilise waste material as fuel	196	71	918	40	1,777	50
82	Industry	Minerals	Cement Production	Geopolymer cement production	0	0	109	434	522	340
83	Industry	Minerals	Cement Production	CCS - back-end chemical absorption	0	0	0	0	4,641	910
84	Industry	Minerals	Cement Production	CCS - oxyfuelling	0	0	0	0	2,321	820
85	Industry	Minerals	Cement Production	Energy monitoring and management system	39	-237	43	-237	84	-185
86	Industry	Minerals	Cement Production	Improved electric motor system controls and variable speed drives	47	-227	122	-146	236	51
87	Industry	Minerals	Cement Production	Energy-efficient utility systems	26	79	68	199	131	488
88	Industry	Minerals	Lime Production	Installation of shaft preheaters	148	-161	312	-222	469	-311
89	Industry	Minerals	Lime Production	Replace rotary kilns with vertical kilns or PFRK	94	461	198	637	597	1,090
90	Industry	Minerals	Lime Production	Use alternative fuels including waste and biomass	0		250	407	1,002	470
91	Industry	Minerals	Lime Production	CCS for lime production	0		0		4,848	889
92	Industry	Minerals	Lime Production	Energy monitoring and management system	10	-221	11	-289	18	-381
93	Industry	Minerals	Lime Production	Improved process control	19	-72	20	-100	30	-111
94	Industry	Minerals	Lime Production	Improved electric motor system controls and VSDs	6	-155	8	-75	16	117
95	Industry	Minerals	Lime Production	Energy-efficient utility systems	5	-83	7	6	13	217

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
96	Industry	Minerals	Lime Production	Improved heat exchanger efficiencies	13	-151	13	-210	20	-290
97	Industry	Chemicals Production	Chemicals Production	CCS for new ammonia production plants process emissions	0	0	110	585	945	585
98	Industry	Chemicals Production	Chemicals Production	Revamp: increase capacity and energy efficiency	316	-160	842	-111	1,699	34
99	Industry	Chemicals Production	Chemicals Production	N2O abatement for new production plants	76	48	185	29	686	20
100	Industry	Chemicals Production	Chemicals Production	Energy monitoring and management system	59	-571	157	-561	317	-513
101	Industry	Chemicals Production	Chemicals Production	Advanced process control	21	-208	56	-315	113	-388
102	Industry	Chemicals Production	Chemicals Production	Improved electric motor system controls and VSDs	152	-403	405	-347	815	-216
103	Industry	Chemicals Production	Chemicals Production	Energy efficient utility systems	51	-143	135	-55	272	147
104	Industry	Chemicals Production	Chemicals Production	Increase process integration and improved heat systems	42	-367	111	-492	227	-606
105	Industry	Chemicals Production	Chemicals Production	Combined heat and power (CHP)	221	292	581	659	1,152	1,310
106	Industry	Mining	Surface and Underground Mining	Use of 1st generation biodiesel (B5) for transport and handling equipment	41	179	58	203	0	0
107	Industry	Mining	Surface and Underground Mining	Improve energy efficiency of mine haul and transport operations	186	667	349	46	798	-1,175
108	Industry	Mining	Surface and Underground Mining	Use of 2nd generation biodiesel (B50) for transport and handling equipment	0		581	146	1,330	176
109	Industry	Mining	Surface and Underground Mining	Use of 2nd generation biodiesel (B100) for transport and handling equipment	0		0		2,659	168

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
110	Industry	Mining	Surface and Underground Mining	Process, demand & energy management system	518	-1,001	1,521	-955	3,948	-842
111	Industry	Mining	Surface and Underground Mining	Energy efficient lighting	104	-896	304	-855	790	-754
112	Industry	Mining	Surface and Underground Mining	Install energy-efficient electric motor systems	2,071	-631	6,084	-603	15,793	-531
113	Industry	Mining	Surface and Underground Mining	Optimise existing electric motor systems (controls and VSDs)	1,036	-973	3,042	-929	7,896	-819
114	Industry	Mining	Surface and Underground Mining	Onsite clean power generation	1,657	1,554	4,867	1,484	12,634	1,308
115	Industry	Other	Pulp and Paper Production	Convert fuel from coal to biomass/residual wood waste	1,225	-165	2,978	-219	6,470	-309
116	Industry	Other	Pulp and Paper Production	Application of Co-generation of Heat and Power (CHP)	343	1,417	1,260	1,197	2,678	1,499
117	Industry	Other	Pulp and Paper Production	Energy recovery system	406	-139	403	-284	875	-406
118	Industry	Other	Pulp and Paper Production	Energy monitoring and management system	32	-352	71	-477	152	-545
119	Industry	Other	Pulp and Paper Production	Energy efficient electric motors, improved controls and variable speed drives	79	-175	212	-152	454	-102
120	Industry	Other	Pulp and Paper Production	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)	34	178	91	215	195	295
121	Industry	Other	Pulp and Paper Production	Improved process control	102	32	201	-44	437	-151
122	Industry	Other	Pulp and Paper Production	Energy efficient boiler systems and kilns and Improved heat systems	203	-110	403	-244	875	-364
123	Industry	Buildings	Residential	Energy efficient appliances	973	-888	1,470	-898	2,772	-913

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
124	Industry	Buildings	Residential	Geyser Blankets	542	-671	1,168	-728	2,553	-881
125	Industry	Buildings	Residential	Improved Insulation - New Buildings	1,160	-129	2,104	-151	4,660	-252
126	Industry	Buildings	Residential	Improved Insulation - Existing Buildings	696	190	1,262	166	2,796	55
127	Industry	Buildings	Residential	Efficient Lighting - FLs	7,019	-923	8,940	-930	10,660	-942
128	Industry	Buildings	Residential	Efficient Lighting - LEDs	241	-899	559	-908	1,333	-922
129	Industry	Buildings	Residential	Solar water heating	1,464	-701	3,216	-749	7,203	-867
130	Industry	Buildings	Residential	LPG for cooking	624	9	1,333	9	2,969	8
131	Industry	Buildings	Residential	Passive building/improved thermal design - New Buildings	1,832	-633	3,322	-686	7,358	-822
132	Industry	Buildings	Commercial/Institutional	Efficient Lighting	1,010	-923	2,015	-931	5,799	-943
133	Industry	Buildings	Commercial/Institutional	Heat pumps - Existing Buildings	293	-343	584	-299	1,681	-242
134	Industry	Buildings	Commercial/Institutional	Heat pumps - New Buildings	340	-397	678	-353	1,952	-297
135	Industry	Buildings	Commercial/Institutional	HVAC: with heat recovery - New Buildings	1,052	-1,061	2,107	-1,218	6,100	-1,425
136	Industry	Buildings	Commercial/Institutional	HVAC:Variable speed drives - Existing Buildings	668	-741	1,332	-747	3,834	-756
137	Industry	Buildings	Commercial/Institutional	HVAC:Variable speed drives - New Buildings	811	-773	1,618	-779	4,655	-789
138	Industry	Buildings	Commercial/Institutional	HVAC: Central air conditioners - New Buildings	242	-483	483	-487	1,390	-493
139	Industry	Buildings	Commercial/Institutional	Energy efficient appliances	218	-889	435	-896	1,252	-908
140	Industry	Buildings	Commercial/Institutional	Passive building/improved thermal design - New Buildings	2,881	-1,068	5,770	-1,226	16,703	-1,432

Table 54: Quantitative data informing the scoring of options for the industry sector as well as scores for the main criteria and the overall weighted score for the 'balanced weighting' scenario

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
46	Industry	Metals	Primary aluminium production	Best process selection for primary aluminium smelting	64	25,859	-56.58	9.27	0.07	0.34	79	68	33	70	78
47	Industry	Metals	Primary aluminium production	Switch to secondary production and increase recycling	62	121,585	-26.90	4.28	0.03	0.34	72	60	31	75	78
48	Industry	Metals	Primary aluminium production	Energy monitoring & management system	67	2,378	-47.84	8.83	0.06	0.33	77	67	33	70	93
49	Industry	Metals	Primary aluminium production	Improved process control	67	9,510	-54.19	9.60	0.07	0.34	79	69	33	70	93
50	Industry	Metals	Primary aluminium production	Improved electric motor system controls and variable speed drives	63	7,133	-9.72	4.23	0.02	0.28	68	60	30	70	93
51	Industry	Metals	Primary aluminium production	Energy-efficient utility systems	61	2,378	15.69	1.17	-0.01	0.58	63	55	31	70	93
52	Industry	Metals	Ferroalloys production	Implementing best available production techniques	58	115,087	-26.10	4.92	0.03	0.33	72	61	31	55	78
53	Industry	Metals	Ferroalloys production	Replace submerged arc furnace semi-closed with closed type	54	91,739	-11.13	4.41	0.02	0.29	69	60	30	55	60

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
54	Industry	Metals	Ferroalloys production	Waste gas recovery and power generation - CO from closed furnace	58	132,764	-25.89	5.49	0.03	0.33	72	62	31	70	60
55	Industry	Metals	Ferroalloys production	Waste heat recovery and power generation from semi-closed furnace - Rankine cycle	29	31,408	256.52	-27.91	-0.26	0.37	8	6	14	55	60
56	Industry	Metals	Ferroalloys production	Waste heat recovery and power generation from semi-closed furnace - organic Rankine cycle	25	31,408	279.64	-30.71	-0.28	0.37	3	2	13	65	43
57	Industry	Metals	Ferroalloys production	Use biocarbon reductants instead of coal/coke	36	99,174	20.32	-3.13	-0.02	0.26	62	48	27	35	8
58	Industry	Metals	Ferroalloys production	Energy monitoring and management system	70	14,947	-85.73	13.84	0.10	0.34	86	76	35	70	93
59	Industry	Metals	Ferroalloys production	Improved electric motor system controls and variable speed drives	62	7,473	-1.35	3.29	0.01	0.22	67	58	29	70	93
60	Industry	Metals	Ferroalloys production	Energy-efficient utility systems	65	7,473	-26.31	6.31	0.04	0.32	72	63	31	70	93
61	Industry	Metals	Ferroalloys production	Improved heat exchanger efficiencies	66	7,473	-68.33	12.00	0.08	0.34	82	73	24	70	93
62	Industry	Metals	Iron and steel production	BOF waste heat and gas recovery	63	5,902	-130.35	22.48	0.16	0.34	96	90	39	55	43

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
63	Industry	Metals	Iron and steel production	Top gas pressure recovery turbine	62	3,584	-94.93	15.61	0.11	0.34	88	79	36	70	43
64	Industry	Metals	Iron and steel production	Electric arc furnaces (EAF) and secondary production route	55	169,738	-11.75	2.15	0.01	0.34	69	56	30	45	78
65	Industry	Metals	Iron and steel production	State-of-the-Art Power Plant	42	94,670	65.31	-6.33	-0.06	0.37	52	42	26	35	60
66	Industry	Metals	Iron and steel production	Top gas-recycling blast furnace (with CCS)	36	75,109	14.21	-1.80	-0.02	0.35	63	50	29	30	8
67	Industry	Metals	Iron and steel production	CCS - blast Furnace (post-combustion)	36	74,121	22.15	-3.04	-0.02	0.35	61	48	28	35	8
68	Industry	Metals	Iron and steel production	State-of-the-art power plant (with CCS)	32	113,702	64.70	-8.32	-0.07	0.35	52	39	25	35	8
69	Industry	Metals	Iron and steel production	DRI - Midrex	43	57,962	43.97	-4.98	-0.05	0.36	56	44	27	30	60
70	Industry	Metals	Iron and steel production	DRI - HYL	40	54,181	40.28	-4.64	-0.04	0.36	57	45	27	30	43
71	Industry	Metals	Iron and steel production	DRI - ULCORED	41	54,969	22.42	-2.66	-0.02	0.36	61	48	28	60	8
72	Industry	Metals	Iron and steel production	Energy monitoring and management system	64	4,469	-20.52	4.39	0.03	0.33	71	60	31	70	93
73	Industry	Metals	Iron and steel production	Improved process control	62	22,343	0.06	1.88	0.01	0.20	66	56	29	70	93

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
74	Industry	Metals	Iron and steel production	Improved electric motor system controls and variable speed drives	68	5,362	-46.31	13.14	0.07	0.31	77	75	33	70	93
75	Industry	Metals	Iron and steel production	Energy efficient boiler systems and kilns	64	8,937	13.79	0.21	-0.01	0.46	63	53	30	85	93
76	Industry	Metals	Iron and steel production	Energy-efficient utility systems	68	3,575	-46.31	13.14	0.07	0.31	77	75	33	70	93
77	Industry	Metals	Iron and steel production	Improved heat exchanger efficiencies	63	8,937	-13.66	3.55	0.02	0.32	69	59	30	70	93
78	Industry	Minerals	Cement production	Improved process control	59	9,242	29.42	-1.08	-0.02	0.41	60	51	29	70	93
79	Industry	Minerals	Cement production	Reduction of clinker content of cement products	61	80,694	-0.08	0.43	0.00	0.21	66	53	29	70	93
80	Industry	Minerals	Cement production	Waste heat recovery from kilns and coolers/ cogeneration	47	6,155	50.17	-4.70	-0.05	0.37	55	45	27	70	43
81	Industry	Minerals	Cement production	Utilise waste material as fuel	52	32,373	5.36	-0.64	-0.01	0.36	65	52	29	80	35
82	Industry	Minerals	Cement production	Geopolymer cement production	41	7,146	26.00	-3.11	-0.03	0.36	60	48	28	70	0
83	Industry	Minerals	Cement production	CCS - back-end chemical absorption	35	56,864	57.06	-7.44	-0.06	0.35	53	40	16	50	18
84	Industry	Minerals	Cement production	CCS - oxyfuelling	36	28,432	50.75	-6.61	-0.06	0.35	55	42	16	50	18

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
85	Industry	Minerals	Cement production	Energy monitoring and management system	64	1,848	-18.71	4.68	0.03	0.32	71	61	31	70	93
86	Industry	Minerals	Cement production	Improved electric motor system controls and variable speed drives	62	4,524	-0.98	2.65	0.01	0.04	67	57	28	70	93
87	Industry	Minerals	Cement production	Energy-efficient utility systems	59	2,513	31.22	-1.28	-0.03	0.41	59	51	28	70	93
88	Industry	Minerals	Lime production	Installation of shaft preheaters	56	10,348	-21.76	4.34	0.03	0.33	71	60	31	70	50
89	Industry	Minerals	Lime production	Replace rotary kilns with vertical kilns or PFRK	53	9,173	49.66	-4.77	-0.05	0.37	55	45	27	75	68
90	Industry	Minerals	Lime production	Use alternative fuels including waste and biomass	50	14,645	17.22	-2.68	-0.02	0.35	62	48	28	55	60
91	Industry	Minerals	Lime production	CCS for lime production	35	37,106	19.93	-2.63	-0.02	0.35	62	48	28	35	0
92	Industry	Minerals	Lime production	Energy monitoring and management system	65	431	-36.98	6.75	0.05	0.33	75	64	32	70	93
93	Industry	Minerals	Lime production	Improved process control	64	760	-20.24	4.52	0.03	0.32	71	60	31	70	93
94	Industry	Minerals	Lime production	Improved electric motor system controls and VSDs	65	341	-25.79	6.45	0.04	0.31	72	63	31	70	93

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
95	Industry	Minerals	Lime production	Energy-efficient utility systems	64	273	-19.57	5.70	0.03	0.30	71	62	31	70	93
96	Industry	Minerals	Lime production	Improved heat exchanger efficiencies	65	506	-29.55	5.64	0.04	0.33	73	62	32	70	93
97	Industry	Chemicals production	Chemicals production	CCS for new ammonia production plants process emissions	56	9,979	12.48	-1.57	-0.01	0.35	63	50	29	90	50
98	Industry	Chemicals production	Chemicals production	Revamp: increase capacity and energy efficiency	44	31,782	-12.00	1.88	0.02	0.30	69	56	30	50	18
99	Industry	Chemicals production	Chemicals production	N2O abatement for new production plants	61	9,836	2.72	-0.32	-0.00	0.36	66	52	29	70	93
100	Industry	Chemicals production	Chemicals production	Energy monitoring and management system	58	5,930	-48.13	8.40	0.06	0.34	77	67	33	70	50
101	Industry	Chemicals production	Chemicals production	Advanced process control	65	2,134	-30.24	6.31	0.04	0.33	73	63	32	70	93
102	Industry	Chemicals Production	Chemicals production	Improved electric motor system controls and VSDs	65	15,228	-34.39	6.71	0.04	0.33	74	64	32	70	93
103	Industry	Chemicals production	Chemicals production	Energy efficient utility systems	63	5,076	-15.11	4.37	0.02	0.31	70	60	31	70	93
104	Industry	Chemicals production	Chemicals production	Increase process integration and improved heat systems	65	4,268	-41.70	7.71	0.05	0.33	76	66	32	70	85

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
105	Industry	Chemicals production	Chemicals production	Combined heat and power (CHP)	53	21,334	42.76	-2.81	-0.04	0.39	57	48	28	70	68
106	Industry	Mining	Surface and underground mining	Use of 1st generation biodiesel (B5) for transport and handling equipment	51	1,004	36.32	-5.15	-0.04	0.35	58	44	37	50	68
107	Industry	Mining	Surface and underground mining	Improve energy efficiency of mine haul and transport operations	65	14,773	6.40	11.22	0.02	0.14	65	71	29	70	100
108	Industry	Mining	Surface and underground mining	Use of 2nd generation biodiesel (B50) for transport and handling equipment	47	21,180	8.32	-1.27	-0.01	0.35	64	51	49	45	25
109	Industry	Mining	Surface and underground mining	Use of 2nd generation biodiesel (B100) for transport and handling equipment	47	30,555	4.90	-0.76	-0.01	0.35	65	51	59	30	25
110	Industry	Mining	Surface and underground mining	Process, demand & energy management system	69	83,759	-56.65	8.90	0.07	0.34	79	68	33	70	100
111	Industry	Mining	Surface and underground mining	Energy efficient lighting	68	16,752	-51.83	8.28	0.06	0.34	78	66	33	70	100
112	Industry	Mining	Surface and underground mining	Install energy-efficient electric motor systems	67	335,037	-38.82	6.61	0.05	0.34	75	64	32	70	100

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
113	Industry	Mining	Surface and underground mining	Optimise existing electric motor systems (controls and VSDs)	69	167,519	-55.31	8.73	0.06	0.34	79	67	33	70	100
114	Industry	Mining	Surface and underground mining	Onsite clean power generation	56	268,030	81.18	-8.52	-0.08	0.37	48	39	25	90	85
115	Industry	Other	Pulp and paper production	Convert fuel from coal to biomass/residual wood waste	66	118,367	-16.42	2.72	0.02	0.34	70	57	31	90	85
116	Industry	Other	Pulp and paper production	Application of co-generation of heat and power (CHP)	52	46,120	87.62	-7.98	-0.08	0.38	46	39	25	70	85
117	Industry	Other	Pulp and paper production	Energy recovery system	67	18,588	-25.42	6.06	0.04	0.32	72	63	31	90	85
118	Industry	Other	Pulp and paper production	Energy monitoring and management system	66	2,824	-39.79	7.19	0.05	0.34	75	65	32	70	93
119	Industry	Other	Pulp and paper production	Energy efficient electric motors, improved controls and variable speed drives	64	8,169	-20.42	4.87	0.03	0.32	71	61	31	70	93
120	Industry	Other	Pulp and paper production	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)	61	3,501	6.51	1.53	0.00	-14.88	65	55	27	70	93
121	Industry	Other	Pulp and paper production	Improved process control	63	8,287	-8.97	3.33	0.02	0.30	68	58	30	70	93

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
122	Industry	Other	Pulp and paper production	Energy efficient boiler systems and kilns and Improved heat systems	64	16,574	-25.51	5.50	0.03	0.32	72	62	31	70	93
123	Industry	Buildings	Residential	Energy efficient appliances	78	47,676	-135.84	21.27	0.16	0.34	97	88	49	70	93
124	Industry	Buildings	Residential	Geyser blankets	71	27,104	-91.36	14.28	0.11	0.34	87	76	36	70	93
125	Industry	Buildings	Residential	Improved insulation - new buildings	71	56,592	-43.41	8.81	0.06	0.32	76	67	53	70	93
126	Industry	Buildings	Residential	Improved insulation - existing buildings	68	33,955	-13.75	5.53	0.03	0.28	69	62	51	70	93
127	Industry	Buildings	Residential	Efficient lighting - FLs	77	328,381	-147.31	23.02	0.17	0.34	100	91	40	65	100
128	Industry	Buildings	Residential	Efficient lighting - LEDs	73	13,155	-110.84	17.35	0.13	0.34	91	82	37	65	100
129	Industry	Buildings	Residential	Solar water heating	76	74,941	-95.51	14.96	0.11	0.34	88	78	56	70	93
130	Industry	Buildings	Residential	LPG for cooking	62	32,001	0.39	-0.05	-0.00	0.36	66	53	39	70	85
131	Industry	Buildings	Residential	Passive building/ improved thermal design - new buildings	71	89,355	-98.53	15.62	0.12	0.34	89	79	46	70	75
132	Industry	Buildings	Commercial/ institutional	Efficient lighting	74	57,750	-114.46	17.89	0.13	0.34	92	82	37	65	100
133	Industry	Buildings	Commercial/ institutional	Heat pumps - existing buildings	67	16,739	-62.06	10.46	0.07	0.34	80	70	34	65	93
134	Industry	Buildings	Commercial/ institutional	Heat pumps - new buildings	68	19,443	-65.54	10.90	0.08	0.34	81	71	34	70	93

ID	Key Sector	Sector	Subsector	Measure	Score*	Total emissions abated ($ktCO_2e$)	NPV of costs per CO_2e mitigated	GVA impact per CO_2e mitigated	Jobs created per $ktCO_2q$ mitigated	Ratio of unskilled to total	Cost	Eco-nomic impact	Social impact	Non-GHG environmental impact	Implement-ability
135	Industry	Buildings	Commercial/ institutional	HVAC: with heat recovery - new buildings	77	60,808	-149.08	23.52	0.17	0.34	100	92	40	70	93
136	Industry	Buildings	Commercial/ institutional	HVAC: variable speed drives - existing buildings	72	38,181	-102.72	16.41	0.12	0.34	90	80	37	70	93
137	Industry	Buildings	Commercial/ institutional	HVAC: variable speed drives - new buildings	72	46,362	-104.79	16.67	0.12	0.34	90	80	37	70	93
138	Industry	Buildings	Commercial/ institutional	HVAC: Central air conditioners - new buildings	71	13,840	-86.17	14.33	0.10	0.34	86	77	36	70	93
139	Industry	Buildings	Commercial/ institutional	Energy efficient appliances	73	12,466	-111.93	17.56	0.13	0.34	92	82	37	70	93
140	Industry	Buildings	Commercial/ institutional	Passive building/ improved thermal design - new buildings	76	166,497	-148.60	23.55	0.17	0.34	100	92	50	70	75

* *'balanced weighting' scenario*

References

ArcelorMittal, March 2013: List of mitigation options for the Iron and Steel Production sector. Personal communication.

Bettgenhäuser K, Boermans T, Schimschar S, 2009: Residential buildings and service sector. Ecofys, Sectoral Emission Reduction Potentials and Economic Costs for Climate Change (SERPEC-CC), 2009.

Cement Sustainability Initiative/European Cement Research Academy (CSI/ECRA, 2009: Development of state of art-techniques in cement manufacturing: trying to look ahead. CSI/ECRA-Technology papers, Geneva.

Chemical and Allied Chemical Industries' Association (CAIA), 2013: Technical inputs to the Mitigation Potential Analysis Project, Industry sector task-team, 2013.

Cohen, B., Lewis, Y. and Mason-Jones, K., 2012: Projections of greenhouse gas emissions trajectories from the South African mining and minerals processing sectors to 2030, NPC Low Carbon Economy Work Programme, The Green House, 25 April, 2012.

Construction Industry Development Board (CIDB), 2009: Greenhouse Gas Emission Baselines and Reduction Potentials from Buildings in South Africa, A discussion document, UNEP DTIE, CIDB Construction Industry Development Board, 2009.

Department of Energy (DoE), 2011: Integrated Resource Plan for Electricity 2010–2030, Pretoria, DoE.

DoE, 2013a: Draft 2012 Integrated Energy Planning Report, Executive Summary (for public consultation), Pretoria, South Africa, available at: http://www.energy.gov.za/files/IEP/IEP_Publications/Draft-2012-Integrated-Energy-Plan.pdf

DoE, 2013: Energy Balances, 2013b: Energy Balances in TJ (1999-2009).xlsx. Excel spreadsheet obtained from DoE.

Department of Environmental Affairs (DEA), 2013: Greenhouse Gas Inventory for South Africa, 2000–2010 (Draft). Pretoria, DEA.

Department pf Resources, Energy and Tourism (DRET), 2010: First Opportunities in Depth: The mining industry. A Look At Results From 2006–2008 For The Energy Efficiency Opportunities Program, Department of Resources, Energy and Tourism, Commonwealth of Australia, 2010.

DRET, 2013: Analyses of Diesel Use for Mine Haul and Transport Operations, Energy Efficiency Opportunities Program, Department of Resources, Energy and Tourism (DRET), Commonwealth of Australia, 2013.

Energy Research Centre (ERC), 2007: Long Term Mitigation Scenarios: Technical Summary, Department of Environment Affairs and Tourism, Pretoria, October 2007.

Energy Research Centre (ERC), 2013: The South African TIMES model (SATIM), Energy Research Centre (ERC) Systems Analysis & Planning Group. Version 2.1

Energy Technology Systems Analysis programme (ETSAP), 2010a: Cement Production, Energy Technology Systems Analysis Programme, 2010.

ETSAP CCS, 2010b: CO2 Capture & Storage, IEA ETSAP, 2010.

European Commission (EC), 2006: Best Available Techniques for Large Combustion Plants, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS).

EC, 2007a: Reference Document on Best Available Techniques for the Manufacture of Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers, Joint Research Centre (JRC), IPTS.

EC, 2007b: Reference Document on Best Available Techniques in the Ceramic Manufacturing Industry, Joint Research Centre (JRC), IPTS.

EC, 2008. Prospective Study of the World Aluminium Industry, Joint Research Centre (JRC), IPTS.

EC, 2009a: Best Available Techniques (BAT) Reference Document for Energy Efficiency. Joint Research Centre (JRC), IPTS.

EC, 2009b: Draft Reference document on Best Available Techniques (BAT) Reference Document for Non-Ferrous Metals Industries, Joint Research Centre (JRC), IPTS.

EC, 2010: Draft Reference Document on Best Available Techniques in the Pulp and Paper Industry, Joint Research Centre (JRC), IPTS.

EC, 2013a: Best Available Techniques (BAT) Reference Document for Production of Cement, Lime and Magnesium Oxide, Joint Research Centre (JRC), IPTS.

EC, 2013b: Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques in the Ferrous Metals processing Industry, IPTS.

EC, 2013c: Best Available Techniques (BAT) Reference Document for Iron and Steel Production, Joint Research Centre (JRC), IPTS.

Holappa, L. 2010: Toward Sustainability in Ferroalloys Production, Aalto University School of Science and Technology, Department of Materials Science and Engineering.

International Aluminium Institute (IAI) 2011a: Aluminium Measuring & Benchmarking 2010. Available at: *www.world-aluminium.org.*

IAI 2011b: Global Aluminium Industry Sustainability Performance 2010. Available at: *http://www.world-aluminium.org.*

Intergovernmental Panel on Climate Change (IPCC), 2007: N2O Emissions from Adipic Acid and Nitric Acid Production, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.

International Energy Agency (IEA), 2009: Energy technology perspectives 2008 – Scenarios and Strategies to 2050.

IEA, 2010: Cement Technology Roadmap 2009. Carbon emissions reductions up to 2050, WBCSD. Available at: *http://www.iea.org/publications/freepublications/publication/Cement.pdf*

IFA, 2010: International Fertilizer Industry Association (IFA), 2010. Energy Efficiency and CO2, Emissions in Ammonia Production, 2008-2009 Summary Report. Available at: *www.fertilizer.org/ifacontent/download/26110/374422/ver.*

Intergovernmental Panel on Climate Change (IPCC), 2006: Guideline for National Greenhouse Gas Inventories, Volume 1, 2, 3. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Molemoeng, N. 2012: Consumption of Fixed Capital and Capital Stock, Seminar on Developing a Programme for the Implementation of the 2008 SNA and supporting statistics. Available at: *http://unstats.un.org/unsd/nationalaccount/workshops/2012/pretoria-sa/sa.asp*

National Treasury, 2012: The Medium Term Budget Policy Statement, Pretoria, National Treasury, available at: www.treasury.gov.za/documents/mtbps/2012/.

nPower Cogen, 2005: Delivering Energy to Industry Combined Heat and Power in Practice, Huntsman Tioxide, Grimsby.

Paper Manufacturers Association of South Africa (PAMSA), 2013: Technical inputs to the Mitigation Potential Analysis Project, Industry sector task-team, 2013.

PPC, 2013: Personal Communication, between R-AEA and Egmont Ottermann PPC Ltd, 2013.

Prince, A., 2007: "Initiating New Projects in the Ammonia Sector" Paper presented at the IFA Technical Committee Meeting, Workshop on Energy Efficiency and CO2 Reduction Prospects in Ammonia Production, 2007.Resource-Net, 2011: Coke Market Survey Annual Report, 2011. Available at *www.resource-net.com/files/Sample_Pages.pdf.*

Riekkola-Vanhanen, M. 1999: Best Available Techniques (BAT) in Ferrochromium Production, The Finish Environment Institute.

South African Petroleum Industry Association (SAPIA), 2011: 2010 Annual Report. Available at: *http://www.sapia.co.za/publications/annual-reports.html*

South African Petroleum Industry Association (SAPIA), 2013: 2012 Annual Report. Available at: http://www.sapia.co.za/publications/annual-reports.html

Statistics South Africa (Stats SA), 2010a: Building Statistics. Available from: *http://www.statssa.gov.za/Publications/Report-50-11-01/Report-50-11-012010.pdf*

Stats SA, 2010b: Archive: P0318 – General Household Survey. Available from: *http://www.statssa.gov.za/publications/statspastfuture.asp?PPN=p0318&SCH=4187*

Sustainable Buildings and Climate Initiative (SBCI), 2009: Greenhouse Gas Emission Baselines and Reduction Potentials from Buildings in South Africa. Paris, United Nations Environment Programme.

ULCOS), 2008: The Trial of the Top Gas Recycling Blast Furnace at LKAB's EBF and Scale-up, GuangqingZuo and Alexandra Hirsch, ULCOS, October, 2008.

United States Environmental Protection Agency (USEPA), 2010: Available and emerging technologies for reducing greenhouse gas emissions from the nitric acid production industry, USEPA Office of Air and Radiation, December 2010.

Voestalpine, 2013: Voestalpine Gives Supply Contract to Siemens and Midrex, Press Release, Voestalpine, July, 2013.

Winkler H, (ed.), 2006: Energy Policies for sustainable Development in South Africa: Options for the Future. Energy Research Centre, Cape Town.

Xstrata, 2012: Power Generation alternatives for recovery of waste heat or energy, provided to Camco by Xstrata, December, 2012.

Notes

Department of Environmental Affairs
Environment House,
473 Steve Biko,
Arcadia,
Pretoria, 0083
South Africa
www.environment.gov.za

Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ) GmbH
Hatfield Gardens, Block C, Groundfloor
333 Grosvenor Street
Hatfield 0028
Pretoria, South Africa
www.giz.de

First publication in 2014

S-1566 • www.studio112.co.za