ENERGY AND RELATED CARBON EMISSION REDUCTION TECHNOLOGIES FOR HOT MIX ASPHALT PLANTS

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ABSTRACT
The global call and commitments to reducing greenhouse gas (GHG) emissions has brought the need to reduce the carbon intensity of all industrial operations. This paper discusses various carbon reduction measures to be implemented on asphalt manufacturing plants, considering a baseline 100 ton per hour (tph) co-current flow drum plant.

The technological recommendations in terms of reducing plant carbon emissions include:

- Stockpiling aggregates under roof on sloped concrete floors
- Counter-current flow design of burner gas and aggregate flow direction in single drum plants
- Frequent replacement of worn flights in the drier
- Effective lagging of all vessels and pipelines containing heated materials
- Tighter control of feed air for combustion and reduction of flue gas heat loss
- Asphalt product storage in closed silos
- Conversion of hot mix asphalt operation to warm mix asphalt operation
- Burner fuel switch from HFO to natural gas

These measures can achieve a 30% HFO energy use reduction and a 35% reduction in GHG emissions (assuming baseline plant with none of these measures implemented).

INTRODUCTION
This year marks the crucial United Nations Framework Convention for Climate Change (UNFCCC) discussions to take place under COP17 in Durban, which is earmarked to formalise a replacement GHG emissions reductions agreement to the Kyoto protocol. Governments and companies need to take the initiative in reducing their GHG emissions through implementing energy efficiency measures and converting to renewable energy sources.

The objective of this paper is to highlight some of the energy efficiency measures which may be applied in the asphalt manufacturing sector and makes use of a baseline 100 ton per hour (tph) inefficient co-current drum plant. The methodology used in assessing the conversion of this baseline plant by implementing various proposed energy efficiency measures is outlined in the following section.

METHODOLOGY
The methodology used to carry out the energy savings calculations is outlined below. The fuel calorific values and emission factors presented in Table 1 were used in this study:

Table 1: Calorific Values of Utilised Fuel Types

Fuel Type	Fuel Calorific Value	Fuel CO_2 Emission Factor
Diesel	45.60 GJ/ton	74.1 kg CO_2/GJ
HFO	42.90 GJ/ton	73.3 kg CO_2/GJ
NG	39.50 GJ/10^3 m^3	56.1 kg CO_2/GJ
Electricity	-	1.2 kg CO_2/kWh[1]

The fuel calorific values are generic values as supplied by the South African Petroleum Industry Association (SAPIA). The emission factors presented for the different fuels were taken from the 2006 Intergovernmental Panel for Climate Change Guidelines for National Greenhouse Gas Inventories *(IPCC, 2006).*

The main energy consumption on a hot mix asphalt plant is as a result of heating in the drier, comprising 60% of the plant's total energy consumption. The evaporation of water from aggregates requires approximately 25% of the plant's energy consumption, but would vary from plant to plant depending on the moisture content of aggregates fed into the process. Electricity and diesel consumption typically comprise 12% and 3% of the plant's total energy consumption respectively. The overall energy intensity of the investigated plant was taken as 300MJ/ton of product.

The technological measures assessed in terms of reducing plant carbon emissions include:

- Stockpiling aggregates under roof on sloped concrete floors
- Counter-current flow design of burner gas and aggregate flow direction in single drum plants
- Frequent replacement of worn flights in the drier
- Effective lagging of all vessels and pipelines containing heated materials
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The capital costs for implementing these measures were obtained from construction companies, drum plant manufacturers, lagging manufacturers, and burner manufacturers. In some cases quotes were obtained from foreign companies, e.g. Astec Inc. in the case of warm mix asphalt plants.

The savings in terms of energy use and resultant fuel use were determined and any other revenue streams/financial & tax incentives investigated, and where applicable incorporated into the cost benefit analysis (CBA). These additional financial incentives incorporate possible carbon credit revenue. The payback period (PP) for implementing capital measures was calculated by dividing capital cost by total monetary savings.

[1] Electricity emission factor equivalent (kg CO_2/GJ) = 333.3 kg CO_2/GJ

The economic feasibility of implementing the various investigated energy efficiency measures is outlined in the following results and discussion chapter below.

FINDINGS AND DISCUSSION

A discussion of the various carbon emission reduction measures is presented below, followed by a summary of the envisaged savings and a basic feasibility assessment of the respective measures.

Carbon Reduction Measure 1: Storing Fine Aggregates under Roof

The installation of a shed with concrete floors and drainage channels for piled aggregate using the following simplistic design is recommended:

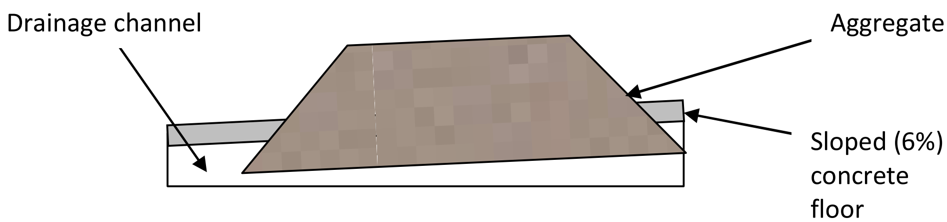

Figure 1: Aggregate placement under roof to effectively drain moisture

The storage of aggregates under roof on sloped concrete floors to allow drainage out of stockpile from the deposition side (i.e. opposite the loading side) has been observed to realise large fuel use reduction in the drier. This is because for every increase of 1% in aggregate moisture content the fuel consumption increases by 10% *(NAPA, 2007)*.

The reduction in moisture content was estimated as follows (accounting for inherent moisture) for the three fine grade aggregate types:

Table 2: Aggregate moisture content reduction

Aggregate Type	Annual flow rate for 100tph plant (tons/yr)	Typical Feed Moisture Content (%)	New Moisture Content (%)
Crusher dust	23 600	5.0%	3.0%
Washed Dust	20 800	7.3%	4.3%
River Sand	20 800	4.0%	3.0%

The savings are hence determined through the difference of the new and typical feed moisture contents for each respective aggregate type multiplied by their respective flow rates to determine the savings in terms of reduction in water required to be evaporated. For this example evaporated water amounts to 1 300 tons/year, and given the latent heat of evaporation of 2 250 kJ/kg, the heat capacity of water heated from ambient to 100°C of 4.184 kJ/kg-K (K stands for degree Kelvin - temperature difference) and the assumed efficiency of HFO drier of 85%, the energy saved can be calculated.

The capital cost for storage of the aggregates in a 1 100 m^2 shed has been determined, and accounts for a two week storage of fine aggregates.

Carbon Reduction Measure 2: Converting Co-current Drum Plant to Counter-current Plant
Two arrangements in terms of the drying process can be applied and are shown in the following figure.

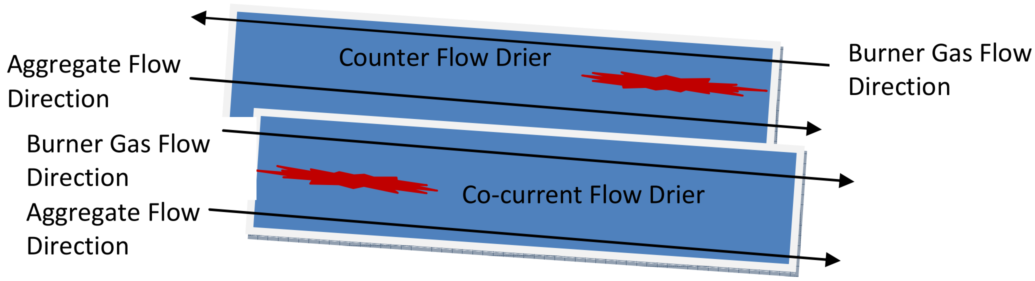

Figure 2: Drier aggregate/burner gas flow direction arrangements

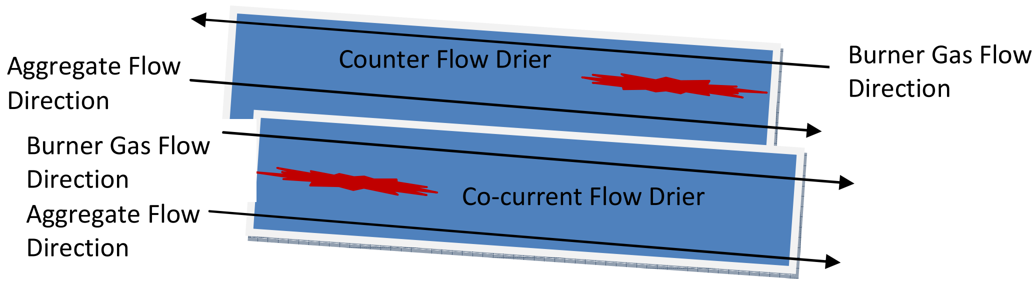

Figure ***2*** above indicates the two flow arrangements in terms of aggregate and burner gas in either a co-current (parallel) or counter-current arrangement.

Retrofitting existing drum driers to operate counter-flow, whereby hot burner gases flow in the opposite direction to the aggregate entering the drier would reduce heat loss via flue gas. The counter flow arrangement allows for decreased exit temperature of gases and more efficient heat transfer due to greater Temperature Difference ΔT. The arrangement requires that the burner nozzle is extended through the mixing compartment of the drum (for single drum plants) and into the drier section by means of tubing. The burner tube is extended well into the drier drum, providing some distance between the flame and the Reclaimed Asphalt (RA)/Bitumen addition to the drum. This allows for indirect pre-heating of the RA/Bitumen from the heat provided by the burner. Careful management of the heating of RA/Bitumen needs to be carried out to prevent production of brittle (low quality) asphalt product *(EAPA; 2007)*.

The temperature profile of co-current and counter-current exhaust gas streams is highlighted in the following table:

Table 3: Temperature profile of co-current versus counter-current driers

Orientation	Annual water evaporated in 100tph plant (tons/yr)	Exhaust (Flue) gas temperature (°C)	Enthalpy (kJ/kg)
Co-current	5 580	170	2 770
Counter-current	5 580	115	2 690

The savings are calculated based on the enthalpy differences of the exhaust (flue) gas water vapour divided by the thermal efficiency of the drier system given reduced flue gas loss through reduced temperature of exhaust air. Exhaust air has a heat capacity of 1 kJ/kg-K. The flue gas loss in terms of total fuel energy input for co-current and counter-current operations were determined to be 5.5% and 3.3% respectively.

Carbon Reduction Measure 3: Regular Replacement of Flights

Worn out flights (which lift the aggregate in the drier to ensure maximum surface area exposure for heating) must be frequently replaced to ensure good heat transfer between drier gases and aggregate. Inefficiencies will be noticed in the flue gas temperature, and hence it is vitally important that flue gas temperature is properly monitored.

Regular, scheduled replacement of flights according to supplier recommended maintenance schedule and operational experience should be carried out (typically requiring ad hoc flight replacement with three year cycle for complete replacement). A flue gas thermocouple should be installed as a check to assist in verifying whether flights are beginning to become worn. The exit gas temperature for a drier with worn flights versus one with well-maintained flights amounts to 195°C and 140°C respectively (producing a temperature reduction of flue gas of 55°C).

Carbon Reduction Measure 4: Effective Lagging of Vessels/Pipelines

The following equipment insulation is recommended as a minimum guideline (http://oee.nrcan.gc.ca; accessed 02/05/2011):

- Bitumen Storage Tanks: 10cm thick mineral fibre (basalt/steel slag type) with aluminium cover
- Bitumen Transfer Pipelines: 5cm thick mineral fibre (basalt/steel slag type) with aluminium cover
- Drier/Mixer: 15-20cm thick mineral fibre (basalt/steel slag type) with aluminium cover. Lagging of the drier alone has been observed to realise 5-10% fuel reduction *(NAPA; 2007)*
- Asphalt Storage Tanks: 10cm thick mineral fibre (basalt/steel slag type) with aluminium cover

Insulation of all vessels and pipelines containing heated materials as per the suggestions provided above or as per supplier recommendations should be carried out. According to *NAPA (2007)* the savings from insulating surfaces containing heated materials amount to 5-10% of fuel use and taking a conservative approach the savings were estimated to be 5% (i.e. taken as an improvement to the thermal efficiency of the HFO-fired heating system).

Carbon Reduction Measure 5: Tighter Feed Air Control to Drier

The typical excess air requirement for an HFO burner is around 20% above stoichiometric requirement[2]. Higher air to fuel ratios would mean unnecessary flue gas thermal energy losses.

This measure involves checking and adjusting the combustion system air-fuel ratio on the drier burner as needed to reduce the amount of excess air passing through the drier and thus improve its combustion efficiency.

An automated control system based on O_2 or CO_2 concentration in the flue gas or a permanently installed manually read meter can be used to control the throttle or the variable speed drive on the fan to trim the exhaust. By reducing the exhaust via a variable speed drive, electricity will also be reduced. The variable speed drive will be locked at maximum speed but can be manually altered in case changes in the fuel require a different amount of oxygen.

Carbon Reduction Measure 6: Asphalt Product Storage

The design of closed asphalt storage silos could reduce the requirement for over-heating of asphalt to allow for thermal losses and would also reduce recycling of asphalt since effective heating and insulation is possible in these cases.

The thermal loss of an open vessel with 20 m^2 exposed to the atmosphere and providing hot mix asphalt (HMA) storage for three hours is used as the base case. Assuming a heat transfer co-efficient of 2.75 kWh/m^2-h and a heating efficiency to maintain the asphalt at 160°C of 85%, the thermal energy required amounts to 700 MJ. The total annual thermal energy requirement for a 2 080 hour annual operation is determined.

Carbon Reduction Measure 7: Conversion of HMA to Warm Mix Asphalt Plant

Conversion to warm mix asphalt (WMA) operation from existing hot mix asphalt (HMA) would reduce the required product output temperature from 170°C to 130°C. The required implementation measure involves retrofitting the drum plant to allow for WMA operation.

Carbon Reduction Measure 8: Burner Fuel Switch from HFO to Natural Gas

This measure assumes ready access to natural gas (i.e. nearby pipeline and availability of supply). The required implementation measure involves retrofitting the drum plant to allow for burning natural gas. The savings are not energy-based, but rather price-based savings.

Summary

The savings of suggested measures (100 tph drum plant) are highlighted in the table below.

Table 4: Summary of energy savings from proposed measures

Carbon Reduction Measure	**HFO (GJ/year)**	**CO_2 (tons/year)**
CRM1: Storing fine aggregates under roof	3 900	290
CRM2: Conversion of co-current to counter-current drum	1 700	130

[2] Air to fuel ratio at which provided oxygen exactly matches the fuel carbon to ensure complete combustion.

CRM3: Regular flight replacement	600	40
CRM4: Effective lagging of vessels/pipelines	1 900	140
CRM5: Tighter feed air control to drier	2 900	210
CRM6: Asphalt product storage	480	30
CRM7: Conversion of HMA to WMA operation	8 400	620
CRM8: Burner fuel switch from HFO to natural gas	-	820
Total	**19 880**	**2 280**

It is evident from Table 4 above that the total potential HFO savings and carbon dioxide reductions from implemented measures amount to 19 880 GJ/year and 2 280 tons CO_2/year respectively. These measures can achieve a 30% HFO energy use reduction and a corresponding 35% reduction in GHG emissions (assuming baseline plant which exhibits none of the above measures – least efficient plant).

A number of energy efficiency measures have been proposed in this paper, and a summary of the potential cost savings and required capital investment is presented in Table 5 below.

Table 5: Energy cost savings and capital investment for energy efficiency measures

Carbon Reduction Measure	**Capital Cost (R)**	**Savings (R/year)**	**PP (years)**	**PP with carbon tax (years)[3]**
CRM1: Storing fine aggregates under roof	830 000	450 000	1.9	1.6
CRM2: Co-current to counter-current drum	880 000	200 000	4.5	4.0
CRM3: Regular flight replacement	63 000	66 000	0.9	0.8
CRM4: Effective lagging of vessels/pipelines	245 000	220 000	1.1	1.0
CRM5: Tighter feed air control to drier	250 000	330 000	0.8	0.7
CRM6: Asphalt product storage	285 000	55 000	5.2	4.6
CRM7: Conversion of HMA to WMA plant	1 300 000	960 000	1.4	1.2
CRM8: Fuel switch from HFO to natural gas	400 000	190 000	2.1	1.1
Total	**4 253 000**	**2 471 000**	**1.7**	**1.5**

The key areas of implementation are presented in no order of priority, and all of these measures are recommended as being financially and technically sound. The most expensive measure is that of drier conversion to WMA, but it also represents a large portion of the savings.

The main recommendations in terms of management interventions to reduce plant energy consumption and resultant GHG emissions involve the following:

- Training of staff on reducing energy consumption, which has most relevance in terms of electricity consumption on the plant
- Control of thermocouple monitoring variables to prevent energy wastage

[3]Payback Period assuming additional savings from reducing carbon tax at R200/ton of CO_2

- Careful monitoring of particularly the flue gas temperature to monitor the efficiency of the drier in terms of heat transfer to input materials and prevention of excess fuel supply into burner
- Continuous monitoring of energy consumption to keep track of performance in this regard and to facilitate continued plant efficiency improvements (which should be communicated to staff on a regular basis)

The strategic level interventions that may be applied incorporate leveraging exemption in terms of carbon tax requirements based on size of plant operation and contribution to the sector total emissions, sourcing green electricity and making use of carbon credits to finance retrofits.

The sourcing of green electricity and carbon credits are not recommended based on the project scale defining that the use of these two mechanisms is too small for plants of the typical 100 tph size analysed in this study. Revenue from carbon credits is thus not considered practical. However the investigation of potential funding via the ESKOM Demand Side Management Energy Efficiency program and Income Tax incentives for green projects may be worthwhile.

From the perspective of the possible exemptions to the carbon tax, this is also not likely to be possible since these may only apply to actual emissions measured on site, and the carbon tax may impact asphalt producers due to environmental levies placed on electricity and fuel purchased. These levies are expected to be standardised and applied to all consumers, however this is still up for discussion since the carbon tax proposed by the Treasury has not been gazetted at this stage.

CONCLUSIONS AND RECOMMENDATIONS

This paper has provided an outline of generalised potential savings from implementing energy efficiency measures on a HMA plant, but does not represent any specific plant. Energy audits of plants would be required to define which of the outlined measures are applicable to specific operations and to optimise measures.

The total potential HFO savings and carbon dioxide reductions from implemented measures amount to 19 880 GJ/year and 2 280 tons CO_2/year respectively. These values represent a 30% HFO energy use reduction and a corresponding 35% reduction in GHG emissions (assuming baseline plant which exhibits none of the savings measures highlighted in this paper – inefficient co-current drum plant).

All of the measures reported are considered to be financially and technically sound. The most expensive measure is that of drier conversion to accommodate WMA, but also has the potential to provide the largest savings.

The strategic level interventions that may be applied incorporate leveraging exemption in terms of carbon tax requirements based on size of plant operation and contribution to the sector total emissions, sourcing green electricity and making use of carbon credits to finance retrofits. However for small operations the latter two approaches are not deemed to be practical.

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KEY WORDS
Energy efficiency measures; warm mix asphalt; carbon reduction