CARBON TRUST
Making business sense of climate change

Industrial Energy Efficiency Accelerator

Guide to the asphalt sector

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1. Executive summary

One way for industry to achieve significant CO_2 reductions is to improve energy efficiency in sector-specific manufacturing processes. The Carbon Trust has been working with a number of industry sectors, as part of its Industrial Energy Efficiency Accelerator (IEEA), to identify where savings can be made in each one. This novel approach aims to deliver quick and substantial reductions in industrial process emissions by accelerating innovation in process control and the uptake of low-carbon technologies.

The asphalt sector emitted 830,000 tonnes of CO_2 (tCO_2) in 2007 from the manufacture of 26 million tonnes (Mt) of product in 350 plants[1]. Fuel for the burners that heat and dry the aggregate is the dominant source of emissions, representing 80% of the total CO_2 produced, while electricity accounts for 20%.

The sector is dominated by five large manufacturers – Aggregate Industries, Cemex, Hanson, Lafarge and Tarmac – who together manufacture 75% of the asphalt used in the UK.

The energy performance of the sector has got worse over the last decade. In 1995, the last time an independent study was carried out in the sector, asphalt manufacture was using 108 kilowatt hours (kWh) per tonne. It is now using 112kWh/tonne.

There is a wide variety in performance between plants, with the most efficient using 70kWh/tonne and the least efficient over 150kWh/tonne.

If the entire sector was able to improve its average energy efficiency from 112kWh/tonne to 95kWh/tonne, it would result in annual savings of £16 million and 125,000tCO_2.

The Carbon Trust worked closely with the asphalt sector in 2008 and 2009 to understand energy use in the manufacturing process and to identify possible ways to improve energy efficiency.

Data collected from submetering of the asphalt manufacturing process indicates that there are opportunities for significant carbon emissions reduction from the sector. These fall into two broad themes:

- innovation in process control
- product strategy innovation.

The sector's historical performance indicates that it is unlikely to achieve significant CO_2 reductions without external assistance or stronger external drivers.

This report discusses in detail the opportunities for energy efficiency and carbon reduction, and presents data that has been gathered as evidence to justify investment in these opportunities.

[1] Mineral Products Association www.mineralproducts.org

2. Background to the Industrial Energy Efficiency Accelerator

Industry is responsible for 25% of the UK's total CO_2 emissions[2]. Experience at the Carbon Trust supports the view of the Committee on Climate Change, which indicated that savings of 4-6mtCO_2 (up to 4% of current UK emissions) should be realistically achievable in industry with appropriate interventions[2].

We believe that CO_2 savings far beyond those set in current policy targets are possible by working more directly with organisations to clarify the opportunities. The impact of policy can also be accelerated and increased if industry sectors are helped to understand their energy use and how to make significant changes in a short timeframe, rather than gradually reduce their emissions over time. What's more, direct intervention can help embed a culture of innovation and good energy management, resulting in a greater long-term impact.

Significant CO_2 reductions in industry are possible by working with those medium-sized industry sectors that are outside of the EU ETS scheme but are affected by either Climate Change Agreements (CCAs) or the Carbon Reduction Commitment (CRC) Energy Efficiency Scheme. These industries are moderately energy intensive and, in total, account for 84mtCO_2 emissions per year [3].

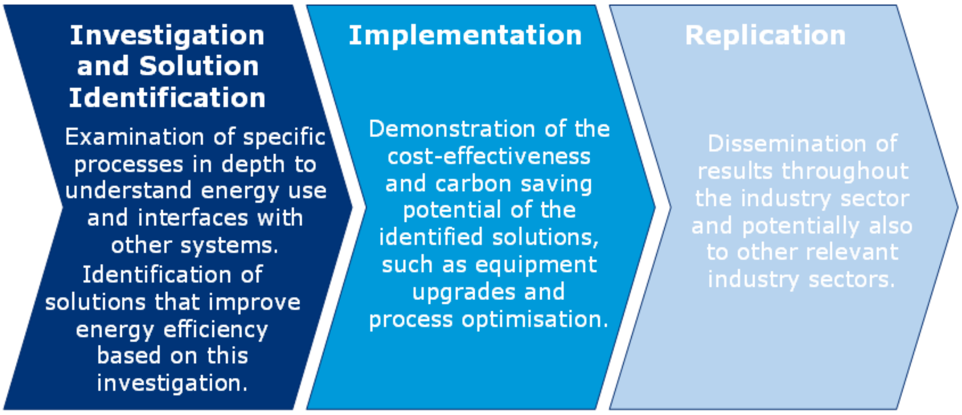
The Carbon Trust currently works with industry by supporting companies to reduce their carbon emissions. The approach is applied across a range of industries but does not offer detailed advice on sector-specific manufacturing processes. More energy intensive industries frequently cite the fact that survey recommendations do not address the bulk of their energy use as a reason for not implementing them. Between 50% and 90% of a site's energy consumption could typically be used by a sector-specific manufacturing process.

In addition, the Carbon Trust Applied Research Scheme has supported the development of a number of industry-related technologies. This scheme is offered in response to applications for support, rather than targeting specific technologies.

Recognising the challenge of reducing CO_2 emissions from industry, and the carbon reduction potential of sector-specific manufacturing processes, we looked at how we could best engage with industry to significantly increase the rate of carbon reduction beyond that delivered by carbon surveys. As a result, we developed the IEEA approach, which was launched as a pilot in 2008.

The IEEA approach focuses on identifying and addressing the reasons why opportunities to reduce emissions in industrial processes are not put into action. This is a three-stage process:

[2] Committee on Climate Change Report, December 2008.
[3] Source: DECC CRC Presentation, Westminster Energy Forum, January 2009



In 2008/09, we undertook the first stage – investigation and solution identification – with three pilot industry sectors:

- animal feed milling
- asphalt manufacture
- plastic bottle blow moulding.

This report details the results and key findings from the investigation work for the asphalt sector.

3. Background to the asphalt sector

This focus of this report is asphalt pavement used for road surfaces, and not other smaller markets such as asphalt roofing and flooring. It includes key statistics for the sector, put into a European and global context. The report also considers the business drivers for the asphalt manufacturers and their current energy performance.

What they manufacture

Asphalt is a composite material comprising aggregate (sand and graded stone) and bitumen. The aggregate provides a structural matrix for strength, grip and wear resistance, whilst the bitumen binds the materials together and makes it sufficiently workable to spread and compact as a road surface. Other additives may include pigments, pellets and bitumen modifiers. Recycled asphalt (RAP), generated from removing existing road surfaces, can also be added in place of fresh aggregate and bitumen.

Asphalt is used for the construction of roads, pathways, pavements, playgrounds and car parks. It is by far the dominant wear surface and base layer material in the UK, used to construct over 95% of the country's roads. Asphalt tends to be manufactured either close to a quarry which can supply the aggregate, or close to where the asphalt will be required – for example, near major roads and within urban areas.

There are many different types of asphalt and their specification and use are covered by the Standard BS EN 13108: 2006. There are believed to be over 500 different road grade asphalts manufactured in the UK, and the number is increasing as manufacturers continue to develop new products. In recent years, these additions include coloured, low noise, high grip and reduced spray surfaces. The technological development of road surfacing has been very rapid in the latter half of the 20th century, driven by a massive road building campaign and growth in the use of road transport.

Asphalt has the following main constituents:

Aggregates such as sand, dust and graded stone, to provide load-bearing strength, wear resistance and grip. The materials used are mainly virgin quarried materials local to the asphalt plant, although RAP can also be used.

Bitumen is added to bind the aggregate together and to give the plastic properties that make asphalt suitable for spreading and compacting. Although bitumen can occur naturally, the grades used for asphalt are manufactured from crude oil, following the distillation of lighter grades such as petroleum and fuel oils. The bitumen content of asphalt varies according to the grade, but is typically between 4.5% and 5.5% by weight. Bitumen itself comes in different grades (a measure of stiffness), and adding polymers or fuel oils gives it additional adhesive properties or lowers the temperature range over which it can be used.

RAP consists of old road surface that has been removed to enable the new one to be laid. It can be added directly into the asphalt mixing process while still cold and wet (possible for quantities up to 30%) or at higher amounts by preheating it in a special flameless dryer. RAP is not always added, but its use is increasing – some modern plants are designed to utilise 90% RAP in their asphalt. Its incorporation solves a waste disposal issue and also reduces the requirement for virgin aggregate and bitumen. However, the carbon consequences of its use have still to be fully studied.

Additives such as fibres, pellets and pigments may be added to impart colour, improve binding characteristics or enhance its properties.

How they manufacture

Most asphalt manufactured in the UK is made by heating and drying a mixture of aggregate materials of various sizes in a dryer. The hot aggregate is mixed with hot bitumen, at which stage other components, such as recycled asphalt (RAP), dust and fibres, may be added. The resulting asphalt is conveyed to insulated storage bins for dispatch, or, in small plants, may be dispatched directly into a truck.

There are three different types of manufacturing plant for hot mix asphalt used in the UK:

i) **Batch heating plants:**

A precise mixture of graded aggregate is weighed and conveyed to a batch heater. After a heating and drying cycle, the hot aggregate is discharged into a mixer, where bitumen and any other required additives are added. The prepared asphalt is conveyed into a hot store ready for dispatch or loaded directly to a vehicle. These plants are well suited to the supply of local markets, which require small quantities of a wide variety of products.

ii) **Drum mix plant:**

In this continuous plant, an accurately weighed aggregate recipe is fed into a heated rotating drum. After heating and drying, the hot aggregate moves into the mixing section of the drum, where bitumen and RAP are added.

These types of plant are best suited to continuous operation with high throughputs in the range of 300-600t/hour. They are not good at coping with product changes or intermittent demand.

The intermittent nature of the demand from road building has not encouraged this type of technology in the UK – about half a dozen such plants exist, but it seems unlikely that many will be purchased in the near future.

iii) **Batch mixer plant (semi-continuous plant):**

This is the most common type of plant employed in the UK. Aggregate materials are conveyed into a rotary dryer for heating and drying, then discharged through screens into graded hot storage bins.

From these bins, a precisely weighed recipe of hot aggregate is conveyed to a mixer where bitumen, RAP and additives are added. The mixed asphalt is stored in hot silo ready for dispatch or, in some smaller plants, directly onto a vehicle. A schematic diagram of a batch mixer plant is shown in Figure 1 below.

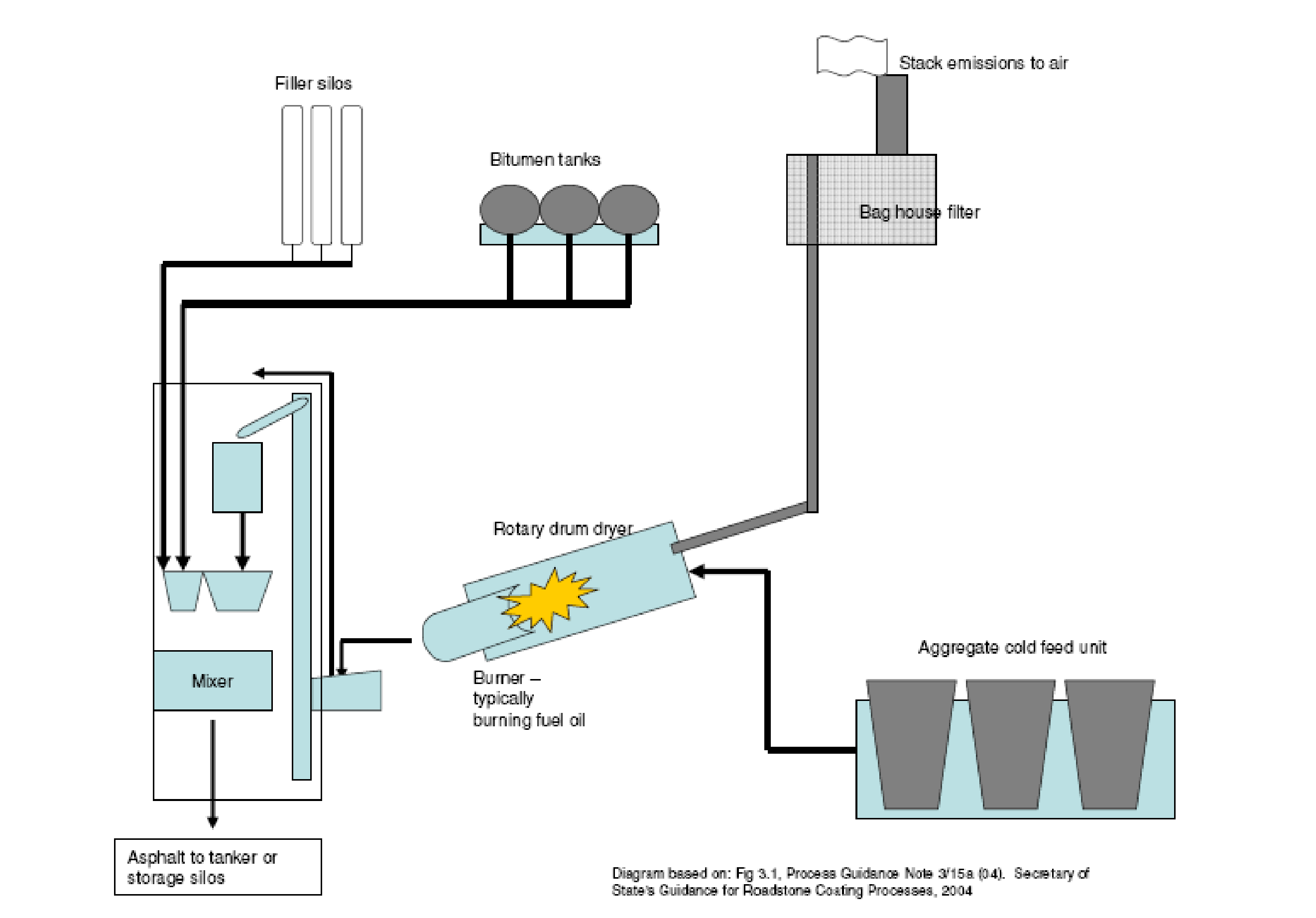


Figure 1:	**Batch mixer asphalt manufacturing process (semi-continuous plant)**

The majority of asphalt manufactured in the UK is **hot mix**, typically mixed at around 170^{o}C to enable the surface to be paved at around 150^{o}C. There are processes – known as warm mixing and cold mixing – that can reduce the temperature at which road paving, and therefore mixing, take place, but they currently represent a very small part of the UK market.

Warm mix asphalt uses bitumen that has been modified to enable it to remain workable at lower temperatures. For instance, additives such as zeolites lubricate the aggregate through the release of water during paving or water injection, and create a foamed bitumen in which bubbles of steam keep it workable. These technologies can lower mixing temperatures, typically down to between 90^{o}C and 130^{o}C. Although the bitumen and/or additives add cost to the manufacturing process, the ability to pave roads at lower temperatures reduces the fuel requirement and therefore the carbon emissions. Warm mix products can be manufactured with the same technology as hot mix, and so most current plants can make a form of warm mix material.

Cold mix asphalt uses cold aggregate and/or RAP mixed with a bitumen emulsion (foam bitumen) and cementitious material. The technique, like some types of warm mix, involves injecting steam or water into bitumen. This increases its surface area and reduces its stiffness, allowing it to mix at a lower temperature.

One asphalt manufacturer offers a product comprising 2% cement, 3% bitumen and 10% pulverised fuel ash and RAP, with the balance being virgin aggregate that has not been dried or heated. They claim a reduction in fuel consumption from nine litres per tonne to one litre per tonne since the aggregate is no longer required to be heated (heating the aggregate represents the bulk of the energy requirement in the manufacturing process). Some of the carbon saving would need to be offset by the embedded CO_2 in the cement (which has a footprint of around 800kgCO_2/tonne, whereas that of hot mix asphalt is 32kgCO_2/tonne). Cold mix materials are manufactured in different plants to hot and warm mix; these can be static plants with material transported by trucks or mobile plants at the point of use.

Asphalt manufacturers and other key stakeholders

There are five large manufacturers of asphalt in the UK, all of them multinational organisations with mineral and building material operations throughout the world. Together these five manufacturers produce over 75% of the asphalt used in the UK.

These companies are:

- Aggregate Industries (part of the Holcim Group)
- Cemex
- Lafarge
- Hanson (part of Heidelberg)
- Tarmac (part of Anglo American).

There are also several medium-sized producers and a large number of much smaller manufacturers.

The interests of the asphalt sector are represented by a number of industry bodies:

- **Mineral Products Association**: the main trade body for the aggregate sector, it has a separate committee for asphalt products as well as an environmental committee.
- **British Aggregate Association**: the body representing independent (smaller) quarry operators, some of whom have asphalt operations.
- **Refined Bitumen Association**: the body representing the bitumen supply industry in the UK, which is dominated by Total, Shell, Nynas, ExxonMobil and Petroplus.
- **Asphalt Industry Alliance**: the alliance between the Mineral Products Association and the Refined Bitumen Association to promote knowledge and best practice within the sector.

Asphalt plants tend to be purchased as a complete plant through these turnkey suppliers. Plants have a life expectancy of over 30 years. With 350 plants in the UK, this gives a renewal rate of roughly 10 per year.

Barriers and drivers to carbon reduction

The market

The UK's Road Building and Maintenance programme is clearly the most important factor in determining the size of the market. As a mature economy, the UK has a well-developed road network, so the number of new roads being built is relatively low. Resurfacing work makes up the main part of the market.

Road surfacing is planned so as to be carried out as quickly as possible and with the least disruption to traffic. This means that road paving on major roads is increasingly carried out overnight, when traffic volumes are low. A large amount of asphalt is thus required in a short space of time.

The high price of bitumen will continue to put pressure on the market price of asphalt, but it will also drive manufacturers and specifiers to minimise material costs. Asphalt manufacturers may look for ways of reducing the amount of bitumen they use in their mixes; incorporating RAP is a way of achieving this as the bitumen is recycled as well as the aggregate. Specifying thinner road surfaces is also a way of using less material per mile of road.

A large number of product types are in demand, so suppliers have to maintain the capability to manufacture a large number of recipes and switch quickly from one product to another. This inevitably leads to a waste of product and energy.

Asphalt manufacturers continue to develop new surface materials that are quieter, more durable, drain well and have higher grip, to differentiate their product in a competitive market. This further increases the number of recipes that asphalt sites are required to make.

There needs to be a balance between the market demand for roads that last a long time and don't deform under heavy axle weights and the requirement for low-cost and sustainable (typically high RAP content) asphalts.

Technology

The major equipment suppliers improve their plant and machinery over time and compete on the basis of quality and performance as well as price. But the pace of technological change remains slow (a common feature of basic industrial processes). The major sources of innovation are:

- bitumen development
- process development for warm and cold mixing
- the incorporation of high levels of RAP.

There are also significant technological developments in road paving, as new machines enable road surfaces to be removed, recycled and repaved in one integrated operation.

The sector is a large user of waste-derived fuel oils. As the asphalt product is relatively insensitive to the quality of fuel being burnt, it represents a process where waste fuels can be burnt, and the ability to buy, store and use different grades of waste oil is likely to become more important.

Asphalt manufacture does not lend itself very well to the use of combined heat and power (CHP), as manufacturing plants are not generally in use for enough hours every week (typical operation is for eight hours a day).

Regulations

Planning permission is an issue in the development of asphalt manufacturing plants. Many are designed to be as discrete as possible, often at the expense of energy efficiency. For example, the most energy efficient design for a plant is thought to be one that is vertically integrated, i.e. with all the process steps sequentially arranged beneath one another. This minimises heat loss and the electricity required for transporting material. But plants designed in this way are often refused planning permission due to their height and the negative visual impact this has.

The CRC is the most important new carbon legislation that will affect the sector. The sector is currently working on issues including eligibility criteria, metering and reporting requirements, along with forecasting and trading, which will act as new drivers for carbon reduction.

Energy and carbon reduction

The three main drivers for energy reduction in asphalt manufacture are cost, regulation and the environment, of which the most significant is cost.

Figure 2 shows the estimated material cost per tonne of asphalt. This illustrates why the sector has previously focused on reducing virgin aggregate and bitumen use, for example by increasing the use of RAP, rather than on energy consumption.

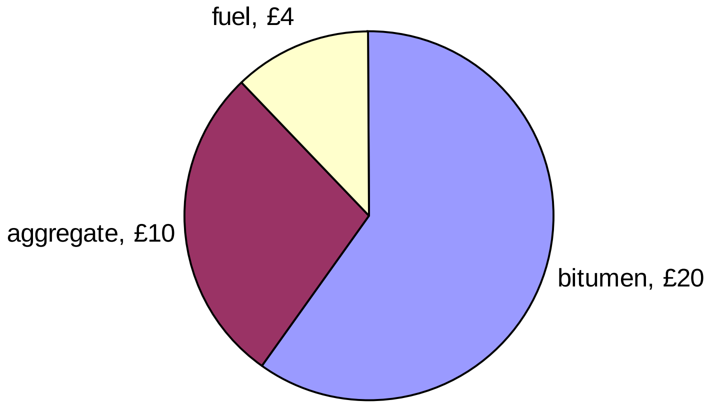


Figure 2: Estimated material cost per tonne for asphalt

4. Key findings

The dominant energy source, in terms of consumption, cost and carbon emissions, is the fuel for the asphalt burner (Figure 5), which can be a liquid or gaseous fuel. Whereas electricity is consumed in a wide variety of equipment, such as motors, compressors, trace heating, office power and lighting, the liquid and gaseous fuels are used almost exclusively in a single piece of equipment – the dryer burner. The thermal energy of an asphalt plant thus represents the largest opportunity for carbon and cost savings, and this report focuses on that opportunity.

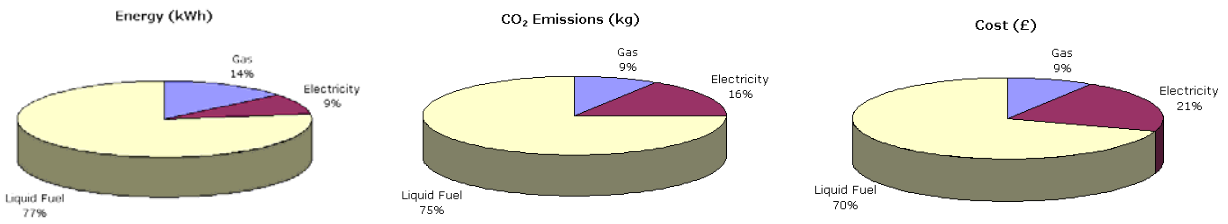


Figure 5 Key fuel data, 2007

Heat balance

Calculating the heat balance for an asphalt plant indicates where the thermal energy is going in the manufacturing process, and so highlights opportunities for energy saving. The simplified heat balance for an asphalt plant is shown in the following table:

	Thermal energy (kW)			Average (%)
	Plant 1	Plant 2	Plant 3	
Heat supplied to asphalt plant				
Heat supplied to burner	9,184	7,749	9,430	100
Heat lost from asphalt plant				
Hot air lost in exhaust	1,129	933	1,016	12
Heating aggregate	3,867	3,300	5,467	48
Evaporating moisture	3,261	2,600	2,723	33
Structural loss from plant	44	44	109	1
Partially burnt fuel (carbon monoxide) (CO)	40	28	295	1
Unmeasured loss	843	844	-180	5
TOTAL	**9,184**	**7,749**	**9,430**	**100**

The majority of the thermal energy is used to heat the aggregate. This suggests that asphalt recipes that do not require being heated to high temperatures will use significantly less energy to produce.

The next most significant consumer of energy is the process of drying out the aggregate. Again, asphalt recipes that do not require dry aggregate (such as cold mix) will use significantly less energy. However, energy consumption can also be lowered by reducing the moisture content of the incoming aggregate, whatever the mix. Well-drained aggregates and sand can have a moisture content of 3% or below, but in very wet conditions the moisture content could be as high as 8%. In the examples in the table above, the average moisture of the aggregates was 3.7%.

Structural losses from the plant are relatively low. Provided the dryer's insulation is maintained in good condition, there is little to be gained by improving it.

Twelve per cent of the heat supplied is lost through the stack as hot air (this excludes the latent heat of the water vapour from the aggregate). Some of this heat could be recovered, although its low temperature could limit the extent it can be reused in the process itself. Reducing the air flow through the system will also lower heat loss.

Optimising the burner controls could minimise the energy lost as unburnt fuel. When heavier oils are used and burners are modulated according to the system load, some combustion inefficiencies are inevitable. However, the CO levels recorded on some sites were excessive.

Thermal modelling

Sensitivity analysis on the main production variables was undertaken using a simple thermal model of an asphalt drum heater. This has highlighted the key production parameters that affect energy efficiency:

	Energy saving per tonne of product		
	kWh	$kgCO_2$	£
2% change in moisture content	8.7	2.25	0.52
10°C change in stone exit temperature	2.8	0.72	0.08
10°C change in flue gas temperature	1.7	0.43	0.05
100% change in excess air	1.5	0.39	0.04

If an asphalt plant is thermally efficient (that is, it is well insulated and has little or no unburned fuel from combustion), then the biggest influence on energy use is the moisture content of the incoming aggregate. A 2% improvement in incoming moisture content, implemented throughout the asphalt sector, would save 58,000tCO_2 and £13 million per year in fuel.

5. Opportunities

In line with the findings in section 4, the significant opportunities for reducing energy and CO_2 emissions for the asphalt sites relate to the asphalt burner. These opportunities fall into two broad themes of innovation in process control and product strategy innovation.

Innovation in process control

Stockpile dewatering

There is a significant opportunity to reduce energy consumption from dewatering aggregate feedstock, before drying in the asphalt burner, by mechanical dewatering or by covering stockpiles. The priority grades of aggregate should be sand, dust and RAP.

This opportunity can be applied to about half of the UK's asphalt sites. At this level, it could lead to savings for the sector of about 58,000tCO_2/year.

Cost

The estimated cost to implement this opportunity is between £50,000 and £250,000 per site, depending on the extent to which changes are required to the site layout, with a payback of less than a year.

Barriers

The barriers to implementation are the cost of the mechanical dewatering equipment or the covering for the stockpiles. A site may also need to undergo significant upheaval and rearrangement to allow for stockpile dewatering.

Air:gas ratio control

Using an advanced burner control system (incorporating oxygen measurement for a programmable air:fuel ratio control and micro-processor control of oil and gas flows) could reduce energy that is currently wasted through inefficiency.

This opportunity can be applied to more than three-quarters of the UK's asphalt sites. At this level, it could lead to savings for the sector of about 25,000tCO_2/year.

Cost

The estimated cost to implement this opportunity is £25,000 per site. The payback period is expected to be three to five years, depending on the size of the site. At larger sites the payback may be two to three years.

Barriers

The main barrier to implementation is the lack of a strong burner maintenance supply chain. Burner reliability is crucial to asphalt production and sites are reluctant to make changes to the kit without solid assurances that things either will not go wrong, or that they have the people to put it right quickly and efficiently.

Computational fluid dynamics and finite element analysis of drying process

Using advanced computational fluid dynamics (CFD) and finite element analysis to model the drying process in the asphalt burner will provide insights into the heating process. These may help improve the design of dryers and optimise methods of operation, which could, in turn, significantly reduce energy consumption.

Assuming around half of asphalt manufacturing sites are able to take advantage of improved burner technology as a result, this could lead to annual savings of 16,500tCO_2.

Cost

pproximately £200,000, but the results could be shared across the whole sector, including burner suppliers.

Barriers

The major barrier is the lack of communication between the asphalt manufacturing industry and the burner manufacturers. Historically, asphalt plant operators have purchased equipment based only on price, which means there has been no incentive for burner manufacturers to develop new technologies. Until the demand is there, they will remain reluctant to do so.

Heat recovery for preheating combustion air

A retrofit heat recovery system, to preheat combustion air for the asphalt burner, can help use significant less energy. The benefits of heat recovery have been demonstrated in many other sectors, but not in the asphalt sector, and there is no established supply chain. Concerns include the effectiveness of a heat exchanger at the low temperatures in the exhaust, the longevity of the materials and the impact of using warmer air in the burner.

A penetration of heat recovery on 75% of asphalt manufacturing sites could lead to sector energy savings of around 34,000tCO_2 per year.

Cost

The estimated cost to implement heat recovery would be £100,000 per site. The expected payback period is around three to five years, depending on the size of the site. At larger sites the payback may be in the region of two to three years.

Barriers

The main barrier to implementation is the engineering needed on each site to allow the solution to be retrofitted – expertise that asphalt manufacturing companies may not currently have in-house.

Accredited training

Training is vital to achieve and sustain energy savings in the asphalt manufacturing sector. General courses in asphalt technology are available on a distance learning basis. Some companies in the industry are developing their own training.

Carbon Trust input to a sector-wide training course – focusing particularly on knowledge gaps such as heating and burners – could help to improve awareness and knowledge of energy management knowledge in the sector.

At least a 50% penetration of the sector would be possible, leading to savings of approximately 16,500tCO_2 per year.

Cost

It would cost about £5,000 per site to implement training across the sector – though the more companies that participate, the greater the economies of scale.

Barriers

There are few barriers to implementing training as all companies are willing to participate. The challenge is getting these companies to collaborate in the development of a suitable programme.

Product strategy innovation

Rationalising asphalt product specifications

The sector believes that the large number of asphalt products in the UK, in comparison with countries such as the US, is the cause of a significant amount of waste. Five to ten per cent of energy use is attributed to clean-outs between the manufacture of different asphalt specifications. Rationalising products would reduce this significantly.

The main cause of the large number of products appears to be that each local authority has their preferred asphalt recipe. It should be possible to identify a small core list of products that suit the needs of all customers in the UK.

However, asphalt manufacturers are also constantly developing new products to gain competitive advantage.

There are three options for changing the behaviour of specifiers:

- Asphalt manufactures agree to restrict choice.
- Government legislates to restrict choice.
- Specifiers are persuaded to use a restricted low carbon list of products.

The first two are very unlikely to happen. The third is the only practical option, but it will be difficult to achieve. Nevertheless, attempts should be made by the industry to work through the Local Government Association in order to influence specifiers to consider the carbon impact of their choice of material.

Realistically, at least 16,500tCO_2 per year could be saved by the sector with almost immediate effect.

Cost

Rationalising asphalt product specifications will cost very little, and therefore give an immediate payback.

Barriers

The main barrier to implementing change in the number of different product specifications is local authorities' tendency to avoid risk. The cost of replacing or repairing road surfacing that did not meet durability requirements would be significant, and specifiers tend to be extremely conservative.

Warm or cold mixing of asphalt

Substantial energy reduction is possible by mixing asphalt at reduced temperatures (warm or cold mixing). Some asphalt companies can already produce warm or cold mix products, but the volumes in demand are very low. This is due to not only the lack of information regarding the products but also the conservative nature of local authorities, the Highways Agency and the various specifiers of road surfacing.

At least 20% of asphalt manufacturing volume could be switched to lower temperature mixes, saving at least 14,500tCO_2 per year.

Cost

The cost to switch to warm or cold mix products is low, both for asphalt manufacturers and local authorities. Minimal technology changes are needed on asphalt manufacturing sites. However, building the case for wider adoption of these products involves robust testing and demonstration of their performance.

Barriers

One of the main barriers to introduction of lower temperature mixed asphalts is that the industry does not speak with one voice. Producing an evidence base for local authorities is too expensive for any one company on its own. Asphalt manufacturers also do not have the cross-agency relationships needed to create significant change in the sector.

Innovative equipment

While opportunities relating to the application of innovative equipment in the asphalt manufacturing sector were assessed, they were considered to be either too difficult to implement, or not worthwhile because they wouldn't deliver sufficient carbon savings.

No	Opportunity summary	Cost per plant	Payback period	Sector saving (tCO_2)	Readiness	Barriers
1	**Moisture content reduction** of incoming feed stocks to reduce the thermal requirement for drying by managed stockpiles, covered stockpiles and mechanical (pumped) drainage.	£50,000 to £250,000	<1 year	58,000	Proven	Infrastructure changes; lack of case study on mechanical drainage.
2	**Air:fuel ratio control** of asphalt burner through oxygen measurement and the use a programmable micro-processor (digital) control system.	£25,000	3-5 years	25,000	Demonstration phase	Robustness of technology; lack of knowledge amongst operators and managers.
3	**CFD and finite element analysis for dryer design** (mass flow patterns, lifter design, temperature profile and control system). The findings should lead to an improved dryer design and control system.	£200,000	Rapid across sector	16,500	R&D required	Complexity of mixes used; lack of interest by equipment manufacturers.
4	**Preheating combustion** air using heat in the exhaust stack.	£100,000	3-5 years	20,000	Demonstration phase	Maintenance and longevity; worries about visual steam plume.
5	**Reduction in number of product recipes** to reduce waste at product changeover.	0	Immediate	16,500	Demonstration phase	Will take a long time; politically difficult; savings not guaranteed.
6	**Warm mixing of asphalt** in conventional plants.	Low	< 1 year	14,500	Demonstration phase	Difficult to access all local authorities; sector has mixed opinions on the merits of warm mix.
7	**Accredited training course** in process heating and engineering of operators and plant managers.	5,000	<1 year	16,500	Demonstration phase	Cost of development; presence of existing courses; companies like to do their own training.
8	**Improve the grading of supplied raw materials** to reduce the amount of over spill from the hot bins and from clean-outs between products.	£10,000 to £50,000	Unknown	800	Demonstration phase	Poor payback.
9	**Continuous CO monitoring** of flue gases to avoid partial combustion of fuel.	£20,000	Unknown	3,300	Demonstration phase	High cost; difficult to incorporate into control system.
10	**Substituting biomass fuels for oil-based fuels** for dryers, either direct fired or by gasification.	£200,000	Unknown	66,600	Demonstration phase	Fuel supply uncertain; advantage is CO_2 reduction rather than fuel/cost saving; technology not proven in the sector; short operating hours lengthens payback.
11	**'In dryer' temperature monitoring** (in addition to exit temperature control) to add predictive control to the burner	£10,000	Unknown	6,700	Demonstration phase	Lack of knowledge of how to interpret information; may require upgrade of control system.

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No	Opportunity summary	Cost per plant	Payback period	Sector saving (tCO_2)	Readiness	Barriers
	and avoid overheating stone.					
12	**Re-circulation** of hot air back into the process.	£50,000	Unknown	20,000	R&D (far)	Increased risk of condensation.
13	**Continuous level sensors** in hot storage bins to avoid overfilling and waste.	£10,000	Unknown	2,500	Proven	Uncertainty on benefit; accuracy and life expectancy of sensor.
14	**Cold mixing of asphalt** in new plants (incorporating RAP).	n/a	< 1 year	100,000	Demonstration phase	Needs further study to determine savings and market potential.
15	**M&T** for performance management of plants. Incorporation of energy performance data within the plant control system.	£20,000	Unknown	6,600	Proven	Not all systems can accommodate the change; lack of fuel metering.
16	**Scheduling tool** to help plant operators optimise the day's production plan.	£5,000	Unknown	2,000	R&D required	Difficult to automate; many 'partial' systems already in place.
17	**Increase capacity and insulation of hot stone storage** for batch mixer plant to enable hot stone to be kept overnight, eliminating end of shift cleanouts.	>£200,000	Unknown	4,100	Demonstration phase	High cost; uncertainty over savings.
18	**Alternative drying methods** e.g. fluidised bed, moving grate/bed, microwave.	>£500,000	Unknown	-	R&D required	Needs R&D programme.
19	**Best practice insulation guide** for hot parts, such as the dryer, elevator, hot bins and asphalt storage. The savings are electric and thermal – *also see opportunity 28*.	£50,000	Unknown	3,200	Proven	Savings dependent on workmanship.
20	**Housing of plant in enclosed structure.**	n/a	Unknown	500	Proven	Only practical for a new plant.
21	**RAP addition** (up to 30% to existing process and above 30% to modified processes).	n/a	Unknown	?	Proven	The impact on SEC of RAP addition in conventional plants has yet to be established. The crucial point is likely to be its moisture content, typical values quoted are 5-7% which means the same thermal input is required as virgin aggregate.
22	**CHP** plant for on-site electricity with heat used for drying. May require gas turbine to ensure high exhaust temperatures for drying.	-	Unknown	-	Demonstration phase	The relatively short operating hours of asphalt plants means that paybacks will be longer.

No	Opportunity summary	Cost per plant	Payback period	Sector saving (tCO_2)	Readiness	Barriers
23	**Electrical efficiency** measures such as compressed air optimisation; procurement of energy efficient motors; maintenance of conveyors and screens to maintain optimum throughput; automated start-up and switch off sequence.	Not Assessed	Unknown		Proven	All well known and understood.

Other opportunities		
24	**Increased process control and automation** using increased local monitoring and an integrated distributed control system.	More relevant to quarries.
25	**Co-operation between manufacturers, paving contractors and highways agencies** to enable more plants to run longer hours. This will enable capital investment to be concentrated on fewer plants and reduce payback times. There will be a fuel and electricity saving.	Feasible study required; intensity of competition.
26	**Fuel specification standards** for emerging waste derived fuels.	Difficult to achieve; without it SECs may go up as fuels become more difficult to burn; uncertainty on fuels.
27	**Connect an auto switch-off valve** to the exit of the air receiver to turn it off when the mixer is off.	
28	**Heat fuel oil prior to burner,** either in heat exchanger, run around coil or on the outside of the skimmer.	
29	**Integrated planer, mixer and paving machine** for turning old roads into new (Marini Voyager Road Recycling Train, can be hot (140°C) or cold mix with cementitious material to take up the water).	
30	**Heat combustion air in bag filter dust hopper.**	Insufficient heat to be effective.

6. Next steps

Next steps for the asphalt sector

Operational staff in the asphalt sector need to be more aware of the scale of the cost and carbon-saving opportunities that energy efficiency presents.

Companies in the sector need to do more to engage staff and create a culture where accepted practices are challenged.

Collaboration as a sector (for example, energy management training or rationalisation of product specifications) would speed up implementation.

Asphalt companies could try to empower their trade association, the Mineral Products Association, to facilitate and push forward energy reduction initiatives.

Submetering of the manufacturing process at all sites is recommended. This would provide the information for more efficient day-to-day operation of the process, as well as providing the evidence for justifying investment in more significant energy saving opportunities.

Working more closely with customers, in particular local authorities, to try and influence their purchasing decisions, would bring significant energy saving and financial benefits. Managers of asphalt companies are starting to think strategically about the impact of the low carbon economy and how to position their business to take advantage of it.

Industry players of all sizes can take advantage of the available support and financial incentives to help them reduce energy and carbon emissions now, for example, through the Carbon Trust.

7. Appendix – methodology

The purpose of the work undertaken in stage 1 of the IEEA with the asphalt sector was:

- to examine the sector-specific manufacturing process in depth
- to understand energy use and interfaces with other systems
- to identify possible solutions that improve energy efficiency based on this investigation.

Three pilot sites were selected from the sector as representative sites, from which a more detailed and accurate understanding of energy consumption in an asphalt plant can be gained.

Company	Site	Plant Type	Fuel	Output	Existing metering
Aggregate Industries	Newark	Semi-continuous batch – Satellite	Kerosene	50 tonnes/hour	Oil flow meter. Half hourly electricity meter for site.
Hanson	Penderyn	Semi-continuous batch – on quarry	Gasoil substitute	240 tonnes/hour	Oil calculated from deliveries. Half hourly electricity meter for site.
Tarmac	Stancombe	Semi-continuous batch – on quarry	Clean fuel oil	240 tonnes/hour	Oil calculated from deliveries. No half hourly electricity meter for site.

The methodology used in this study included:

- an initial information gathering phase to build relationships and understand the process and sector
- desk-based research into equipment and innovation
- analysis of historic process and energy data and new submetered data to identify sub-optimal performance and quantify energy efficiency opportunities
- site visits and discussions with key industry contacts and site personnel
- workshops with equipment suppliers and asphalt companies
- workshops with operational and commercial representatives in asphalt companies, to discuss barriers to implementation.

A vital part of the work was communication with the sector to:

- guide the project's direction and keep it relevant to the sector
- install metering and monitoring equipment
- provide historical data on technologies, production rates and energy consumption
- assist the consultation with equipment manufacturers
- provide innovative ideas for energy efficiency
- assess ideas so that recommendations could be made for phase 2 projects.

Comprehensive submetering of the asphalt manufacturing process was installed on the three sites as follows:

Oil flow meter

Oxygen analyser

kWh meter

Moisture measurement in stockpiles

Data logger

Figure 3: Newark Express Plant

Figure 4: Oil meter totaliser

This was combined with production data and process operating conditions to analyse patterns and trends in energy use.

8. Acknowledgements

This report has been produced by the Carbon Trust with support from Enviros Consulting Ltd, the Mineral Products Association, Aggregate Industries, Cemex, Hanson, Lafarge and Tarmac.

The Carbon Trust receives funding from Government including the Department of Energy and Climate Change, the Department for Transport, the Scottish Government, the Welsh Assembly Government and Invest Northern Ireland.

The Carbon Trust is a company limited by guarantee and registered in England and Wales under Company number 4190230 with its Registered Office at: 6th Floor, 5 New Street Square, London, EC4A 3BF.

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