Industrial Energy Efficiency Accelerator

Guide to the industrial bakery sector
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1. Executive summary

At the Carbon Trust, we believe that it’s possible for industry to significantly reduce its CO₂ emissions by improving the efficiency of sector-specific manufacturing processes. Through our Industrial Energy Efficiency Accelerator (IEEA) we have therefore been working with a number of sectors to deliver a step change reduction in industrial process emissions. We aim to accelerate both innovation in process control and the uptake of low carbon technologies.

Each year, the UK industrial bakery sector produces approximately 2.5 million tonnes (mt) of baked goods, mainly bread, across some 89 sites.¹ To do so, requires energy consumption of some 2,000 gigawatt hours (GWh), which equates to emissions of approximately 570,000 tonnes of CO₂ (tCO₂) per year.

The Carbon Trust has been working closely with the industrial bakery sector in 2009 and 2010 to understand the energy use in the bread manufacturing process and then to identify opportunities capable of making a step change in energy efficiency.

In an industrial bakery the prover, oven, cooler and associated steam boiler plant typically account for between 50% and 60% of the total carbon emissions, with the oven using the most energy.

We focused on the operation of the prover, oven and cooler processes common to all bakeries, when identifying opportunities to improve energy efficiency. The energy saving potential of other major uses, such as compressed air, boilers and space heating, is well understood and generally available.

In addition to our monitoring programme, we worked closely with the sector to develop a list of opportunities for carbon reduction.

The overall maximum carbon saving potential for the sector through good practice and future innovation is estimated to be 26.5% or 151,000tCO₂ per year. The good practice element of this, which includes well-documented efficiency measures that can be implemented without Carbon Trust funding, can deliver around 10% carbon savings (57,000tCO₂ per year). Other more innovative opportunities offer the remaining carbon saving potential identified (94,000tCO₂ per annum). The level of carbon savings that are actually achieved will depend on how many measures the sector implements.

Innovative opportunities for significant carbon emissions reduction applicable across the sector fall into four broad concepts:

1) Improve oven combustion efficiency
2) Reduce thermal mass of baking tins
3) Improve control of oven and cooler electrical equipment
4) Recover oven heat.

¹ Data supplied by the Food and Drink Federation for the year to September 2008
The potential carbon and financial benefits from implementing these opportunities at the 89 sites that make up the sector are summarised below:

<table>
<thead>
<tr>
<th></th>
<th>Improve combustion efficiency of ovens</th>
<th>Reduce thermal mass of baking tins</th>
<th>Integrated electrical control</th>
<th>Heat recovery from ovens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated project payback for each site (years)</td>
<td>3</td>
<td>-</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>Average CO₂ saving – site level (tCO₂/year)</td>
<td>196</td>
<td>70 – 115</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>Percentage of sites the technology can be applied</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Maximum CO₂ saving (tCO₂/yr) – assumes maximum take-up</td>
<td>17,466</td>
<td>6,164</td>
<td>5,761</td>
<td>4,935</td>
</tr>
<tr>
<td>Market penetration over 10 years</td>
<td>50%</td>
<td>50%</td>
<td>75%</td>
<td>30%</td>
</tr>
</tbody>
</table>

This guide discusses in detail the opportunities for energy efficiency and carbon reduction in the bakery sector. It also presents the data gathered as evidence to justify investment in these opportunities.

The Carbon Trust has a key role to play in helping to accelerate the new technologies and market conditions that will deliver them.
2. Background to Industrial Energy Efficiency Accelerator

The IEEA aims to deliver a step change reduction in industrial process emissions by accelerating innovation in process control and the uptake of low carbon technologies.

Industry is responsible for 25% of the UK’s total CO₂ emissions. The Carbon Trust’s experience supports the view of the Committee on Climate Change, which indicated that savings of 4-6mtCO₂ (up to 4% of current emissions) should be realistically achievable in industry with appropriate interventions².

We believe that by demonstrating the available opportunities to organisations, far greater savings than the current policy targets are possible. It’s also possible to accelerate and increase the impact of policy by helping industry sectors to understand their energy use. In this way we can achieve a step change reduction in emissions, rather than having an incremental effect. Direct intervention can also help embed a culture of innovation and good energy management, resulting in a long-term impact.

We believe we can significantly reduce industry emissions by working with a range of medium-scale industry sectors that are outside the EU Emissions Trading Scheme (EU ETS) but are impacted by either Climate Change Agreements (CCAs) or the Carbon Reduction Commitment Energy Efficiency Scheme (CRC). These industries are moderately energy intensive and, in total, account for 84MtCO₂ emissions per year.

The Carbon Trust’s existing approach to working with industry is through our Advice activities, supporting companies to reduce their carbon emissions. This is applied across a range of industries but is not able to look in-depth at sector-specific manufacturing processes. More energy-intensive industries frequently cite as a reason for not implementing survey recommendations, that they do not address the majority of their energy use. Between 50% and 90% of a site’s energy consumption could typically be used by a sector-specific manufacturing process.

In addition, Carbon Trust Applied Research scheme has supported the development of a number of industry-related technologies. This scheme works in response to applications for support, rather than proactively looking for high-opportunity technologies in development. The IEEA will complement and extend the existing advice by including support for industries to tackle the significant emissions from sector-specific processes.

Recognising the challenge of reducing CO₂ emissions from industry, and the potential impact of targeting sector-specific processes, we investigated how we could best engage with industry to deliver significant increases in carbon reduction, beyond those delivered by existing Carbon Trust services. In 2008 the Carbon Trust launched the IEEA.

² Committee on Climate Change Report, December 2008
The IEEA approach focuses on identifying and addressing the barriers preventing industries from improving the efficiency of their processes. There are three stages to the approach:

- **Investigation and Solution Identification**: Examination of specific processes in depth to understand energy use and interfaces with other systems. Identification of solutions that improve energy efficiency based on this investigation.
- **Implementation**: Demonstration of the cost-effectiveness and carbon saving potential of the identified solutions, such as equipment upgrades and process optimisation.
- **Replication**: Dissemination of results throughout the industry sector and potentially also to other relevant industry sectors.

In 2008/2009 we undertook the investigation and solution identification stage with three pilot industry sectors: animal feed milling, asphalt manufacture and plastic bottle blow moulding. This led to six stage 2 implementation projects which we supported in 2010.

A further three sectors were commissioned for investigation and solution identification in 2009/10: dairy, confectionery and bakery.
3. Background to the industrial bakery sector

This section offers a brief description of the industrial bakery sector in the UK, describing the bread baking process as used through the sector. We have included key energy performance statistics and discuss the key technological changes that have already been introduced in the sector. We conclude with the business drivers for industrial bakeries and we identify suppliers of bakery equipment.

What they manufacture

Baking within the food sector covers a wide range of products, e.g. bread, morning goods, biscuits and pies. Bakery production can be split into three main categories:

- large industrial bakeries – those producing large volumes of product
- in-store supermarket bakeries – sized to meet the store demands
- master or kraft bakeries – these include small-scale producers and high street bakers.

The Carbon Trust and the Food and Drink Federation (FDF) identified the bakery sector as an ideal focus for the IEEA programme, as sites are energy-intensive operations and a major source of carbon emissions.

Based on information made available by the FDF the carbon emissions from energy use for industrial bakeries in the UK are estimated to be around 570,000tCO₂/year. The output of the sector is 2.5mt of baked goods each year of which bread is the major product. There are approximately 89 large industrial bakeries in the UK.

Thus bread-making industrial bakeries were selected for the detailed investigations.

The main constituents (by weight) for bread production are flour and water. Further ingredients include yeast, salt, fat, improvers and preservatives and for specific products additional ingredients will be used, e.g. seeds, fruit etc.

Recipes for specific products vary. For a conventional white or brown bread loaf the composition (by weight) is typically around 55-60% flour, 35-40% water and 5-10% other ingredients. This varies significantly for loaves containing seeds and fruit.

How they manufacture

There are two main methods for the production of bread. These are the bulk fermentation process (BFP) and the Chorleywood bread process (CBP), the latter now dominating industrial bread production. The main characteristics of the two processes are summarised below.

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2 Data supplied by Food and Drink Federation for the year to September 2008
a) Bulk fermentation process

This is the traditional way of making bread where ingredients are mixed together to form a dough and then fermented for up to three hours. The fermentation process changes the dough from a dense mass into an elastic product which can then be cooked and cooled. The BFP has now largely been replaced by the CBP.

b) Chorleywood bread process

Developed in the early 1960s, this process is now used throughout the UK commercial bread industry. It allows bread to be produced without the need to ferment the dough in bulk. The CBP has the following benefits for commercial bakers:

- Bread is made considerably faster and therefore production is more efficient compared to the BFP.
- A much higher proportion of soft UK wheat flour can be used.
- The finished product has more consistent colour, volume and keeping qualities.

The main production stages of the process are:

- **Mixing** – raw ingredients are transferred from large storage silos into dough mixers according to the required recipe. The resulting dough is mixed intensely for a few minutes achieving a temperature of 28°C. The temperature of the dough mixture is maintained by adding chilled water and cooling the mixer itself. The amount of work put into the dough during the mixing process is controlled to an exact predetermined value, depending on the type of bread being made. Under these conditions the yeast can begin to grow and the dough will start to become elastic.

- **Dividing** – the large dough mass is tipped into a divider which produces dough pieces of the correct weight for the product being made.

- **First proving** – the dough pieces are allowed to ‘rest’ for around 10 minutes in a controlled atmosphere.

- **Moulding** – the dough pieces are then processed through a moulding machine to achieve the appropriate shape for baking.

- **Tinning** – the dough pieces are then placed in baking tins. Lids are added to the tins for products that are required to have a flat top profile. A typical baking tin will have the capacity to bake four 800g standard large loaves and will weigh around 6kg without a lid and up to 8.5kg with a lid.

- **Final proving** – the bread passes to the final prover where it is allowed to rise over approximately an hour, achieving approximately 90% of its final size. This expansion is the result of the yeast growing and producing CO₂. If the humidity and temperature of the prover atmosphere are not tightly controlled, the dough will either rise too much or not enough – either way it will spoil the product. Typically, the prover control set-points are a humidity of 85% and temperature of approximately 40°C. Direct steam injection is generally used to maintain humidity while the prover air is normally heated using gas-fired or steam heater batteries.

- **Baking** – the bread is then baked at between 230°C and 270°C for approximately 25 minutes, depending on the specific requirements of the product. A typical plant consists of a travelling oven with multiple burners so that the desired temperature profile can be achieved along its length. Natural gas is generally the fuel of choice and both indirect and direct-fired systems are used. In an indirect-fired oven the gas is combusted in fire tubes and the resulting flue gases pass from the oven through dedicated flues via heat exchangers. The heat of combustion is conveyed to the oven atmosphere by radiation and convection from the outside of the heat exchangers and there is no direct contact between the combustion gases and the product. There are
additional extract vents to remove excess oven gases in indirect-fired ovens. In direct-fired ovens the products of combustion pass into the oven space. They have common flues for combustion products and oven gases. Steam is sometimes injected directly into the first section of ovens to produce a glaze effect on the bread top while preventing over colouring and early crust formation.

- **De-lidding and de-tinning** – when the tins come out of the oven, any lids will be removed, typically by magnetic lifters. The bread is then removed from the tins, normally using a vacuum system. Occasionally a small pulse of compressed air will be used to assist with the release of the bread from the tin. The tins are then cleaned and cooled to be used again.

- **Cooling** – bread then passes through a cooler plant for approximately two hours. This is essentially a large ventilated box. Temperature and humidity are tightly controlled in the cooler by varying air flow rate using dampers, the use of water sprays and occasionally by a chiller plant. Typically, the temperature in the cooler is maintained at approximately 20°C and the humidity at 85-90%. If the bread is not cooled sufficiently, it will collapse when slicing is attempted and water will condense on the inside of the packaging.

- **Slicing / packing** – the bread is sliced and packed ready for despatch. Slicing and bagging machines operate at ambient conditions. The bread is sliced, the bag opened, the loaf is inserted and the bag is then sealed.

- **Despatch** – it is important that the temperature of the despatch area is controlled correctly or the shelf life of the bread will be reduced. The despatch areas of bakeries are typically heated by gas-fired convective systems. The operating temperature for the despatch depends on the bakery, but can be 20–25°C.

A schematic of the CBP is included in figure 1 which sets out the process activities, key operating parameters and, at a high level, the mass flow for a conventional 800g loaf. The main control parameters within the production process – from mixing (production of the dough) through to the final bagged loaf – are temperature and humidity levels at the proving, baking and cooling stages. In terms of the mass flow, for a typical 800g loaf (finished weight) the typical dough weight is around 900–930g. The main weight loss occurs during baking and cooling, which is predominately due to the evaporation of water.
<table>
<thead>
<tr>
<th>Process</th>
<th>Operating Conditions</th>
<th>Mass Flow for typical 800 g loaf (finished wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Process Temp</td>
<td>Humidity</td>
</tr>
<tr>
<td>Ingredients handling</td>
<td>ambient</td>
<td>ambient</td>
</tr>
<tr>
<td>Mix</td>
<td>28°C</td>
<td>ambient</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divide</td>
<td>28°C</td>
<td>ambient</td>
</tr>
<tr>
<td>First proof</td>
<td>30°C</td>
<td></td>
</tr>
<tr>
<td>Moulding</td>
<td>30°C</td>
<td>ambient</td>
</tr>
<tr>
<td>Final proof</td>
<td>40°C</td>
<td>70% - 85%</td>
</tr>
<tr>
<td>Bake</td>
<td>230 – 270°C</td>
<td>-</td>
</tr>
<tr>
<td>De-pan</td>
<td>~90°C</td>
<td>ambient</td>
</tr>
<tr>
<td>Cool</td>
<td>20°C</td>
<td>90%</td>
</tr>
<tr>
<td>Slicing/packing</td>
<td>ambient</td>
<td>ambient</td>
</tr>
<tr>
<td>Despatch</td>
<td>Depends on bakery aim for 25°C</td>
<td>ambient</td>
</tr>
</tbody>
</table>

*Figure 1: Outline of Chorleywood bread process*
Baking process carbon emissions

The focus of the Stage 1 IEEA work is to identify opportunities to deliver carbon savings through innovation to the baking process. Figure 2 shows a breakdown of the carbon emissions from each process on a typical bread bakery site.\(^3\) They are shown as a percentage of the total site emissions.

You will see that the largest single site energy consumer is the baking oven. Other significant uses include proving, cooling processes and also space heating and electrical power for ingredients handling, conveyors and compressed air. The two colours on the graph bars show the maximum and minimum range of typical usage.

![Graph showing breakdown of carbon emissions from industrial bakery processes](image)

**Figure 2: Breakdown of CO\(_2\) emissions from industrial bakery processes**

Figure 3 then presents the CBP flow identifying carbon emission points where possible and the main energy uses.

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\(^3\) Typical data from the detailed investigations undertaken as part of this project and SKM Enviros/bakery company experience
<table>
<thead>
<tr>
<th>Process</th>
<th>Typical Carbon (CO2) emissions % of total site</th>
<th>Main energy use resulting in carbon emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingredients handling</td>
<td></td>
<td>Electricity for materials handling, e.g. Flour conveying</td>
</tr>
<tr>
<td>Mix</td>
<td></td>
<td>Electricity for motors and chilled water (small scale)</td>
</tr>
<tr>
<td>Divide</td>
<td></td>
<td>Electricity for motors and drives</td>
</tr>
<tr>
<td>First proof</td>
<td></td>
<td>Electricity for motors and drives</td>
</tr>
<tr>
<td>Moulding</td>
<td></td>
<td>Electricity for motors and drives</td>
</tr>
<tr>
<td>Final proof</td>
<td></td>
<td>Electricity for motors and drives</td>
</tr>
<tr>
<td>Bake</td>
<td><strong>50</strong></td>
<td>Electricity for motors and drivers, Steam – humidity control, Gas – heating</td>
</tr>
<tr>
<td>De-pan</td>
<td></td>
<td>Electricity for motors and drivers, Steam – product quality</td>
</tr>
<tr>
<td>Cool</td>
<td></td>
<td>Electricity for motors and drivers, Water –humidity control / cooling</td>
</tr>
<tr>
<td>Slicing/packing</td>
<td></td>
<td>Electricity for motors and drivers, Gas – Space heating</td>
</tr>
<tr>
<td>Despatch</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Overview of bakery processes, carbon emissions and energy use
By focusing on the proving, baking and cooling operations our investigations covered a major part of the carbon emissions for a typical bakery – typically from Figures 2 and 3 around 50-60% of total site emissions. The oven is the largest of the three consumers and typically accounts for between 35% and 45% of the total site carbon emissions.

The remaining carbon emissions for a bakery site relate to plant operation, such as the mixers, conveyors, tray wash operations and also building services such as lighting and heating and ventilation. For these operations there are efficiency opportunities which can be realised through established ‘good practice’ activities.

Proving, baking and cooling operations are a continuous process. Exact operating regimes for bakeries vary in terms of total operating hours. For example, a well-used plant will run continuously, with short gaps as required, and a single maintenance shutdown for maybe 8-12 hours each week – so energy demands are reasonably constant. Examples of plant energy consumption patterns are presented in Section 5.

**Energy costs**

Based on an ‘average’ bakery having an annual energy bill of £865,000, the combined operating cost for the proving, baking and cooling operations would be £430,000-£520,000, of which the oven(s)\(^4\) could represent £290,000-£380,000.

**Manufacturers and other key stakeholders**

Three companies produce well over half of the total output for the industrial baking sector\(^5\). These are Allied Bakeries (Kingsmill and Allisons Brands), Premier Foods Bakeries (Hovis brand) and Warburtons.\(^6\) In addition there are a large number of commercial regional bakeries, including:

- Fine Lady Bakeries Ltd. (Banbury – produces for major multiple retailers)
- Frank Roberts and Sons Ltd. (Cheshire)
- Rathbones (owned by Morrisons supermarkets)
- W.D. Irwins and Sons Ltd. (Northern Ireland)
- William Jackson (Hull)

Three bakeries were selected for detailed investigation work, to identify energy saving opportunities and to gain evidence to build a business case for their implementation. We have included a rationale for site selection and the details of the operations at each one in Section 4.

In the UK the sector is represented by the FDF as well as the Federation of Bakers (FoB) and National Association of Master Bakers (NAMB).

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\(^4\) For a site there can be one or more ovens in place depending on its scale and also the products being produced.

\(^5\) The industrial baking sector has been defined as the UK operating sites which have Climate Change Agreements (CCAs). This is 89 sites in total. It is anticipated that most industrial bakeries will have CCAs as they provide a significant financial benefit and therefore the vast majority of emissions are captured in the data presented.

\(^6\) From data supplied by the Food and Drink Federation.
Energy consumption and carbon emissions of sector and sites

Figure 4 summarises the annual energy consumption from the industrial bakery sector based on sector level information made available to the project by the FDF. Overall annual energy use is 2,000GWh (based on delivered energy) with emissions of 570,000tCO₂.

Based on there being 89 industrial bakery sites, the average emissions per site are 6,400tCO₂ per year.

**Figure 4: Annual sector energy consumption and carbon emissions**

<table>
<thead>
<tr>
<th>Energy type</th>
<th>Energy use (GWh)</th>
<th>CO₂ emissions (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (delivered)</td>
<td>560</td>
<td>300,000</td>
</tr>
<tr>
<td>Natural gas</td>
<td>1,400</td>
<td>260,000</td>
</tr>
<tr>
<td>Fuel oil and Liquid Propane Gas</td>
<td>40</td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>2,000</strong></td>
<td><strong>570,000</strong></td>
</tr>
</tbody>
</table>

We were given access to annual energy data for 13 bakeries, which we used to determine the relationship between the amount of delivered energy a site uses each year and its annual production. This is shown in figures 5 and 6 and discussed later in the guide.

**Figure 5: Relationship between fossil fuel use and production at 13 bakery sites**

There is significant variance in fossil fuel usage (natural gas) and production with the correlation between being 0.557.

However, the correlation is stronger between electricity use and production, at 0.77, as shown by figure 6.

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7 The correlation range is from 0 – 1. If the correlation was 1 then the best fit would base through all of the data points.
Figure 6: Electricity use and production relationship at 13 bakery sites

**Bakery sites specific energy consumption**

The average specific energy consumption (SEC) defined as ‘delivered energy per tonne of product produced for the sector (across all sites)’ is estimated to be:

- Fossil fuels (predominately gas) 551 kWh per tonne of product
- Electricity 218 kWh per tonne of product

Figures 7 and 8 show SEC variation for the 13 example bakery sites.

Figure 7: Fossil fuel specific energy consumption at 13 bakery sites
Figures 5 to 8 show that there is significant variation in SEC at the sites investigated. This is primarily due to differences in their baking operations and technology, including:

- product formulation – different products have different process energy requirements
- plant technology – variations in the design and scale of plant, e.g. age of plant, indirect or direct-fired ovens, throughput of plant age and efficiency of process plant
- production volumes – bakeries with higher production volumes will tend to be more energy efficient
- operating hours – plants that work harder will tend to be more efficient
- number of products – plants with few product changes can run at higher production rates with fewer breaks
- degree of automation – bakeries with a higher proportion of automation will tend to use more electricity for motive power
- control efficiency – for example, controls on process and space heating systems
- site location – this will impact space heating demands.

The range of SECs also suggests that there is potential to improve energy efficiency.

**Progress on improving energy performance**

There is now greater interest in energy efficiency within the sector, because of compliance requirements, cost control and, more recently, corporate responsibility.

In the past, the focus was on introducing good practice, particularly on primary plant services. Actions included:

- turn-off campaigns for conveyors
- shutdown procedures for major plant, e.g. provers, ovens, coolers
- compressed air management practices
- more efficient air compressor plant, including variable speed drive units
- reduction of compressed air leakage rate
- high-efficiency lighting applications – the installation of T5 fluorescent high-frequency systems in productions areas
- occupancy control of lights in lower use areas such as, offices, meeting rooms, stores and plant rooms
- monitoring and targeting programmes
- improved insulation of major process plant such as ovens and provers
- reducing the amount of air entering despatch areas – by improving seals and air curtains
- space heating control improvements – office wet systems temperature compensation and boiler optimisation; process area convector heater advanced controls
- variable speed drives (VSDs) on bakery ventilation systems
- improved insulation of steam and chilled water distribution systems
- energy awareness campaigns.

Some improvements have been made to improve the efficiency of bakery plant, either by changing operating practices or using new technologies – but these have been limited. This is because main plant items typically have long lifetimes, with equipment over 30 years old still in operation. So major energy using plant, such as provers, ovens and coolers are often operating according to their original set-up and specification.

**Business drivers**

The bakery sector is extremely competitive and main drivers are inevitably product, price and quality. The current recession means consumers are more price conscious, so the industry is heavily focused on reducing costs by making operations and procurement more efficient. Quality, taste and nutrition are also key to increasing and retaining customers.

These drivers mean that energy, and so carbon efficiency, is of increasing interest to the sector.

**Impact of carbon legislation**

The Climate Change Levy (CCL) is charged on non-domestic energy bills for both electricity and selected fossil fuels, including natural gas. Industrial bakeries can receive a rebate on the Levy if they have a CCA with associated energy performance targets, and this financial benefit is a significant driver.

If all sites received the maximum rebate, the Levy rebate for the whole sector would be approximately £3.8m per year (based on the energy use presented in this guide).

Industrial bakeries have had the opportunity to have a CCA since 2001, and this will continue until 2012 – with the potential for this to be extended to 2017.

The CRC was launched in April 2010 to provide an incentive driven compliance requirement for carbon reduction. The participation of bakery companies in the CRC will depend on their organisational structure, the level of CCA coverage they have and how much energy they use.

Other indirect carbon regulation which impacts on bakeries includes the EU ETS and also the Renewable Obligation (RO).
Carbon and energy saving drivers

‘Typical’ carbon emissions for an industrial bakery are in the region of 6,400tCO2 per year with carbon emissions being evenly split between electricity and natural gas use. Assuming energy costs of 7.5p/kWh and 2.5p/kWh for electricity and gas respectively, typical annual costs for energy use would be in the region of £865,000. So reducing energy costs is a major sector driver.

In addition to direct cost reduction, corporate responsibility is also a key driver for carbon reduction. Key stakeholders include retailers and consumers. In recent years, retailers have put in place carbon reduction targets for their operations and are also engaging with their supply chain to deliver carbon savings. Consumers are becoming more environmentally aware, and one key development in providing information on the carbon impact of products has been the publication of the first carbon label. This sets out the supply chain carbon footprint from agricultural operations through to the consumer, for a branded product.

The drive for carbon reduction through corporate responsibility includes both direct energy use within the production operations and also any carbon embedded within the raw materials used, e.g. packaging, flour and other ingredients. Therefore the overall carbon agenda for the bakery sector, alongside others, is to focus both on operational emissions and those within the wider supply chain. Key supply chain actions include producing a wider variety of loaves to help minimise consumer waste and reducing packaging weights.

Business barriers

By engaging with the sector, we identified some of the key barriers to implementing innovations. These are summarised below and have been considered as part of the evaluation of opportunities which are discussed in Sections 5 and 6.

a) **Cost** – the implementation of new innovations will need to have a good return on investment, and a payback of less than four years was given as acceptable. So it will be important to deliver innovative improvements that can deliver the required financial benefits within the payback criteria.

b) **Business case** – this will need to be robust, which means capturing all costs and financial savings (which must be deliverable). The sector would like to see all potential and knock-on benefits captured, e.g. could a carbon reduction measure also help increase productivity or reduce maintenance requirements?

c) **Product quality** – if an innovation could affect product quality then this would be a key barrier. Innovations would need to have a proven track record to gain credibility with the sector.

d) **Proven technology** – the sector has previously implemented innovations, most notably heat recovery on ovens. However, because a number of test applications have failed, there are concerns about the potential to deliver proven solutions with the longevity to maximise savings.

e) **Maintainability** – if an installation requires a lot of time-consuming maintenance, there is a danger it may fall into disrepair. Companies and solution providers would also need to consider how to provide staff training.
4. Methodology

The purpose of the first stage of the IEEA was to examine the sector-specific manufacturing processes in depth, understand their energy use and interaction with other systems and identify possible energy efficiencies.

Host bakery site selection

We selected three bakeries, representative of the sector as a whole, and installed meters on one baking line within each for detailed monitoring. The host bakeries’ characteristics are summarised below:

**Bakery A** – produces a complex variety of bread and morning goods. The baking line selected uses:
- an indirect-fired oven, with two burners and the facility for steam injection
- a dedicated cooler
- steam heated prover plant.

A variety of conventional 800g and 400g loaves were made on the line in steel tins which sometimes used lids. The line selected for monitoring produces around 2-2.5t of product per hour.

**Bakery B** – produces bread loaves and morning goods. The baking line selected for detailed monitoring uses:
- a direct-fired oven, with three gas-fired heating zones
- a dedicated cooler
- a prover with gas-fired heating and steam injection for humidity control.

The plant produces large bread loaves in lidded tins. The line selected for monitoring is a high volume line capable of producing five tonnes of 800g loaves every hour.

**Bakery C** – produces a variety of bread loaves and morning goods products. The line selected for detailed monitoring was an indirect-fired oven with
- three burners
- a dedicated cooler
- a prover heated by a gas burner and direct steam injection humidity control.

The primary products produced are 400g to 800g loaves.

Monitoring requirements

Our detailed monitoring strategy addressed significant electricity, gas and steam inputs to the processes and collated them with production and plant control parameters. This enabled us to characterise and quantify carbon emissions from the proving, baking and cooling processes.
Typical monitoring points are presented in figure 9. Energy data was collected at five minute intervals to provide a high level of granularity for analysis.

![Figure 9: Typical monitoring arrangement](image)

Production and operational data provided by the bakeries included:

- Dough/ product weights through the process (although only one bakery was able to supply both product throughput and mix information)
- Dough/ product moisture content through process
- Oven temperature profiles
- Prover/ cooler temperature and humidity set-points
- Product type
- Tin weights averaged (for each site).

Additionally, we manually logged plant operating conditions such as temperature and humidity during the monitoring work, and found these to be relatively stable during operation.

Characterising heat rejection is key to defining performance and efficiencies. For indirect ovens there are multiple flues for combustion gases and also oven exhausts for each zone. For direct-fired ovens there is only the oven extractions.

For each of these release points we completed spot measurements for temperature, oxygen and, where possible, gas velocities during typical production periods – i.e. at normal throughput. The measurements were found to be stable with limited fluctuation during the monitoring periods.

**Engagement with sector**

In addition to the detailed monitoring work, the other key activities undertaken with the sector included a FDF launch meeting, site visits (to non-host bakeries), supply chain engagement, equipment supplier contacts and a sector-wide workshop.
5. Key findings

Distribution of energy use in the process

The metering installed allowed operational practices to be measured for the selected processes: provers, ovens and coolers.

Examples of typical energy consumption profiles for the provers, ovens and coolers are presented on an hourly basis with production data being adjusted to take account of dough/bread progress through the plant. Primary production data was usually based on the unit dough count before the final prover.

As bread stays in the final prover approximately one hour, the oven production data is adjusted to be one hour behind the prover data, and similarly the cooler production is adjusted to take account of the bread being in the oven around 25 minutes.

Prover energy use

Steam heated and gas-heated provers were monitored at different bakeries.

Figure 10 shows the energy use and throughput of a steam only heated prover over a typical operating week. Steam consumption is calculated, taking into account how efficient the boiler generating it is. In this case the peaks observed in the steam use are caused by steam injection to the oven on the same production line, i.e. this meter measured the combined steam use to the prover and oven. Steam is used by the oven for specific products and therefore the lower base load use is associated with the operation of the prover. Prover steam use during production is stable at around 80-90kW; when steam is injected to the oven, total consumption rises to around 160kW.

In this scenario, the steam used on the prover represents 70% of total consumption, with the oven using the remaining 30%.

Figure 10: Energy use and production of steam-heated prover for typical week
Figure 11: Energy use and production of gas-fired prover for typical week

Figure 11 presents energy use and throughput for a prover using gas heating to preheat air entering the prover, and steam injection for humidity control. For this prover the steam consumption presented is a dedicated supply. The throughput for this prover is approximately three times as much as that in figure 10.

The SEC (kWh/t of product) for the steam-heated and gas-fired (with steam humidity control) provers assessed in terms of heat input is as follows:

- Steam-heated and humidity control: 5.5 kWh/t (this does not include steam to oven)
- Gas-heated (with steam humidity control): 1.9 kWh/t (includes gas and steam use)

The monitoring shows the gas-fired prover to be more efficient. This is due to:

- reduction in losses associated with steam production
- less energy lost through the fabric of the gas-fired plant, because of its greater scale
- better operating practices.

The location of the prover air intake and leakage are also important. Air input is drawn from the bakery and so the ambient temperature in the bakery will significantly affect how much heating the prover requires. The rate of warm air leaking from the prover will also influence performance.

For prover electricity use the SECs measured were far closer at 0.31 kWh/t and 0.29 kWh/t for the steam-heated and gas-heated units. As the major electrical use is conveyor motors and drives within a prover similar consumption would be expected.

From figures 10 and 11 operating practice observations are as follows:
- **Major gaps in production** – both examples shown have a major production gap on Saturday. For the steam-heated prover (figure 10) steam and electricity consumption continue during the gap although it is reduced due to no product throughput. For the gas-heated prover the plant is shutdown during major gaps. Turning off the steam-heated prover during the major gap on a Saturday should save:
  - 0.30tCO₂
  - £40

- **Short production gaps** – the steam-heated prover usage remains at the same levels as production. For the gas-fired unit the gas use reduces but steam and power remain at production levels. Short production gaps observed on the steam-heated unit last for between one and four hours. On the gas-fired prover they are less frequent and the gaps smaller in duration. Focus on optimising gap shutdowns will also support improvements in energy efficiency.

**Oven energy use**

Figures 12 and 13 present examples of oven energy use related to production throughput. Figure 11 summarises the weekly consumption for an indirect oven and figure 12 for a direct-fired unit. The direct unit monitored was installed in the last five years and the indirect ovens assessed were all over 30 years old.

![Figure 12: Energy use and production of indirect-fired oven for a typical week](image)

**Figure 12: Energy use and production of indirect-fired oven for a typical week**
Figure 13: Energy use and production of direct-fired oven for typical week

The main observation is that the oven gas use does react to reductions in throughput, but the reduction is less pronounced for the indirect-fired ovens.

Electricity use for the ovens is constant and does not vary with product throughput (as fans operate continuously and are damper controlled). In terms of significant gaps in production (Saturday) both the indirect and direct ovens are shut down. There is a short delay before electricity consumption drops because the fans need to stay on after production ends to avoid overheating within the oven.

The SECs for the indirect and direct ovens monitored were calculated and are summarised below:

- **Indirect** – SEC circa 590 kWh/t for gas use and 32 kWh/t for electricity
- **Direct** – SEC circa 221 kWh/t for gas use and 6 kWh/t for electricity

The ovens considered in the work had a wide range of throughputs. The direct oven was larger and the throughput range between this and the smallest indirect oven was approximately 3:1. Therefore through its scale and the fact it is relatively new the direct oven would be expected to be significantly more efficient.

A key variance between the ovens is that indirect-fired ovens have both flue losses and exhaust gases from the oven baking processes being exhausted to atmosphere. In comparison the direct oven has only the oven exhaust extractions comprising combustion products and gases/vapour from the baking process. Irrespective of scale this is a fundamental design difference and would support direct ovens being more efficient due to potentially reduced losses to atmosphere.

Figure 13 compares gas consumption for direct and indirect ovens to production. This allows a simple comparison of usage for these oven types. The indirect ovens appear to have less correlation with production compared to the direct unit. We would expect this as observations during the monitoring (see figure 14) indicate shutdown and control is better on the direct oven.
Figure 14: Energy use and production relationship for indirect and direct ovens

The lines of best fit in figure 14 provide an estimate of performance in terms of the fixed and variable load on the ovens. The correlation for the indirect ovens is relatively poor compared to that for direct-fired ovens, which is probably due to the more modern direct-fired ovens having superior operational control systems. The variable energy use from the lines of best fit suggests that the indirect ovens have a 20% higher usage per production unit compared to the direct-fired ovens. This indicates that the direct-fired ovens tested are able to respond to changes in production rates more efficiently. The fixed load (independent of production) for the indirect ovens is 45% higher than the direct-fired units. This is probably due to better control of the direct-fired ovens during production breaks and potentially because of higher standing heat losses from the indirect plants.

The data presented in figure 14 has been used to calculate the SEC for direct and indirect-fired ovens which is shown in figure 15. This confirms the impact of production rates where the indirect-fired oven SEC increases dramatically as production reduces. For the direct-fired oven, SEC does increase as production decreases, but due to its higher throughput the impact is less pronounced.
Figure 15: Specific energy consumptions for indirect and direct ovens

Cooler energy use

Energy performance data for an older traditional cooler (30 years operation) and more modern cooler plant (about three years old) is presented in figures 16 and 17.

Figure 16: Energy use and production of older cooler plant for typical week
Figure 17: Energy use and production of modern cooler plant for typical week

The older plant uses significantly more energy to cool a unit mass of bread on an absolute basis, even though the unit has lower throughput compared to the modern cooler. The older cooler is not well controlled and essentially operates at a fixed speed irrespective of throughput.

In contrast, the new cooler electricity demand is reacting to throughput and appears to be well controlled. Control is based on humidity, temperature and extraction rates from the oven, allowing the fans’ electricity use to be moderated. However, air flow rates are still controlled with dampers, and electricity use could be further reduced by using variable speed drives (VSDs) to control the operation of the fan motor.

Figure 18 shows the two cooler SECs. The older cooler SEC increases exponentially as production is reduced, due to the fixed load of the unit. The SEC for the modern cooler is relatively flat because it gives better control.
Summary of plant loads and initial operational observations

Based on our monitoring work, the typical operating loads for plants varied depending on age, technology type and throughput. In summary the typical operating loads were:

- Prover gas use (or equivalent steam use for heating): 40-60kWth
- Prover steam use (humidity control): 40-60kWth
- Prover electricity use: 5-15kWe
- Oven gas use: 900-1,300kWth\(^8\)
- Oven electricity use: 30-60kWe\(^9\)
- Cooler electricity use: 30-60kWe

Ovens

The analysis identified significant variance in oven electricity and gas use, highlighting that better control could deliver improvement. This control relates not only in relation to ensuring good start-up and shutdown procedures but also on improving the control during production to respond to changes in throughput. We prepared an energy balance to help define further opportunities for improving the efficiency of the oven, and summarised this below.

Prover

For the prover, the use of direct gas firing for heating appears to be more efficient than steam heating. Humidity control with steam was used on all the provers monitored. Electricity consumption on the provers is relatively low and associated with conveyors and fans.

\(^8\) kWth – thermal kW load
\(^9\) KWe – electrical kW load
Coolers

The control of coolers varied between sites, with the new cooler having better control – and therefore a better SEC. This was also partly due to the larger size of the new cooler.

Process energy balances

Oven thermal balance

The monitoring thermal balances presented in figures 19 and 20 include both direct and indirect-fired ovens and are in terms of percentage of natural gas consumed.

**Figure 19: Indirect-fired oven thermal energy balance**

**Figure 20: Direct-fired oven thermal energy balance**
The factors influencing each area of energy use/loss are:

- **Fabric losses** – influenced by the thickness and integrity of oven insulation. Older ovens will tend to have insulation of lower specification, which is more likely to be damaged and result in greater losses. Overall, the fabric losses were not found to be a major source of losses from the ovens.

- **Combustion losses** – the major factor is the set-up and maintenance of burners. There is only manual set-up of burners at service intervals. The more excess air there is, the more energy is lost. For indirect-fired ovens the combustion products pass through a heat exchanger and are then discharged to the atmosphere. The typical temperature of the flue gases is about 250–300°C. On direct-fired ovens the combustion products enter the oven and are exhausted with gases/vapour from the baking process.

- **Energy to tins** – tins are of conventional design in steel and require a fixed amount of energy to heat to oven operating temperature. Reducing this energy demand requires lighter tins or alternative materials to give the tins a lower thermal mass. Typically the ratio of tin to bread is around 2:1 for the work undertaken.

- **Oven extracts** – the volume of oven extract gases is usually controlled by manual dampers and is therefore fixed. The oven extraction on an indirect oven comprises only the air and products from baking (predominately water vapour but also traces of fat and particulates). For a direct-fired oven, the extractions are the same as an indirect oven, except the combustion gases are also present. The extraction temperature of the gases will be the same as the operating temperature of the oven zones which is typically around 250°C.

- **Water evaporation/heat to dough** – the energy requirement depends on throughput and the recipe. The calculation of the exact energy requirements for baking bread to both heat the dough and then to evaporate the water was based on the following parameters:
  
  - the average temperature of the dough entering the oven was 40°C (exit temperature from prover)
  - the exit temperature of the bread (internal temperature) was 95°C (based on typical temperatures provided by the bakeries).

  The water loss from evaporation is not measured routinely at the exit of the oven, but based on discussions with the participating sites, it is typically around 50g when producing an 800g loaf.

- **Other losses** – these include fixed heat losses to the oven sole (moving bed of oven), losses for open oven inspection hatches (which are under the control of operators) and losses from when the bread goes in and comes out of the oven.
Key findings from the thermal energy balances for the two types of oven are as follows:

- Direct-fired oven efficiency is estimated to be 32% compared to around 15% for the example indirect-fired oven. The efficiency is calculated based on:

\[
\text{Efficiency} = \frac{\text{Theoretical energy required for baking}}{\text{Actual thermal input to the oven}}
\]

It is important to note that the ovens monitored ranged from about 900-1,300kW thermal input at full load. While larger plants can be expected to be more efficient, the size of the variances observed between indirect and direct-fired ovens indicate that like for like, direct-fired ovens are more efficient. This is reflected by the trend towards direct-fired ovens in bakery new builds\(^{10}\).

- For indirect-fired ovens, the largest energy losses are the burner flue gases and oven exhausts to atmosphere. These account for approximately 60% of the total thermal input to the oven.
- For direct-fired ovens, losses from oven exhausts account for approximately 20% of the total thermal input.
- Tins, usually made of steel, are a significant source of energy losses. Typically, the ratio of steel to bread passing through the oven is 2:1. The losses per loaf are the same for a direct and indirect oven, but for direct-fired ovens the absolute percentage loss is higher, because the ovens are more efficient.
- Fabric losses appear to be relatively low for both oven types and generally the ovens appeared to have reasonable insulation.
- In general, we found that the oven heat balances were consistent. The major effect on performance was caused by gaps due to product changes and operation with no production, particularly at start-up and shutdown.

Overall, the metering and analysis work we did accounted for over 90% of the thermal energy input.

\(^{10}\) This is based on feedback from the sector workshop on 18 June 2010 – FDF.
Oven electricity use

The main electricity consumers are the fans circulating air within the oven. These tend to be fixed-speed with manual dampers used for control when required.

A large indirect-fired oven would generally have exhaust vent fans in each zone and a fan in the feed and delivery extract hood at each end of the plant. In addition there could be a turbulence fan and circulation fans in each zone.

A large direct-fired oven would have vent exhaust fans on each zone and hood exhaust fans at either end of the oven. There would also be a circulation fan in each zone. The direct-fired oven we monitored was relatively new and used automatic dampers to control its fans.

The oven electricity load on the direct-fired oven was significantly lower at around 30kW, on average, compared to around 60kW on the indirect-fired plant. The primary reason for this variance is the additional large turbulence fans on the indirect-fired ovens that are needed to ensure adequate heat transfer from the heat exchangers in the oven and the air being circulated. Such fans are not present in direct-fired ovens. The indirect ovens were also older and the control on the newer oven appears to be better, which also contributes to reduced consumption.

High-efficiency motors are normally used on newer plant and are generally considered if a motor has to be replaced.

There are a large number of small motors (often less than 0.5kW) installed on the conveyors used to transport dough to and bread from the oven. The key issue with these motors is ensuring that they are switched off when the conveyors are empty.

Prover energy balance

We summarised the energy use for proving the bread earlier in the document. Prover consumption varies depending on the size of unit and the heating method used (either gas-fired or steam). Figure 21 shows the typical overall energy split for a prover, and you can see that the thermal energy demand dominates. This typically varies from 80-160kW depending on throughput.
Figure 21: Typical prover energy balance

The main control parameters are temperature and humidity, which both require about the same amount of energy. Air circulation fans are the main users of electricity in the prover, with a smaller quantity being used by the plant drives. VSDs are not generally used and the relative volumes of fresh and recycled air are controlled by dampers, depending on the air temperature and humidity requirements.

The energy needed to maintain prover temperature is normally supplied by an integral gas-fired burner or steam heat exchanger fed by an external boiler plant. From our analysis the gas-fired prover is more efficient.

Cooler energy balance

The main use of energy in a typical cooler is associated with the air circulation fans, although a smaller quantity of electricity is used for main plant drives. The temperature and humidity of the atmosphere in a bread cooler are generally maintained by controlling the proportion of fresh and recycled air – and by injecting water into the air stream, where necessary, to maintain humidity levels. Air stream volumes are generally controlled by dampers, which vary their position according to the plant control parameters. VSDs are not generally used. Typically, the operating electrical load is around 30-60kWe. We found that newer plants had more effective temperature control and were generally more efficient. Figure 22 shows the typical electrical energy split for cooler plant operation.
Figure 22: Typical cooler electrical energy balance

Plant management findings

Observations of site operations and analysis of the energy data highlighted areas where energy was being wasted. These included inefficient operational practices, including:

- conveyor plant left running for long periods when empty
- oven extraction dampers fully open when they should be partially shut (the extraction vents for direct and indirect ovens are a major area of energy loss, as the thermal mass balances demonstrate)
- major plant such as ovens, provers and coolers not being staggered at start-up and shutdown with the progress of bread through the plant.

Conveyor plant

Management procedures for turn-off and/or controls to allow automatic shutdown can reduce the amount of time conveyors run during non-production or short breaks. Some improvements to shutting down conveyors have been made but further opportunities still exist.

Oven extraction dampers

Gases from the oven are extracted via dedicated vents. Losses vary depending on the set-up and size of the oven. For both the indirect and direct ovens, losses from extraction are a major source of heat rejection.

Optimising extraction settings can lead to significant savings, but remember to consider any impact this could have on product quality. The indirect oven extraction dampers we saw were set fully open, so there is an opportunity to make savings. For the direct-fired oven, the extraction combines combustion and baking gases. The direct oven monitored is already more efficient, so reducing extraction losses might prove more difficult.
**Plant scheduling**

There is an opportunity to save energy by turning off major plant when not in use.

Our monitoring work highlighted some examples of good practice (e.g. where ovens are shutdown during major gaps), but one of the plants was not effectively controlling its prover shutdown. So improving shutdown and gapping procedures offers further potential to deliver good practice savings. Figures 23 and 24 show the savings that can be made by improving shutdown procedures.

Figure 23 highlights the effect of not switching off the main oven fans at the appropriate time during a shutdown. It is clear that the oven runs on for a significant period after the cooler has been shut down. Given that bread stays in the cooler for about two hours, the oven should shut down two hours before the cooler finishes. In this case, the oven fans ran on for an extra five hours with no product. During this time it would have consumed over 250kWh of electricity. This equates to a cost of £20 for this one shutdown and emissions of 0.13tCO₂.

![Figure 23: Electricity use of oven and cooler plant through a shutdown](image)

It is also important to ensure that the operation of the oven and prover are correctly scheduled. The example data shown in figure 24 highlights that the oven carries on for more than two hours after the prover has been shut down, even though the product stays in the oven for no more than 25 minutes. In addition, as the shutdown is coming to an end the oven is switched back on before the prover, although the product stays in the prover for about an hour.
We estimate that a saving of approximately 2% of annual energy use of a typical bakery should be possible by improving plant shutdown and management procedures. This would equate to a saving of approximately 11,400tCO₂ if applied across the sector.

Process performance

In addition to improving plant shutdowns and start-ups, alongside optimising operating conditions, there is potential to improve overall process performance. This would require a focus on the overall baking process – from ingredients handling through to final despatch. This activity would typically be part of an overall continuous improvement programme, e.g. lean or manufacturing excellence.

The work undertaken in the IEEA does not extend to defining overall optimisation opportunities for the entire process. However, if production throughput scheduling can be optimised to maximise throughput, and therefore allow longer shutdowns or increased output, then carbon savings will be possible.

Product changes

For one site operating an indirect oven, we obtained detailed production data on a product by product basis. This meant we could assess how different products affected the plant’s energy performance.

The frequency distribution analysis presented in figure 25 shows the gas SEC occurring for different products in the same oven. It shows that there is a significant variation in the SEC for the gas consumed for different products, but most SECs are between 0.3 kWh/kg and 0.6kWh/kg. The high SEC values, over 0.7kWh/kg, are due to very short production runs and/or proximity to production breaks.
Figure 25: Variation in gas SEC for four products produced by an indirect bakery oven

The reasons for the variations in a single product SEC will be throughput and operational practices. The mixing of the product and the proving, baking and cooling stages are all closely scheduled, but there was significant difference in individual batch times for the same product. This may reduce throughput and so increase the SEC. The SEC increase is due to the plant (prover, oven and cooler) energy use not changing significantly with short changes in product throughput. In terms of operating practices, the operating set-points would be fixed for each product. However, operators can adjust settings during production, which could influence energy use.

To minimise SEC variance the scheduling of the mixing process and the feed to the prover, oven and cooler needs to be optimised to minimise variations in throughput. This will help to minimise the SEC range and thereby reduce gas usage.

There are significant savings to be made by optimising the overall process. If the production level for the site was consistent throughout the day then the overall run time for the oven would be reduced, leading to more downtime. Optimising processes might also potentially increase output.

Optimising processes to minimise the SEC range – and reduce any high SEC occurrences – should be considered as part of an overall process review. This will help identify any limiting factors that might restrict potential.

Detailed production data was not available for other sites including the direct-fired oven. As the direct-fired oven is already more efficient we don’t think there are as many opportunities for improving control and scheduling, but it should still deliver some benefits.

A similar analysis was undertaken to determine the range in the SEC for oven electricity use in kWh/kg of product produced.
Figure 26: Variation in electricity SEC for five products produced by bakery oven

Figure 26 shows less variation in the SEC for each product for electricity use than for use of gas, with most occurrences between 0.02kWh/kg and 0.025kWh/kg. Activities that would impact on the oven’s electrical SEC would be throughput (generally, the higher this is the more efficient the oven) and damper settings on oven exhausts, circulation and turbulence fans. A lower overall SEC should be achieved by improving operating procedures, scheduling to maintain high oven throughput and increasing operators’ awareness of damper settings.

Combustion efficiency and control

Oxygen content spot measurements were taken from the flues of both the indirect-fired and direct-fired ovens during the on-site investigations. Typical results are detailed in figure 27.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Indirect-fired oven 1</th>
<th>Indirect-fired oven 2</th>
<th>Direct-fired oven</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feed end</td>
<td>Delivery end</td>
<td>Feed end</td>
</tr>
<tr>
<td>Flue gas temperature</td>
<td>336°C</td>
<td>273°C</td>
<td>270°C</td>
</tr>
<tr>
<td>Oxygen</td>
<td>14%</td>
<td>15.1%</td>
<td>13.4%</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>4.0%</td>
<td>3.4%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Excess Air</td>
<td>177%</td>
<td>226%</td>
<td>157%</td>
</tr>
</tbody>
</table>

Figure 27: Averaged results of spot flue gas monitoring of baking ovens

For indirect-fired ovens the burners are set-up with a high level of excess air, measured at levels of 250% (this is calculated by determining the O₂ levels in the combustion gases) during production runs on all of flues. The excess air levels obtained from the vents of the direct-fired oven were similar to the indirect ovens.
6. Opportunities

Summary of opportunities

The monitoring programme and observations from the site activities identified energy efficiency improvement opportunities, and we have estimated their savings potential. Where required, we have also developed cost estimates for the improvements, which has enabled us to calculate a simple payback on investment.

A key objective from the work was to understand the potential for carbon savings across the sector. Therefore the results obtained from the detailed monitoring have been used to calculate sector potential by estimating the maximum number of sites which might be able to adopt the improvement. This estimate is based on understanding the type of plant on site (i.e. indirect or direct ovens) and also whether the improvement would be best suited to new build and/or retrofit.

Our work with the sector showed a 50:50 split between indirect and direct oven operations. Those we spoke to felt there was little potential for new build or replacement of major plant items, and their main interest was in retrofit opportunities – i.e. those that could be applied to existing plant.

This section summarises the energy efficiency improvements identified. It sets out opportunities considered to be ‘good practice’ and those which fall under the category of innovation. The latter may be suitable candidates for Carbon Trust support, if required, to help accelerate their take-up in the sector.

The innovation projects highlighted are restricted to the cooler and oven, with no projects identified for improving prover energy efficiency. However, its operation is intrinsically linked to the oven and cooling processes, so it is important to monitor its energy use. Overall, the electricity consumption of the prover was found to be quite small and there is no major opportunity for reducing the amount it uses, although the prover thermal energy use data confirmed that it is a good potential sink for heat recovered from the oven.

Good practice opportunities

General good practice measures

There are generic opportunities to reduce the energy use of bakery utility services including, compressed air, steam and space heating. Good practice activities for other plant/equipment within the bakery include:

- turn-off campaigns for conveyors
- improvement to compressed air management practices
- more efficient air compressor plant, including variable speed drive units
- reduction of compressed air leakage rate
- high-efficiency lighting applications – the installation of T5 fluorescent high-frequency systems in productions areas
- occupancy control of lights in lower use areas such as, offices, meeting rooms, stores and plant rooms
- reduction of air ingress to despatch area, by improving seals and air curtains
- space heating control improvements – office wet systems temperature compensation and boiler optimisation; process area convctor heater advanced controls
- the use of VSD on bakery ventilation systems
- improved insulation of steam and chilled water distribution systems
- energy awareness campaigns.

**Bakery process specific good practice opportunities**

Measures detailed in figure 28 are fairly straightforward process-specific measures for the sector to implement, which represent good practice opportunities well documented for the baking process. There are no significant barriers to prevent full implementation.

Overall we estimate that the good practice opportunities below, alongside improvements that can be delivered for other plant/equipment and utility services, could deliver on average a 10% saving in total carbon emissions for the sector. This would represent a carbon reduction of 57,000tCO₂ per year.
<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Plant</th>
<th>Costs to implement (£ per plant)</th>
<th>Payback (years)</th>
<th>% of sites where applicable</th>
<th>Indicative total CO₂ saving by sector (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven combustion efficiency through improved maintenance operations and measurements</td>
<td>Oven</td>
<td>Maintenance costs only</td>
<td>N/A</td>
<td>100</td>
<td>6,935</td>
</tr>
<tr>
<td>Oven burner firing rate modulation to control temperature more effectively rather than high fire/low fire control</td>
<td>Oven</td>
<td>£25,000</td>
<td>5.7</td>
<td>100</td>
<td>2,877</td>
</tr>
<tr>
<td>Reduce hot oven gas extraction from ovens through optimising damper settings</td>
<td>Oven</td>
<td>No capital cost</td>
<td>N/A</td>
<td>100</td>
<td>6,164</td>
</tr>
<tr>
<td>Direct drive or non-slip drive on fans</td>
<td>Oven</td>
<td>£5,000</td>
<td>1.9</td>
<td>100</td>
<td>1,625</td>
</tr>
<tr>
<td>Balance oven airflows to reduce losses</td>
<td>Oven</td>
<td>To be confirmed</td>
<td>To be confirmed</td>
<td>100</td>
<td>To be confirmed</td>
</tr>
<tr>
<td>Phased manual shut down of oven burners during product gaps and shutdowns</td>
<td>Oven</td>
<td>No capital cost</td>
<td>N/A</td>
<td>100</td>
<td>1,027</td>
</tr>
<tr>
<td>Automatic switch off or conversion to low fire of oven burners during gapping and shutdown</td>
<td>Oven</td>
<td>£20,000</td>
<td>6.4</td>
<td>100</td>
<td>2,055</td>
</tr>
<tr>
<td>Manual shut down/ turn down of oven fans during gapping</td>
<td>Oven</td>
<td>No capital cost</td>
<td>N/A</td>
<td>100</td>
<td>739</td>
</tr>
<tr>
<td>Improve shutdown during production gaps</td>
<td>Prover, oven and cooler</td>
<td>No capital cost</td>
<td>N/A</td>
<td>100</td>
<td>11,400</td>
</tr>
<tr>
<td>Production scheduling</td>
<td>Baking process</td>
<td>Lean / manufacturing excellence activity</td>
<td>Good</td>
<td>90%</td>
<td>TBC – expected to be significant but further work required to quantify</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>32,822</strong></td>
</tr>
</tbody>
</table>

It should be noted that the savings identified are not necessarily additional.

*Figure 28: Good practice opportunities identified*
Opportunities for innovation

The following section considers measures identified that still have significant barriers to widespread implementation. These are summarised in figure 29.

Improved combustion efficiency

Indirect ovens

Figure 27 shows the indirect-fired oven burners to be set up with a high level of excess air. The measurements made indicated excess air levels of 250% during production runs on all flues.

For the indirect-fired ovens there is no monitoring of the combustion conditions other than during burner servicing. Burners appear to be set-up to ensure reliable oven operation and good product quality. Significant savings on flue gas heat losses could be made by setting up the burners for good energy efficiency and reducing the excess air levels.

A certain amount of excess air is required to maintain good combustion while minimising flue losses. Ideally, levels of below 100% should be achievable for indirect-fired ovens (this equates to 10.5% oxygen in the flue gases). Improving and sustaining improvements to combustion conditions can be delivered by regularly servicing the burners. However, this does require a proactive maintenance programme and making sure burner settings remain in place between servicing. It will be important to ensure that the temperature of the fire and recirculation tubes of ovens does not exceed the manufacturer’s recommendations when optimising combustion settings. In addition, the safe operation of the oven is paramount and any control will need to be fail-safe so that burner control does not result in dangerous operation.

Closer management of combustion conditions could be achieved by using an automated control system, such as oxygen trim. These systems constantly compare flue gas oxygen levels to programmed set-points and adjust the air to fuel ratio to maintain optimum values. Such systems are commonly used in other industries but are not normally applied to baking ovens. Oxygen trim would allow a closer control over excess air levels and should ensure that efficient levels are maintained at all times. There will be no ‘drift away’ from efficient operations conditions between services, making sure savings are maintained. To realise the benefits from oxygen trim, operation will need to be improved to allow the air to fuel ratio to be adjusted during firing. Therefore the development of combustion control will require an integrated measurement and control system for the burners. Therefore the burner might need to be upgraded or modified.

It is estimated that gas saving of up to 10% of can be made for an indirect oven by reducing the levels of excess air during combustion. Sustaining these savings is a key issue, and may not be achieved if it is reliant on maintenance and regular checking of burner settings. Automated control would support ongoing delivery of savings and could deliver further benefits. An additional 2% is considered possible from automated combustion control, which would also improve the annual sustainability of the savings.
Direct-fired oven

We analysed the exhaust gases from the vents of direct-fired ovens and found that excess air levels were similar to that of the indirect ovens. The optimisation of the direct-fired oven for combustion is more complex as the combustion products exhaust into the oven. The main control parameters for product quality are the operating temperature of the oven and ensuring adequate heat transfer. In addition, if air ingress occurs then this will add to issues relating to control of the burners based on excess air levels.

The benefits from optimising combustion for the direct-fired oven would potentially be less than for an indirect-fired unit. The exact optimum condition is not known and this would require further work as part of any development to deliver improved combustion performance.

Reduction of baking tin thermal mass

The oven heat balances presented in figure 19 and 20 show that a significant amount of the energy input to the oven is used to heat the bread tins. They have to be heated to the oven operating temperature (nominally 250°C) during baking and are cooled again before a fresh dough piece is added.

![Figure 29: Traditional steel baking tins](image)

Typically, the energy needed to heat the tins varies between 10% and 30% of thermal input, depending on the efficiency of the oven itself. Clearly a reduction in tin weight or a move away from steel to a material with a lower thermal mass will produce energy savings.

Bakery tins are traditionally made of steel and are robustly built to ensure that they have a long working life despite a significant amount of manual handling. Tins are recoated periodically and repaired to maintain their performance. However, over recent decades there has been a significant reduction in the levels of manual handling as process automation has increased. There may now be an opportunity to reduce the quantity of steel while still preserving tin life. Figure 30 demonstrates the relationship between tin weight loss and savings in gas consumption for a typical indirect-fired oven. This is based on a theoretical calculation of the heat required to raise the temperature of a tin through the oven.
Primary assumptions for the calculation are:

- Temperature of tin entering oven: 4°C
- Temperature of tin exiting oven: 250°C
- Specific heat capacity of tin metal: 0.5 megajoules/kg °C
- Typical tin mass: 8kg

A 30% reduction in tin weight would produce a 3.5% saving in overall oven thermal energy use.

![Tin Weight Savings](chart)

**Figure 30: Savings in oven thermal energy use by reducing weight of baking tins**

Significantly less heat would be lost if the tins were made from materials with lower thermal mass, such as thermoplastics or alternative metals. Tin manufacturers, such as Dupont, have been developing tins of this type and their adoption could reduce the tin heating requirement by up to 50%. Clearly this would yield very significant energy savings but there are a number of potential problems to be overcome before they could be used. These include:

- **Strength/working life** – would alternative materials stand-up to the thermal requirements and handling processes?
- **Effect on product** – would new material influence baking times or bread quality?
- **Magnetic handling** – would handling equipment, such as de-lidders, have to be modified or replaced?

**Electrical system integration – cooler**

In general, the temperature and humidity of a bakery cooler plant is controlled by mains water spray injection and by varying the proportions of recycled and fresh air flow. A water spray flow rate of approximately 0.5m³/hr was recorded for a large cooler at one of the host sites. Air flow rate is usually controlled by dampers, which is inefficient. There is a poor relationship between energy use and production rates through the cooler, as shown in figure 31. In this example the energy use of the
cooler varies little over the week, except during major production breaks, while there is significant variation in production.

The relationship between energy use and production could be improved if an integrated control system was used for the cooler plant. This would incorporate the use of VSDs rather than damper control of air and water flow rates. Many of the installed cooler plants are ageing and their fans may not be as efficient as more modern models. For example, it may be possible to make use of improved fan impellor designs that are now available.

The monitoring work identified that a new cooler (about three years old) was more efficient than older units. This was due to the improved control that allows the fans to reduce power input depending on the load. This control comprises effective automatic damper control of air flow rates based on achieving the correct cooler conditions.

Comparing the new cooler plant operation and the older units, there is a significant savings potential from retrofitting improved control to existing coolers.

We estimate that it’s possible to reduce the amount of electricity a cooler uses by 20% by improving fan control and air movement efficiency for existing plant older plant (as identified at two of the monitored sites). The exact savings potential depends on the operating loads currently on the plant and ensuring control improvements do not impact on product quality.

Figure 31: Variation of cooler electricity use (kWh) and production (kg)
Electrical system integration – oven

The primary users of electricity on a baking oven, as highlighted in section 5, are:

- burner combustion air fans
- circulation fans
- turbulence fans
- extraction fans
- the oven drive motor.

Of these the circulation and turbulence fans are the largest energy users.

Figure 32 shows the typical relationship between production and electricity consumption in a bakery oven.

![Graph showing variation of oven electricity use (kWh) and production (kg)](image)

**Figure 32: Variation of oven electricity use (kWh) and production (kg)**

Electricity use is virtually constant, except during major shutdowns, despite major changes in plant output. The air flow rates associated with the main fans are generally controlled by dampers which in many cases are adjusted manually. Very few changes are made to oven fan settings to reflect changes to production levels. An integrated control system for control of oven fans would allow the air flow to be adjusted according to the demand. VSDs on the fan motors could be incorporated to improve the efficiency at lower flow rates. It may also be possible to use modern fan impellors of a more efficient design.

As with the cooler, significant savings should be possible. The exact level of savings will depend on how well the oven fans can be reduced, in terms of their operating load, while maintaining product quality and safe operation of the oven. For the purposes of this study, an estimated savings potential of 20% has been made. This is indicative and would be for retrofitting of existing ovens.

Improving control of the fans within the oven has the potential to reduce electricity use, and also optimise heat transfer and product quality. The sector were interested in
heat transfer within the oven, but wanted to see further research to determine how this might be achieved.

Consider both safety and product quality if making changes to oven fan control. The issue of product quality relates to whether changes in fan operation would result in changes in heat transfer rates to the product and oven operating temperatures being achieved.

**Oven heat recovery**

The typical heat balance for direct and indirect-fired bakery ovens detailed in figures 19 and 20 highlight the large quantities of energy that is lost through the oven flues (indirect only) and exhausts (direct and indirect).

Bakeries made attempts to recover heat from ovens without success. Reasons cited were:

- safety issues during indirect recovery operation (e.g. explosive conditions due to natural gas build up)
- problems with contamination of the heat exchanger
- performance of the heat exchanger (recovering sufficient heat).

A further issue raised was the extent of the heat supply network for delivering recovered heat to potential end users.

Ideal heat sinks will have long operating hours, require energy at low temperature and will be technically easy to integrate. Within a bakery, heat sinks close to the oven usually include pre-heating combustion and prover air. Other heat sinks such as the supply of hot water for process applications, boiler water pre-heating and space heating (in despatch) will be further from the oven. The exact distances will vary by site but a heat distribution network would be required.

Indirect-fired ovens’ combustion gas flues are particularly attractive for heat recovery since they contain no contaminants from the baking process. Approximately 20-30% of the available heat in the combustion gases could be recovered at relatively high temperatures without condensing the water in the flues. Larger quantities of heat could be recovered (over 50%) if condensing heat recovery technologies were used to recover the latent heat of the moisture-laden gases. However, this is more likely to affect the burner operation because of increased back pressure.

The potential heat available from the combustion flues of one of the indirect ovens assessed would be around 120-200kW, depending on whether the latent heat is recovered. For the prover the heat demand for pre-heating air could be in the region of 50kW and combustion air pre-heat could take a further 60kW (this is approximate, based on increasing the air feed temperature to the burners from 25°C to 80°C. If a higher temperature is possible then this could increase as a heat sink. The set-up of the burners would have to be adjusted if the combustion air was pre-heated, but it should not affect their performance. Further heat sinks including space heating, process hot water demands and pre-heating boiler provide further potential. The space heating load will vary with ambient temperature, but will be a significant for a large part of the year due to the need for maintaining despatch temperatures.
Further heat recovery is possible from the oven extraction on the indirect and direct ovens. This exhaust stream contains moisture from baking and other contaminants off the bread, such as fats and particulates. Significant quantities of heat are available for recovery from the oven exhausts, but handling the dirty air stream makes this more complex. Therefore, design of recovery systems will need to consider contaminants and how to ensure a robust solution for recovery is provided from the oven extracts that does not require excessive maintenance.

A key issue raised by the sector, in relation to heat recovery, was that installed equipment does not require frequent or complex maintenance. For the oven, up to 20% of the heat available could be recovered if only the sensible heat is utilised. A further 30% may be recovered from the latent heat available.

**Business cases**

**Improve oven combustion efficiency**

The monitoring results and sector feedback identified combustion as a high priority, as there is the potential for major carbon savings (up to 17,466tCO₂/yr for the sector) and should be applicable to existing facilities, i.e. retrofit. From the workshop, the level of knowledge on combustion control was limited and maintenance was focused on ensuring safe operation not maximising efficiency.

Within the good practice improvements identified was the need to ensure burners were commissioned to operate as efficiently as possible within the confines of the existing equipment. This would deliver significant savings (up to 6,935tCO₂/yr for the sector) but concerns on whether these savings would be maintained were raised. For example, ongoing savings would require proactive maintenance procedures and rely on suppliers adopting practices to ensure efficient set-up of equipment.

Given the above, and the savings potential available, the sector was interested in using better combustion control from improved burner operation, with active management. For example, one option to deliver this would be to use oxygen trim with burner control improvements to allow combustion conditions to be optimised throughout plant operation. A key barrier to delivering more automated combustion control, and maximising and sustaining carbon savings, is the need to have technology proven within the sector. This was the main concern raised during the opportunities workshop and, therefore, the sector was interested in seeing combustion efficiency improvements demonstrated on ovens.

To allow combustion efficiency improvements to be developed, the most effective intervention would be to support demonstration of combustion efficiency improvements. In particular, effective control of excess combustion air, at a commercial scale, to provide the evidence base in terms of achieving savings and costs for implementation.

Summarised below is an overview of the benefits and actions required to develop this opportunity within Stage 2 of the IEEA programme (assuming 89 sites).
## Improved combustion efficiency

| Technology maturity and need for support | The application of combustion efficiency through improved control such as O₂ trim and burner operations is well-established in other sectors, e.g. boiler plant operation. The key issue objective is to establish suitable technologies and confirm the financial benefit and carbon savings that can be delivered. Ideally projects would need to be at a commercial scale so that outputs can be considered representative to the industry. |
| Annual carbon saving potential | Maximum – 17,466tCO₂ |
| Market penetration | 50% in 10 years |
| Project persistence | High – 10 years |
| Lifetime CO₂ saving (based on 50% take-up over 10 years) | 87,330 |
| Sector energy saving | £1.18m per year |
| Cost of technology (once mature) | £40,000-£120,000 (average £80,000) |
| Payback | Average 3 years |
| **Overview of Stage 2 project** | Carbon Trust could support demonstration project(s) in Stage 2 of the IEEA to maximise combustion efficiency of existing ovens. This would focus on optimising combustion conditions through improved control and burner technology. A suitable consortium to take this forward would include a bakery company with indirect and direct-fired ovens and a burner manufacturer/technology supplier |
| **Cost of demonstration project and possible structure** | The estimated cost for running a demonstration project at commercial scale is likely to be in the region of £150,000-£200,000 depending on the actual work to be undertaken. Typical activities to be completed for a demonstration project would include:  
  - assessment of current oven installations – representative sample – to establish combustion equipment specification and operating practices  
  - design and costing of proposed combustion efficiency improvement and installation of monitoring methodology  
  - commissioning and operation to optimise performance  
  - ongoing operation to confirm performance both in energy saving, operating reliability, etc  
  - defining solution and process to roll out to sector  
  - promoting findings from work. |
| Cost of carbon | £1.5 to £2.1 per tonne of CO₂ (based on 10-year implementation rate) |
| Barriers to adoption | The technology may prove to be too expensive to give a satisfactory payback except for plants that are highly utilised  
The supply chain may not put in sufficient market resources to exploit the developed technology.  
It may not be practical for direct-fired ovens |
Reduce thermal mass of baking tins

Significant quantities of energy are absorbed by the tins in the baking oven and large energy savings could be made if their thermal mass is reduced. The monitoring results have highlighted that reducing baking tin weight by 30% across the sector would deliver an annual carbon saving of 6,164tCO₂/yr. The workshop highlighted that baking tins were of traditional design, and the prime considerations of the bakery companies were reliability and endurance rather than their energy performance. The key barriers identified to changing tin design are around their technical performance. Key concerns were that:

- a new tin design may affect product quality or baking times
- it may not be possible to modify the tin handling systems of industrial bakeries to accept new tins
- lighter tins, or those made of alternative materials, may have a shorter operational life.

The sector has showed interest in the potential energy savings that could be achieved, but it will want to see how practical it is to use baking tins of a new design before widespread adoption. The Carbon Trust could provide support through Stage 2 of the IEEA to provide this evidence. It will be necessary to support a demonstration project at a commercial scale, and over a sufficiently long period, to prove that the savings are achievable within the technical constraints.

Summarised below is an overview of the benefits and actions required to develop this opportunity within Stage 2 of the IEEA programme.

<table>
<thead>
<tr>
<th>Reduce thermal mass of baking tins</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology maturity and need for support</strong></td>
</tr>
<tr>
<td><strong>Annual carbon saving potential</strong></td>
</tr>
<tr>
<td><strong>Market penetration</strong></td>
</tr>
<tr>
<td><strong>Project persistence</strong></td>
</tr>
<tr>
<td><strong>Lifetime CO₂ saving (based on 50% take-up over 10 years)</strong></td>
</tr>
<tr>
<td><strong>Sector energy saving</strong></td>
</tr>
<tr>
<td><strong>Cost of technology (once mature)</strong></td>
</tr>
</tbody>
</table>
Reduce thermal mass of baking tins

<table>
<thead>
<tr>
<th>Payback</th>
<th>N/A</th>
</tr>
</thead>
</table>

**Overview of Stage 2 project**

Carbon Trust could support demonstration project(s) in Stage 2 of the IEEA to trial new tin designs. This would focus on developing designs that were practical and enduring under normal bakery conditions and maintain product quality. A suitable consortia for developing this opportunity would be a baking tin manufacturer working together with a baking company towards a practical new tin design.

**Cost of demonstration project and possible structure**

The estimated cost for running a demonstration project at commercial scale is likely to be in the region of £50,000-£200,000, depending on the actual work done. Typical activities to be completed for a demonstration project would include:

- assessment of current plant requirements – to establish potential for tin redesign and assess handling practices
- design and costing of proposed baking tin
- development of project monitoring
- trials to confirm product quality and baking times maintained.
- ongoing operation to confirm tin performance over extended period
- defining the solution and process to roll out to sector
- promoting findings from work.

**Cost of carbon**

£1.6 to £6.4 per tonne of CO₂ (based on 10-year implementation rate)

**Barriers to adoption**

It may not be possible to modify industrial bakeries’ tin handling systems to accept new tins if new materials are used. The new tins may not have sufficient longevity to be economic. The re-designed tins may have a detrimental effect on product quality and/or baking times. The supply chain may not put in sufficient market resources to exploit the developed technology.

**Improved control of cooler fans**

There was significant interest at the workshop in retrofitting integrated electrical control to existing cooler plant. This would include the use of VSDs and improved impellor design. There is a significant number of older cooler plants within the sector and there is a large potential saving available from upgrading their control (up to 5,761tCO₂/yr for sector). The key barrier identified at the workshop was that the technology was unproven as a retrofit on existing plant. The sector is interested in a practical demonstration project on a typical plant to test feasibility.

Summarised below is an overview of the benefits of this opportunity.
## Electrical integration of cooler plant

| **Technology maturity and need for support** | Improved control strategies, such as VSDs, have been applied to new bakery coolers successfully. It will be important to prove to the sector that these improvements can be applied successfully to existing cooler plant and the predicted energy savings can be achieved. A demonstration project will have to be at a commercial scale to prove benefits and technical feasibility. |
| **Annual carbon saving potential** | Maximum – 5,761tCO₂ |
| **Market penetration** | 75% in 10 years |
| **Project persistence** | High – 10 years |
| **Lifetime CO₂ saving (based on 50% take-up over 10 years)** | 43,270 |
| **Sector energy saving** | £786k per year |
| **Cost of technology (once mature)** | £20,000-£30,000 (average £25,000) |
| **Payback** | Average four years |
| **Overview of project** | To develop an integrated control strategy for existing cooler plant. A suitable collaboration would be between a manufacturer of cooler plant and a bakery company with older coolers. |
| **Cost of demonstration project and possible structure** | The estimated cost for running a demonstration project at commercial scale is likely to be in the region of £50,000-£100,000 depending on the actual work done. Typical activities to be completed for a demonstration project would include: |
| | - assessment of current cooler installations – representative sample – to establish current control strategies and operating practices. |
| | - design and costing of proposed control improvement and installation of monitoring methodology. |
| | - commissioning and phase 1 operation to optimise performance and learnings from optimisation. |
| | - ongoing operation to confirm performance both in energy saving, operating reliability etc. |
| | - defining solution and process to roll out to sector. |
| | - promoting findings from work. |
| **Cost of carbon** | £1.1 to £2.3 per tonne of CO₂ (based on 10-year implementation rate) |
| **Barriers to adoption** | The technology may prove to be too expensive to give a satisfactory payback, except for plants that are well used. |
| | The retrofitting of technology to older plants may not be feasible. |
| | The supply chain may not put in sufficient market resources to exploit the developed technology. |

## Electrical integration of oven

There is significant potential for the retrofitting of integrated electrical control to existing oven plant. This would include the use of VSDs and improved impellor design. There is a potential saving of up to 4,934tCO₂/year across the sector. However, there
was some concern expressed at the workshop that the technology was unproven as a retrofit on existing plant. This is particularly relevant given the complexity of baking oven operation and the potential effect on product quality and/or baking time. The sector is interested in a practical demonstration project on a typical plant to test feasibility and ensure that there are no significant detrimental implications to the product.

In order to develop the retrofitting of oven control improvements on older plant it is recommended that a demonstration on an existing plant cooler to provide the evidence base for the sector in terms of achieving savings and costs for implementation.

Summarised below is an overview of the benefits and actions required to develop this opportunity.

### Electrical integration of oven plant

| Technology maturity and need for support | Modern bakery ovens have integrated control strategies, often incorporating VSDs, which maintain oven conditions while maximising electrical energy efficiency. It will be important to prove to the sector that these improvements can be applied successfully to existing ovens plant and the predicted energy savings can be achieved. The major difficulties to retrofitting this technology are likely to be maintaining the heat distribution across the oven and ensuring product quality. A demonstration project will have to be at a commercial scale to prove benefits and technical feasibility. |
| Annual carbon saving potential | Maximum – 4,935tCO₂ |
| Market penetration | 30% in 10 years |
| Project persistence | High – 10 years |
| Lifetime CO₂ saving (based on 30% take-up over 10 years) | 14,805 |
| Sector energy saving | £239k per year |
| Cost of technology (once mature) | £20,000–£30,000 (average £25,000) |
| Payback | Average 4.5 years |
| Overview of project | To develop an integrated control strategy for existing oven plant. This would focus on optimising oven operation through improved control and fan impellor design. A suitable collaboration would be between a bakery company and oven manufacturer. |
| Cost of demonstration project and possible structure | The estimated cost for running a demonstration project at commercial scale would be expected to be in the region of £50,000 - £100,000 depending on the actual work to be undertaken. Typical activities to be completed for a demonstration project would include: |
| | • assessment of current oven installations – representative sample – to establish current control strategies and operating practices |
| | • design and costing of proposed control improvement and installation of monitoring methodology |
| | • commissioning and phase 1 operation to optimise performance |
and learnings from optimisation

- ongoing operation to confirm performance both in energy saving, operating reliability etc
- defining solution and process to roll out to sector
- promoting findings from work.

Cost of carbon

| £3.4 to £6.8 per tonne of CO₂ (based on 10-year implementation rate) |

Barriers to adoption

| The technology may prove to be too expensive to give a satisfactory payback except for plants that are highly utilised. |
| The retrofitting of technology to older plants may not be feasible |
| Automatic control strategy may affect product quality or oven operation |
| The supply chain may not put in sufficient market resources to exploit the developed technology. |

Oven heat recovery

The monitoring results have confirmed that this has the potential to deliver major carbon savings (up to 17,466tCO₂/yr for the sector). For this reason the sector is positive towards the concept of oven heat recovery, despite there being a number of failed installations in the past. From the workshop the level of knowledge of new heat recovery techniques and applications in other industries was limited, but the sector is keen to apply the technology. A key barrier is the lack of proof that the technology can be supplied to bakery ovens successfully, but this could be addressed by establishing a demonstration project.

To allow oven heat recovery to be developed, it is recommended that the Carbon Trust provide support through Stage 2 of the IEEA. The most effective intervention would be to support demonstration of a project a commercial scale to provide the evidence base for the sector in terms of achieving savings and technical feasibility and economics of implementation.

Summarised below is an overview of the benefits and actions required to develop this opportunity within Stage 2 of the IEEA programme.

Oven heat recovery

| Technology maturity and need for support |
| Heat recovery from oven flues and vents has been attempted by a number of equipment suppliers and bakery companies in the past. However the majority have failed to deliver the expected benefits. Now, with new technologies – such as heat pipes and self cleaning heat exchangers – and the changing economics of saving energy, there is an opportunity to apply the technique across the sector. However, there is a need to prove to the sector that heat recovery is technically and economically feasible. A demonstration project would need to be at a commercial scale to gain credibility within the sector. |

| Annual carbon saving potential |
| Maximum – 20,805tCO₂ |

| Market penetration |
| 50% in 10 years |
## Oven heat recovery

<table>
<thead>
<tr>
<th><strong>Project persistence</strong></th>
<th>High – 10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lifetime CO₂ saving</strong></td>
<td>104,025</td>
</tr>
<tr>
<td>(based on 50% take-up over 10 years)</td>
<td></td>
</tr>
<tr>
<td><strong>Sector energy saving</strong></td>
<td>£769k per year</td>
</tr>
<tr>
<td><strong>Cost of technology</strong></td>
<td>£60,000 to £150,000</td>
</tr>
<tr>
<td>(once mature)</td>
<td></td>
</tr>
<tr>
<td><strong>Payback</strong></td>
<td>6 years</td>
</tr>
</tbody>
</table>

### Overview of Stage 2 project
Carbon Trust could support demonstration project(s) in Stage 2 of the IEEA to trial heat recovery from oven flues/vents. This would focus on developing designs that were practical and enduring under normal bakery conditions. The best uses for recovered heat would be in areas with long hours of operation and that have a fairly low recovery temperature, such as prover heating, steam boiler make-up, hot water generation and preheating of combustion air. Other potential uses for the recovered heat include space heating and the tray wash but these uses are either more seasonal or more difficult (and expensive) to integrate into a scheme. It is anticipated that the best way that the innovation could be taken forward would be through a collaboration project between a bakery company and technology provider. Projects may be required for heat recovery from both indirect-fired ovens combustion flues and oven vents.

### Cost of demonstration project and possible structure
The estimated cost for running a demonstration project at commercial scale would be expected to be in the region of £150,000-£300,000 depending on the actual work to be undertaken. Typical activities to be completed for a demonstration project would include:

- assessment of current plant requirements – to establish potential for heat recovery and likely heat sinks
- design and costing of proposed heat recovery system
- development of project monitoring
- trials to confirm operational feasibility and that there are no detrimental effects on oven
- ongoing operation to confirm maintenance requirements and monitor any decrease in performance over time
- defining solution and process to roll out to sector
- promoting findings from work.

### Cost of carbon
£1.4 to £2.9 per tonne of CO₂ (based on 10-year implementation rate)

### Barriers to Adoption
Heat recovery technology may not be feasible on baking ovens, particularly older plants
There may be insufficient heat sinks for economic applications
The supply chain may not put in sufficient market resources to exploit the developed technology.
Figure 33 lists the measures identified that still have significant barriers to widespread implementation. It should be noted that the savings presented cannot be summed as some are either/or opportunities.

For the opportunities presented in figure 33 the maximum potential carbon saving would be in the region of 94,300tCO₂ per year. This is based on the maximum implementation potential across the sector for the opportunities that deliver the highest carbon savings. This represents a further 16.5% of total sector carbon emissions and approximately 30% of the emissions associated with the proving, baking and cooling.
Figure 33: Opportunities for innovation

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Cost to implement (per plant) £</th>
<th>Payback (years)</th>
<th>% of sites where applicable</th>
<th>Total CO2 saving by sector (tonnes)</th>
<th>Barriers to implementation</th>
<th>Strategy to address barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Combustion efficiency</strong></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>High-efficiency combustion e.g. radiant burners</td>
<td>To be determined</td>
<td>N/A</td>
<td>10</td>
<td>1,901</td>
<td>Needs to be demonstrated. Likely to be applicable to new build only and implications on product quality need to be considered.</td>
<td>Sector to engage with suppliers on new plant build regarding optimisation of burner technology to deliver product quality while optimising energy efficiency. This would link with broader activities on efficiency of heat transfer to the product as well as minimising heat wastage.</td>
</tr>
<tr>
<td>Automatic control of oven burner combustion</td>
<td>80,000</td>
<td>3.0</td>
<td>100</td>
<td>17,466</td>
<td>Needs to be demonstrated. More difficult on direct-fired ovens. Effect on product quality is also a concern as is maintenance of equipment. If it is complex or requires regular and time consuming maintenance than this could result in the technology not being used to its full potential.</td>
<td>Commercial scale tests to build confidence in industry regarding savings potential and to assess issues on maintenance and production quality.</td>
</tr>
<tr>
<td><strong>Reduce thermal mass of baking tins</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce weight of baking tins</td>
<td>No capital, phased replacement</td>
<td>N/A</td>
<td>100</td>
<td>6,164</td>
<td>Robustness of tins. Product quality.</td>
<td>Design and trials to demonstrate performance.</td>
</tr>
<tr>
<td>Baking tins made from low thermal mass materials</td>
<td>No capital, phased replacement</td>
<td>N/A</td>
<td>100</td>
<td>10,124</td>
<td>Robustness of tins. Product quality. Issues with magnetic handling.</td>
<td>Design and trials to demonstrate performance.</td>
</tr>
<tr>
<td><strong>Electrical integration of cooler</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve control of cooler fans, e.g. improved set-point monitoring and fan operation</td>
<td>25,000</td>
<td>3.8</td>
<td>90</td>
<td>4,136</td>
<td>Concern that product quality maintained.</td>
<td>Prove capability for retrofit at commercial scale, while maintaining product quality.</td>
</tr>
<tr>
<td>More efficient fan impellor</td>
<td>To be confirmed</td>
<td>N/A</td>
<td>90</td>
<td>1,625</td>
<td>Concern that product quality</td>
<td>Research project to prove</td>
</tr>
<tr>
<td>Opportunity</td>
<td>Cost to implement (per plant) £</td>
<td>Payback (years)</td>
<td>% of sites where applicable</td>
<td>Total CO2 saving by sector (tonnes)</td>
<td>Barriers to implementation</td>
<td>Strategy to address barriers</td>
</tr>
<tr>
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</tr>
<tr>
<td>design for cooler</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>maintained. Is it economic on retrofit?</td>
<td>capability and economics.</td>
</tr>
<tr>
<td><strong>Electrical integration of oven</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved control of oven fans, e.g. improved set-point monitoring and fan operation</td>
<td>25,000</td>
<td>4.5</td>
<td>90</td>
<td>3,545</td>
<td>Concern that product quality is maintained.</td>
<td>Prove capability for retrofit at commercial scale which demonstrates heat distribution and that quality of product is not impacted.</td>
</tr>
<tr>
<td>More efficient fan impellor design for oven</td>
<td>To be confirmed</td>
<td>N/A</td>
<td>90</td>
<td>1,389</td>
<td>Concern that product quality maintained. Is it economic on retrofit?</td>
<td>Research project to prove capability and economics.</td>
</tr>
<tr>
<td>Improved heat distribution across oven</td>
<td>To be confirmed</td>
<td>N/A</td>
<td>90</td>
<td>N/A</td>
<td>Product quality maintained. Economic viability.</td>
<td>Industrial research to assess options.</td>
</tr>
<tr>
<td>Automatic control of oven shut down and gapping</td>
<td>30,000</td>
<td>3.0</td>
<td>80</td>
<td>6,614</td>
<td>Age of ovens. Complexity of control functions.</td>
<td>Prove that it can be applied as retrofit economically.</td>
</tr>
<tr>
<td><strong>Heat recovery from oven flues and exhaust vents</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensible heat recovery from indirect oven flue gases</td>
<td>60,000</td>
<td>4.5</td>
<td>50</td>
<td>6,010</td>
<td>Previous failures. Cost. Uses for recovered heat. Oven pressure effects.</td>
<td>Establish commercial scale research project.</td>
</tr>
<tr>
<td>Sensible and latent heat recovery from indirect oven flue gases</td>
<td>120,000</td>
<td>5.7</td>
<td>50</td>
<td>10,274</td>
<td>Previous failures. Cost. Uses for recovered heat.</td>
<td>Establish commercial scale research project.</td>
</tr>
<tr>
<td>Sensible heat recovery from oven (direct and indirect) exhausts</td>
<td>100,000</td>
<td>6.4</td>
<td>90</td>
<td>6,781</td>
<td>Previous failures. Cost. Uses for recovered heat. Oven pressure effects direct ovens.</td>
<td>Establish commercial scale research project.</td>
</tr>
<tr>
<td>Sensible and latent heat recovery from (indirect and direct) oven exhausts</td>
<td>150,000</td>
<td>6.8</td>
<td>90</td>
<td>10,531</td>
<td>Previous failures. Cost. Uses for recovered heat. Oven pressure effects direct ovens.</td>
<td>Establish commercial scale research project.</td>
</tr>
<tr>
<td><strong>Alternative heat sources for oven</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Micro turbine / fuel cell to provide hot gases to oven</td>
<td>150,000</td>
<td>5.0</td>
<td>10</td>
<td>26,700</td>
<td>Novel technology. Adds complexity to plant operation.</td>
<td>Research project to assess feasibility.</td>
</tr>
</tbody>
</table>
7. Next steps

Next steps for the sector

Given that the level of awareness of the need for energy saving in the bakery industry is high, the sector has already taken steps to improve efficiency. However, more work should be done to raise the awareness of what is still possible at a site level. Specifically:

**Implement general good practice measures**

More robust implementation of good practice opportunities at all sites in the sector is possible. Operational staff should be made more aware of the level of opportunity that is still available by considering the following recommendations:

- Turn-off campaigns for conveyors
- Improvement to compressed air management practices
- More efficient air compressor plant, including VSDs
- Reduction of compressed air leakage rate
- High-efficiency lighting applications – the installation of T5 fluorescent high-frequency systems in productions areas
- Occupancy control of lights in lower use areas such as, offices, meeting rooms, stores and plant rooms
- Reduce air ingress to despatch area – improve seals and air curtains
- Space heating control improvements – office wet systems temperature compensation and boiler optimisation. Process area convector heater advanced controls
- The use of VSDs on bakery ventilation systems
- Improved insulation of steam and chilled water distribution systems
- Energy awareness campaigns

**Implement specific bakery good practice measures**

By working closely with equipment suppliers (where appropriate), bakeries should consider:

- increasing oven combustion efficiency by improving maintenance operations and measurements
- modulating oven burner firing rate to control temperature more effectively, rather than high fire/low fire control
- reducing hot oven gas extraction from ovens through optimising damper settings
- using direct drive or non-slip drive on fans
- balancing oven airflow to reduce losses
- a phased manual shut down of oven burners during product gaps and shutdowns
- automatic switch off or conversion to low fire of oven burners during gapping and shutdown
- manual shut down/ turn down of oven fans during gapping
- improved prover, oven and cooler shutdown during production gaps
- reviewing their production baking process schedule.
Engage in IEEA projects
Companies should consider taking advantage of potential Carbon Trust support within the IEEA programme to participate in research or pilot projects developing the market readiness of the following innovative concepts as part of IEEA Stage 2:

- Improve oven combustion efficiency
- Reduce thermal mass of baking tins
- Oven heat recovery

There are potential risks with implementing unproven technologies at active bakeries. And innovative equipment not yet in commercial manufacture is likely to have a relatively high cost. So any projects brought to the Carbon trust should be sufficiently large in scale to provide a realistic and replicable evidence base for energy performance, process integration and production impacts – and therefore demonstrate the technology’s applicability and potential cost-effectiveness to the bakery sector in more detail.

The opportunities identified in section 6 are those that offer potential beyond current good practice activities to deliver carbon savings.

In addition to the concepts identified above, a further area of interest identified by the sector was heat transfer improvements to the product. This is an extremely complex subject and the sector recognises that it is difficult to quantify opportunities without far more fundamental research. Although savings cannot be defined through this work, the industry could consider delivering heat transfer efficiencies and deploy near market solutions.

Next steps for the Carbon Trust
Following its work as part of the IEEA, the Carbon Trust can now update and improve its advice to companies in the industrial bakery sector. The Carbon Trust also has account managers to build relationships with the sector and ensure that opportunities for energy saving and emissions reduction are maximised.

The Carbon Trust is hoping to support the implementation of the following concepts elaborated in this guide:

- Improve oven combustion efficiency
- Reduce thermal mass of baking tins
- Oven heat recovery

Throughout this work, the Carbon Trust will continue to disseminate knowledge and help replicate energy-efficiency best practices across the bakery sector.
8. Acknowledgements
This report has been prepared by the Carbon Trust from the technical work completed by SKM Enviros Ltd with assistance from the Food and Drink Association.
Appendix 1 – Sector stakeholders

Equipment suppliers/ academic organisations alongside bakery companies, engaged in the programme in Table 1

Table A1: Bakery equipment suppliers/ Stakeholders engaged in Programme

<table>
<thead>
<tr>
<th>Company</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spooner Industries Ltd</td>
<td>Supplier of bakery equipment including ovens, provers and coolers</td>
</tr>
<tr>
<td>Railway Road</td>
<td></td>
</tr>
<tr>
<td>Ilkley</td>
<td></td>
</tr>
<tr>
<td>West Yorkshire</td>
<td></td>
</tr>
<tr>
<td>LS29 8JB</td>
<td></td>
</tr>
<tr>
<td>01943 609505</td>
<td></td>
</tr>
<tr>
<td><a href="http://www.spooner.co.uk">www.spooner.co.uk</a></td>
<td></td>
</tr>
<tr>
<td>Baker Perkins Ltd</td>
<td>Supplier of bakery equipment including ovens, provers, mixers Moulders</td>
</tr>
<tr>
<td>Manor Drive</td>
<td></td>
</tr>
<tr>
<td>Paston Parkway</td>
<td></td>
</tr>
<tr>
<td>Peterborough</td>
<td></td>
</tr>
<tr>
<td>PE4 7AP</td>
<td></td>
</tr>
<tr>
<td>01733 283000</td>
<td></td>
</tr>
<tr>
<td><a href="http://www.bakerperkinsgroup.com">www.bakerperkinsgroup.com</a></td>
<td></td>
</tr>
<tr>
<td>European Process Plant Ltd</td>
<td>Supplier of bakery equipment including provers, mixers, ovens and slicing machines</td>
</tr>
<tr>
<td>EPP House, Epsom Business Park</td>
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<tr>
<td>Kiln Lane</td>
<td></td>
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<tr>
<td>Epsom</td>
<td></td>
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<tr>
<td>Surrey</td>
<td></td>
</tr>
<tr>
<td>01372 745558</td>
<td></td>
</tr>
<tr>
<td><a href="http://www.europeanprocessplant.co.uk">www.europeanprocessplant.co.uk</a></td>
<td></td>
</tr>
<tr>
<td>FBS Prestige</td>
<td>Supplier of baking tins</td>
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<tr>
<td>Lilac grove</td>
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<tr>
<td>Beeston</td>
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<tr>
<td>Nottingham</td>
<td></td>
</tr>
<tr>
<td>NG9 1PF</td>
<td></td>
</tr>
<tr>
<td>08452 505400</td>
<td></td>
</tr>
<tr>
<td><a href="http://www.fbsprestige.com">www.fbsprestige.com</a></td>
<td></td>
</tr>
<tr>
<td>Exhausto</td>
<td>Technology supplier – heat recovery from oven exhausts</td>
</tr>
<tr>
<td>Unit 3, Lancaster Court</td>
<td></td>
</tr>
<tr>
<td>Coronation road</td>
<td></td>
</tr>
<tr>
<td>Cresssex Business Park</td>
<td></td>
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<tr>
<td>High Wycombe</td>
<td></td>
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<tr>
<td>Bucks</td>
<td></td>
</tr>
<tr>
<td>HP123TD</td>
<td></td>
</tr>
<tr>
<td><a href="http://www.exhausto-cdt.co.uk">www.exhausto-cdt.co.uk</a></td>
<td></td>
</tr>
<tr>
<td>Company</td>
<td>Activity</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Capway Systems UK Ltd</td>
<td>Supplier of bakery automation systems and equipment including microwave ovens</td>
</tr>
<tr>
<td>Unit 17, The Sidings Station Road Guiseley Leeds West Yorkshire LS208BX 01943 8712000 <a href="http://www.capway.nl">www.capway.nl</a></td>
<td></td>
</tr>
<tr>
<td>Campden BRI</td>
<td>Food and drink research and technical services</td>
</tr>
<tr>
<td>Station Road Chipping Campden Gloucestershire GL556LD 01386 842000 <a href="http://www.campden.co.uk">www.campden.co.uk</a></td>
<td></td>
</tr>
<tr>
<td>University of Leeds</td>
<td>Research projects on plant efficiency with major bakers</td>
</tr>
<tr>
<td>School of Mechanical Engineering Leeds LS2 9JT <a href="http://www.engineering.leeds.ac.uk">www.engineering.leeds.ac.uk</a></td>
<td></td>
</tr>
<tr>
<td>Aerogen Company Ltd</td>
<td>Oven burner supplier</td>
</tr>
<tr>
<td>Unit 3, Alton Business Centre Omega Park Alton Hampshire GU342YU 01420 837444 <a href="http://www.aerogen.co.uk">www.aerogen.co.uk</a></td>
<td></td>
</tr>
</tbody>
</table>