Raising the bar in PET bottle lightweighting

Research findings that achieved a new European lightweighting standard for carbonated drinks bottles made from PET.
WRAP works in partnership to encourage and enable businesses and consumers to be more efficient in their use of materials and recycle more things more often. This helps to minimise landfill, reduce carbon emissions and improve our environment.
This project was initiated by Esterform Packaging, with the support of WRAP’s Innovation Fund, to develop innovative packaging that could reduce household packaging waste originating from the retail sector.

While the rate of recovery of bottles is improving rapidly from a low base, reducing the weight of beverage packaging provides a further powerful way of conserving materials, reducing packaging weight and reducing the energy used in production and transport. The cost savings involved also provide an incentive to invest in the new tooling needed to produce the lighter bottles.

This project makes use of recent improvements in blow moulding technology, resin technology and preform design as a means of further reducing the weight of PET bottles made in the UK. Two bottles were selected for their potential to become optimum packaging weight examples for the beverage market:

- a 500ml Carbonated Soft Drinks (CSD) bottle for Radnor Hills. This bottle was initially 25g, and it has been successfully redesigned and produced at the target weight of 20g; and
- a two litre CSD bottle for a major CSD manufacturer. This bottle was initially 42g, and was successfully redesigned at the target weight of 40g.

The reduction in packaging weight achieved directly through this project was 250 tonnes of PET per annum, which is equivalent to the elimination of 8.3 million (30g) bottles from the waste stream.

If the new designs were adopted throughout the UK beverage market for these bottle sizes, the savings of PET being used would be 3,400 tonnes, which is equivalent to 113 million 30g bottles.

The weight savings also lead to energy savings during processing. For Esterform Packaging the new preform designs could deliver annual energy savings of over 200MWhr. Energy savings of over 2,810MWhr would be achieved if the two new designs were adopted across the UK beverage industry.

The development of the new preforms has led to applications beyond those that were originally intended, extending the weight savings achieved and delivering even greater environmental benefits.

This validates the approach adopted in this project, as well as showing the value of disseminating the improved efficiencies throughout the UK beverage industry.
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2 Project scope

2.1 Background
This project was developed with the support of WRAP’s Innovation Fund, to develop and trial innovative packaging that will reduce household packaging waste originating from the retail sector.

According to WRAP’s 2006 UK Plastic bottle recycling survey, the total quantity of plastic bottles entering the UK household waste stream is approximately 510,000 tonnes per annum, with an estimated 85,000 tonnes of bottles collected by the end of 2005. This represents a recycling rate of 17%, and is equivalent to 2,125 million plastic bottles.

If the same approach were applied to the whole of the beverage market, a 10% weight reduction would result in savings of 19,000 tonnes, which would be equivalent to removing more than 570 million bottles (with an average weight of 30g each) from the waste stream.

While the rate of recovery of bottles is improving rapidly from a low base, the approach of lightweighting beverage packaging originating from the retail sector provides a further powerful way to minimise waste at source, and reduce raw material processing and distribution costs. This is because it provides an economic incentive to make the necessary changes to the bottles, provided it is technically feasible to do so.

If a weight reduction feasibility study is successful then new tooling would be required, which, while initially expensive, can be amortised over a number of years to recoup the capital outlay. Since virgin PET costs approximately £800 per tonne, each reduction of 100 tonnes would represent a saving of £80,000.

The opportunity to reduce the weight of two bottles beyond current levels has been made possible by exploiting recent improvements that have occurred in blow moulding technology, resin technology and preform design.

2.2 Aim of the project
This project investigated the technical and commercial feasibility of reducing the weight of two specific PET bottles made in the UK by Esterform Packaging, for two major beverage fillers supplying supermarkets:

- a 500ml CSD bottle used by Radnor Hills; and
- a two litre CSD bottle.

These two bottles were selected because they were already very competitive in terms of packaging weight in the market place. The target weight for each bottle would set a new optimum packaging weight for these sizes of PET bottles, and as a result, others across the industry would be encouraged to follow suit in light-weighting.

The 500ml bottle was initially 25g, and the target weight was 20g (a reduction of 20%). The two litre bottle was initially 42g, and the target weight was 40g (a reduction of 4.8%).

The potential reduction in packaging weight that might be achieved through this project would be 250 tonnes of PET per annum for the two product lines in the trials - equivalent to 8.3 million bottles.

If the new designs were adopted for the whole of the UK market, then the savings of packaging materials would increase to 3,400 tonnes (equivalent to 113 million bottles).

The key steps taken in the project were:
- the re-design of the preforms using the latest techniques available to the PET industry and Esterform Packaging;
- the manufacture and testing of the new designs in conjunction with preform machine suppliers, blow-moulding machine suppliers and beverage fillers; and
- testing of the new designs in short- and long-term performance tests and filling trials.

2.3 Timescales
The project was begun in May 2005, and completed at the end of May 2006.

2.4 Project partners
The project was initiated by Esterform Packaging with the collaboration of two of their customers. Technical expertise was provided by Husky, SIG and Sidel, key providers of world-class PET moulding and processing technology.

The project was managed by Nextek Limited. The key partners and contacts are shown in Table 1.

<table>
<thead>
<tr>
<th>Partner</th>
<th>Role</th>
<th>Key Contacts</th>
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<tr>
<td>Esterform Packaging</td>
<td>Leading organisation, preform manufacturer</td>
<td>Mark Tyne, Director</td>
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<tr>
<td></td>
<td>and bottle supplier</td>
<td></td>
</tr>
<tr>
<td>Nextek Pty Ltd</td>
<td>Project management</td>
<td>Professor Edward Kosior</td>
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<td>CSD manufacturer</td>
<td>Bottle filler</td>
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<tr>
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<td>Preform design and blow moulding</td>
<td>Stephen Martin</td>
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<td>Krones</td>
<td>Preform design and blow moulding</td>
<td>Karl Hopkins</td>
</tr>
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</table>

Table 1
Project partners
2.5 Project methodology

The weight of PET bottles is determined predominantly by the bottle performance requirements and specification of the neck and base.

The neck design is influenced by handling requirements, and the closure style used. Different neck finishes can have different weights associated with design features.

The design and weight of the base is related to the requirement to withstand the internal pressure of a carbonated product. Hence still water bottles can be lighter than carbonated beverage bottles.

The mid-section body of the bottle was the focus for manipulation of design for lightweighting in this project, since the design of the neck and base was unchanged. This lightweighting would be achieved by gaining better material distribution during the blow moulding steps, by exploiting new developments in PET resin (energy-absorbing additives) and improvements in preform heating in blow moulding machines.

Esterform Packaging anticipated being able to lightweight the samples of the 500ml bottle from 25g to 22g and possibly 20g (the lightest bottle in Europe is currently 22g. In the UK the 500ml bottles are typically 23-25g).

The target for the two litre bottle was a reduction from 42g to 40g. Currently two litre bottles are 41.5-42g.

The project was carried out in the manner described in the bullet points, in order to achieve the best technical result in the shortest time:

- development of a process checklist;
- development of new designs via a Computer Aided Design (CAD) system;
- adaptation of the preform designs to suit bottle and blowing machinery;
- resolution of any nesting issues though preform redesign via CAD simulation;
- feedback from machinery companies, Krones, SIG and Husky, received and used in the designs;
- quotations requested for preforms from Husky;
- moulds, and/or core pins manufactured by Husky;
- preforms for use in trials manufactured by Husky;
- bottles blown and tested by Esterform Packaging;
- line trials conducted at the laboratories of Esterform Packaging and fillers;
- approval testing conducted by the filler companies; and
- successful new designs were to be commercialised by Esterform Packaging for supply to the fillers.
2.6 Manufacturing considerations

A carbonated drink in a PET bottle

- Light may affect some ingredients; high storage temperatures would force CO₂ out of solution into headspace, making drink fizzy on opening; would also soften bottle.
- Diffusion of gases depends on their relative concentrations, so more oxygen outside means it will diffuse inwards, as PET is permeable.
- CO₂ loss through bottle wall, about 0.04 volumes per week.
- Up to 1% water may evaporate through bottle wall over shelf life.
- Up to 5% of CO₂ and other volatile ingredients may diffuse through bottle wall, and/or be absorbed by the plastic.
- All materials leach some components into their contents, the quantity affected by reactions with the contents, but well within safe limits.
- Odours from the environment could taint product.
- Depending on the product, up to 5% of CO₂ may diffuse through bottle wall, and/or be absorbed by the plastic.
- Components of plastic or materials used in manufacture may migrate into drink (e.g., minute, harmless traces of acetaldehyde, PET oligomer).
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- PET bottles made thin for least material (a 2 L bottle is <40 g), relies on internal pressure for rigidity.
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- PET bottles are lighter and much less liable to breakage than glass bottles, use less energy for transportation.
- Glass bottles would be considered for many similar applications; glass is impermeable, commonly used in 350 mL to 1.5 L sizes, with 2 L glass bottles considered the maximum size for easy and safe handling.

Figure 1 Manufacturing considerations for a carbonated drink in PET bottle.
3 Lightweighting two litre bottles

3.1 Preform design
The size, shape and surface features, as well as bottle performance requirements of the final bottle shape, determine the shape of a preform. Structural designers use well-known expansion ratios, since a controlled amount of stretching at controlled temperatures determines the physical performance of the bottles.

The standard preform used for two litre bottles at a major CSD manufacturer has been 42g for a number of years. This preform has already been optimised and reduced in weight from 44g, and the success of further reduction was not immediately assured. For this reason the project team decided to assess the performance of a 41g preform as well as a 40g preform.

The design team developed the new designs through an iterative process, first looking at ways to improve the design to meet the bottle performance requirements by minimising the weight of the relevant neck, mid-section and base parts of the bottle and contracting these into the design of the preform. The preform was then redesigned to meet the heating and expansion requirements for creating the final bottle shape. The new design was then analysed and modified by the machinery specialists from Husky, Sidel, SIG and Krones for ease of moulding and blow moulding. CAD simulation was used to detect and then avoid potential problems such as preform nesting. This process was repeated once the final design was arrived at, to ensure that it represented the best possible design for the target lightweight bottle.

The technical project team at Esterform Packaging developed the designs for lightweighted bottles as shown in drawings in Appendix 7.2

An order was placed with Husky to manufacture new moulds, and to mould 5,000 preforms of each design. The blow moulding of the preforms into bottles and the testing of lightweight bottles was carried out at Esterform Packaging. Burst pressure, Carbon Dioxide (CO₂) retention creep behaviour tests, blowing trials, and conveying and filling level tests were all carried out.

Appendix 7.1 provides a simple diagram of the injection blow moulding process.

3.2 Typical design points considered for lightweight product development

Preform design to suit bottle:
- material distribution – establish weight required in neck, body and base;
- stretch ratios best possible for performance, avoiding creep, CO₂ loss etc; and
- design of preform to suit injection moulding process - wall, flow length, tip thickness etc.

Preform design to suit blowing machine:
- neck damage when tipping or handling preforms;
- nesting* of preforms;
- support for collar ledge for roller in-feeds;
- output speeds;
- efficiency;
- palletising; and
- air conveying.

Bottle performance, filling line:
- handling to filler;
- labelling, expansion of label panel; and
- packing, expansion of body.

Bottle performance in market place:
- effect of label panel creep;
- base performance; and
- shelf life/CO₂ loss.

Typical steps to achieve design:
- establish customer bottle weight now;
- establish preform weight and design used now; and
- establish bottle performance that is required by the customer.

By using a computer model, investigate whether savings can be made on:
- bottle neck - known specifications to be worked-to;
- bottle petaloid base - proven designs and performance weight specification to be followed; and
- bottle body - are there thick areas that could be reduced etc?

From findings, produce proposed preform design

Supply preform design to the blowing machine supplier for feedback on:
- suitability in relation to the finished bottle;
- confirmation that the blowing machine output speed will not be effected and that it will blow efficiently;
- confirmation that the preform will handle efficiently through the machine; and
- any other comments?

Supply preform design to Husky for feedback on suitability for good quality and efficient production:
- confirm that tip thickness is optimum;
- confirm that wall thickness is sufficient to prevent knit lines at the neck;
- confirm that the injection pressure required to fill the cavity is not excessive, preventing premature mould wear; and
- any other comments?

*Nesting = the base of one preform locating in the opening of another preform during manufacture and/or distribution. Can effect production efficiencies.
3.3 Blow moulding trial for preforms
The blow moulding trial of the 41g and 40g preforms for two litre bottles was carried out with staff from Esterform Packaging present.

For this initial trial, 500 of each of the 40g and 41g preforms were supplied and run on the Krones blowing machine, producing two litre petaloid bottles.

The machine was set up to run the standard 42g preform, to keep the adjustments to a minimum. After this setting-up phase, the 41g preform was the first to be trialled, followed by the 40g preform.

The following observations were made at the trials:
- A minor decrease in the temperature at the tip of the preform mould was all that was required. No other changes were necessary;
- The machine performance was not affected;
- The base weight achieved was 8.5g/9g, within the normal acceptable specification;
- The bottles passed the customer’s burst test at 10 bar;
- The bottles look good and received a positive response from the customer.
- The 40g bottles appeared to be produced more easily than the 41g.

3.4 Creep testing of two litre bottles
The creep behaviour test examines the progressive expansion of a bottle under pressure once it is filled and carbonated. Plastics are visco-elastic materials, and continue to respond to applied pressures over time – this behaviour is known as ‘creep’. In a lightweight bottle the progressive expansion may affect appearance, CO₂ retention and adhesion of an applied label, and so it is important to characterise this behaviour.

The creep behaviour of the lightweight bottles was analysed, starting on the 7th October. This was carried out by pressurising the filled bottles with CO₂ to 3.5 atmospheres, and monitoring changes in dimensions and pressure. The key factor here was to determine whether the lightweight bottles creep and lose CO₂ significantly faster than the standard 42g bottle. The testing was carried out for three months, to simulate expected shelf life.

The results for retention of CO₂ pressure and circumference are shown below, and indicate that even though there are minor changes due to lightweighting, there is no significant difference between the 3 bottles.

<table>
<thead>
<tr>
<th>Date</th>
<th>40g CO₂</th>
<th>40g Circumference</th>
<th>41g CO₂</th>
<th>41g Circumference</th>
<th>42g CO₂</th>
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<td>30.8cm</td>
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<tr>
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3.5 Line trials
The initial on-line testing of the two litre bottles was carried out on a small scale and completed with satisfactory results for filling, capping and labelling performance.

More extensive trials were planned using preforms in four different weights. Esterform Packaging moulded a further 80,000 preforms to be used in extensive online trials to validate the performance of the lighter preforms.

Esterform Packaging made 40,000 additional ‘WRAP’ preforms, i.e. 20,000 each of the 41g and 40g preforms.

In addition, Esterform Packaging modified another preform tool by making new cores, to bring the weight of the preforms to 41.5g and 40g. They made 40,000 preforms, i.e. 20,000 of each of the 41.5g and 40g preforms. This step was taken to investigate whether the tooling costs for lightweighting could be reduced.

These preforms were run and then tested for line performance as well as for the creep behaviour of the four types of preforms over a further three months.

This large scale trial shows that the two companies are seriously considering ways of turning into commercial reality the potential revealed by the initial test results.

3.6 Conclusions on the suitability of lightweight two litre bottles.
The redesign of the two litre preform and the subsequent test results show that the bottle meets:

- the physical requirements of a bottle, relating to burst pressure strength and base weight for example;
- processing protocols (i.e. conditions were little changed from standard settings during blow moulding);
- line filling, capping and labelling performance requirements;
- CO2 retention performance requirements; and
- requirements for resistance to creep under carbonation pressures.

These results show that it is highly likely that a 40g preform can be used for two litre bottles.

3.7 Other applications for the lightweight 40g preforms
The 40g preform was also successfully tested as a replacement for a 1.5 litre water bottle that currently uses a 44g preform.

The redesign of the preform to a shorter format means that the stretching ratio would be higher and the physical properties improved.

The success of this application means that there are further opportunities to look into for this 40g preform, with even further savings in PET that could be achieved.
4 Lightweighting 500ml bottles

4.1 Preform design
The typical weight of 500ml bottles in UK is 23g to 25g. Esterform Packaging currently uses 25g preforms, and they anticipated being able to lightweight the 500ml bottle to 22g and possibly 20g.

The size, shape and surface features of the final bottle determine the shape of a preform. Designers use well-known expansion ratios, since a controlled amount of stretching at controlled temperatures determines the physical performance of the bottles.

Since the design of the neck is determined by the closure specification, the redesign of the preform to deliver a reduction in weight may result in a preform diameter that is less than the diameter of the neck opening. This situation can lead to ‘nesting’ of the preforms, which can lead to difficulties in unscrambling the preforms as they go from the storage bins into the blow moulding machines.

CAD simulation predicted that this could have been the situation with the two lightweighting designs, though the dimensions were changed (i.e. the diameter was increased and the length reduced compared to the ideal guidelines) to avoid this possibility. The preforms were still within the typical design guidelines used to predict axial and longitudinal expansion, in order to achieve acceptable physical properties. The preform designs for the 22g and 20g preforms are shown in Appendix 7.3.

4.2 Blow moulding trial for 20g and 22g preforms for 500ml bottles
The trial of the 20g and 22g preforms was carried out at Esterform Packaging using four-foot and five-foot petaloid bases, and they were compared to the standard 25g bottle.

The differences between the preform designs are shown in Figure 4. The redesign of the preforms has resulted in a preform that is shorter but larger in diameter, to avoid nesting problems that would occur if the external diameter were reduced in the lightweighting process. The shape of the bottles is shown in the CAD images in Figure 5.

The four variants and the standard moulded bottles are shown in Figures 6 and 7.
4.3 Performance of 20g and 22g 500ml bottles

The specification for the 25g, four-foot standard bottle is:

- base weight: 4.5g minimum to 6.0g maximum;
- panel weight: 7.7g minimum to 9.0g maximum;
- burst Test: 150 psi minimum;
- height: 215.4 ± 1mm; and
- fill height: 505 mls ± 5 mls at 40 mm;

The results for the 20g and 22g preforms (see Table 3), show that the 20g and 22g bottles in the four-foot and five-foot versions meet the physical specifications for the standard bottle with the related lighter weights on the base and panel.

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<th>20g 4ft</th>
<th>20g 5ft</th>
<th>22g 4ft</th>
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<th>20g 5ft</th>
<th>22g 4ft</th>
<th>22g 5ft</th>
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Table 3

Properties of 20g and 22g bottles in four- and five-foot variations.
4.4 Stability tests
The performance of the 20g and 22g bottles was tested for stability under pressurised conditions. The results are shown in Appendix 7.4.

The key findings are:
- the four-foot existing 25g bottle is stable at all pressures;
- the five-foot petaloid 20g and 22g bottles remained stable at all pressures;
- the four-foot bottle at 22g started losing stability at 60psi, but was still relatively good at 75psi;
- the four-foot bottle at 20g started losing stability at 40psi, and was considered very bad at 60psi;
- the use of the five-footed preform improved the material base distribution; and
- the material distribution near the neck was not as good as was desired, potentially indicating a need to redesign the preform.

4.5 Material redistribution improvement
In order to improve the material distribution in the neck section, a redesign of the preform was considered, as shown in Appendix 7.5.

Sidel was consulted on the redesign, and the new dimensional specifications for the preform were only slightly different from the original.

Husky was also consulted on the newly redesigned preform. Their advice was that further thinning of the neck section would make injection moulding of the preform problematic and could result in poor neck thread definition.

As a result of these two discussions a further moulding trial was conducted with new processing conditions. An improved material distribution was achieved.

One issue that has arisen is the current preference of Radnor Hills for a four-footed base for stylistic reasons. This may have implications for how far the lightweighting process can be taken, given the limitations of the four-foot base compared to the five-foot base.

4.6 On-line testing at Radnor Hills
The on-line testing of the 20g, 500ml water bottles at Radnor Hills was completed with satisfactory results for filling, capping and labelling performance.

Insufficient bottles were available for the assessment of unscrambling, though this is not anticipated to be a problem. The bottles were assessed for carbonation level performance for three months’ shelf life.

Radnor Hills confirmed that the 20g, 500ml bottles had met their filling and shelf life requirements for standard bottles.

4.7 Other applications for the 500ml, 20g preforms
The improvement in the material distribution has meant that the 20g preform could be considered for other applications as well as the Radnor Hills bottle.

Esterform Packaging conducted blowing trials on the bottles shown in Figure 8. Esterform Packaging is currently conducting further tests on the applicability of the lighter preforms.

The bottles that could potentially be made from the preform are:
- the 500ml standard Petaloid bottle, drawing A242-B-04-3 in Appendix 7.6. Esterform Packaging has a considerable number of other customers that take this bottle. Although the five-foot version performed better than the four-foot standard, Esterform Packaging’s customers require the look of the four-foot;
- the 500ml ‘Ribbed’ bottle. Bottles have been successfully blown, and can be used for both still and carbonated products;
- the 500ml ‘Squound’ bottle. This bottle is specifically for one of Esterform Packaging’s customers. Bottles have been successfully blown and Esterform Packaging will meet with the customer to present samples;
- the 500ml ‘Water Wave’ bottle. Bottles have been successfully blown;
- the 500ml ‘Sport’ bottle. Bottles have been successfully blown; and
- the 500ml ‘CH Carbonates Petaloid’ bottle. Bottles have been successfully blown.

Figure 8
Different bottle styles that could potentially use the 500ml, 20g preform.
5 Benefit analysis

5.1 Energy, carbon and CO₂ emissions savings of new preform designs

The energy consumed in the drying of resin and melting of PET to make a preform and then bottle, is directly related to its weight. The reduction in energy consumption is proportional to the weight savings and can be readily calculated from the weight of PET that avoids being processed. The savings are most significant for the melting of PET.

CO₂ emissions can be calculated from power consumption data. However, although the average electricity emissions are 0.43 kg CO₂/KWh (Carbon Trust, 2005), the figures used here are for marginal electricity, i.e. the electricity production that is turned on or off as a response to changes in demand. In the UK, the marginal fuel is gas, which instead gives a figure for electricity of 0.36 kg CO₂/KWh (DTI Energy Trends, 2005).

The data in Table 4 shows that the new preform designs could deliver annual energy savings of over 200MWhr. The projection for energy savings was over 2,810MWhr if the technology were to be adopted in the two designs across the UK beverage industry.

These savings can also be expressed in terms of the number of UK households that could be powered by these quantities as shown in Table 5. The calculations show that the Esterform Packaging savings are equivalent to the energy consumption of 52 households, and the UK savings of 703 households. The data is based on the annual household energy consumption of 4000kWh for a three-bedroom house in the UK¹.

<table>
<thead>
<tr>
<th>Moulding Energy for preforms</th>
<th>Moulding kWh</th>
<th>Preform heating kWh</th>
<th>Total Saving kWh</th>
<th>Total Saving kg CO₂</th>
<th>Total Saving kg Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy to process 1kg PET</td>
<td>0.80</td>
<td>0.0267</td>
<td>0.83</td>
<td>0.36</td>
<td>0.273 kg C/kg CO₂</td>
</tr>
<tr>
<td>Energy savings for 30 million 500ml bottles @ 5g reduction</td>
<td>120,000</td>
<td>4,005</td>
<td>124,005</td>
<td>44,642</td>
<td>12,175</td>
</tr>
<tr>
<td>Energy savings for 50 million 2 litre bottles @ 2g reduction</td>
<td>80,000</td>
<td>2,670</td>
<td>82,670</td>
<td>29,761</td>
<td>8,117</td>
</tr>
<tr>
<td>Total savings for Esterform (80 million bottles)</td>
<td>200,000</td>
<td>6,675</td>
<td>206,675</td>
<td>74,403</td>
<td>20,292</td>
</tr>
<tr>
<td>Energy savings for 80 million 500ml bottles @ 5g reduction</td>
<td>320,000</td>
<td>10,680</td>
<td>330,680</td>
<td>119,045</td>
<td>32,467</td>
</tr>
<tr>
<td>Energy savings for 1500 million 2 litre bottles @ 2g reduction</td>
<td>2,400,100</td>
<td>80,100</td>
<td>2,480,100</td>
<td>892,836</td>
<td>243,501</td>
</tr>
<tr>
<td>Total savings for UK (1,580 million bottles²)</td>
<td>2,720,000</td>
<td>90,780</td>
<td>2,810,780</td>
<td>1,011,881</td>
<td>275,967</td>
</tr>
</tbody>
</table>

Table 4

Overview: Energy and carbon saving using the lightweight preform, based on data provided by Husky, plus associated CO₂ and carbon emissions calculations

<table>
<thead>
<tr>
<th>Annual energy consumption for a three-bed household in UK</th>
<th>4,000 kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total annual energy saving for Esterform</td>
<td>206,667 kWh</td>
</tr>
<tr>
<td>Equivalent number of three-bed households</td>
<td>52</td>
</tr>
<tr>
<td>Total annual energy saving for UK</td>
<td>2,810,780 kWh</td>
</tr>
<tr>
<td>Equivalent number of three-bed households</td>
<td>703</td>
</tr>
<tr>
<td>Energy saving per 100 tonnes equivalent to number of households</td>
<td>21</td>
</tr>
</tbody>
</table>

Table 5

Energy saving expressed in household energy consumption per year

¹ Source: University of Strathclyde, http://www.esru.strath.ac.uk/EandE/web_lite/01-02RE_info/hac.htm

₂ =3,600 tonnes of PET
5.2 Material savings for Esterform Packaging

Table 6
Simple assessment of material cost saving opportunity by moving to the lighter weight preform.

<table>
<thead>
<tr>
<th>Preform weight (g)</th>
<th>Weight saving</th>
<th>Market volume</th>
<th>Weight of PET</th>
<th>Cost saving @£800/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Final %</td>
<td>tpa</td>
<td>tpa</td>
<td>£</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>40</td>
<td>7%</td>
<td>1500</td>
<td>105</td>
</tr>
<tr>
<td>25</td>
<td>20</td>
<td>20%</td>
<td>160</td>
<td>32</td>
</tr>
</tbody>
</table>

Assumptions:
Volume of 500ml bottles would double from existing 80 tonnes p.a. to 160 tonnes p.a.

5.3 Benefit analysis if lightweighting on these bottle sizes was replicated across the sector

The Esterform Packaging project clearly demonstrates that a move to lighter weight preforms brings with it benefits in terms of material savings, energy savings and carbon emissions. If this lightweighting on these bottle sizes was replicated across the whole carbonated soft drinks sector, the savings can be seen in Table 7.

Table 7
Overall benefit analysis
6 Overall conclusions

- The approach taken in this project has been successful due to the latest advances in PET technology being applied to the two bottles selected.
- The lightweight 20g and 40g designs are currently meeting the key success criteria set by the current bottle specifications at both Esterform Packaging and the fillers’ plants.
- New applications for the 40g and 20g preforms have been blown and are also being considered by customers beyond the initial scope of the project. It is expected that this approach will lead to significantly larger weight savings in PET than originally anticipated.
- This project has delivered additional benefits in savings in the costs of materials and energy input, thereby delivering multiple environmental benefits.
- This strongly validates the approach used in this project, also highlighting the value in disseminating the improved efficiencies throughout the UK beverage industry.
7 Appendices

7.1 Injection blow-moulding process
7.2
Two litre preform 41g and 40g designs
7.3 Designs for 20g for 22g preforms for 500ml bottles.
7.4 Pressure and dimensional stability tests on the 20g, 22g and 25g bottles

<table>
<thead>
<tr>
<th>500ml lightweight bottle for WRAP project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preforms conforming to drawings (20g) E774-P-05 - (22g) E795-P-02</td>
</tr>
<tr>
<td>Bottles conforming to drawings (four-foot) A242-B-04-3 - (five-foot) E803-B-01</td>
</tr>
<tr>
<td>Test Temperature of water</td>
</tr>
<tr>
<td>Test results from first blown bottles 30th November 05:-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effect of pressure on diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>diameter</td>
</tr>
<tr>
<td>Bottle weight/style</td>
</tr>
<tr>
<td>20g five-foot</td>
</tr>
<tr>
<td>20g four-foot</td>
</tr>
<tr>
<td>22g five-foot</td>
</tr>
<tr>
<td>22g four-foot</td>
</tr>
<tr>
<td>Existing 25g four-foot</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Base clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm at 0psi</td>
</tr>
<tr>
<td>20g five-foot</td>
</tr>
<tr>
<td>20g four-foot</td>
</tr>
<tr>
<td>22g five-foot</td>
</tr>
<tr>
<td>22g four-foot</td>
</tr>
<tr>
<td>Existing 25g four-foot</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Base performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>The five-foot petaloid 20g and 22g remained stable at all pressures.</td>
</tr>
<tr>
<td>The four-foot at 20g started losing stability at 40psi, and was very bad at 60psi.</td>
</tr>
<tr>
<td>The four-foot at 22g started losing stability at 60psi, and was still relatively good at 75psi.</td>
</tr>
<tr>
<td>The existing four-foot bottle at 25g is stable at all pressures.</td>
</tr>
</tbody>
</table>
7.5

Improved design for 20g preform for 500ml bottles
7.6 Bottle variations tested with 20g preforms

500ml standard Petaloid bottle, drawing A242-B-04-3.

This is the principal bottle being evaluated for Radnor Springs.