Life Cycle Inventory Comparison of Paper and Plastic Based Packaging Systems for Strawberry Distribution

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ABSTRACT: The goal of this study was to conduct a Life Cycle Inventory (LCI) analysis based comparison of eleven primary container and pillow wrap combinations for the distribution of fresh strawberries. Three of the primary containers studied were paper based (molded pulp, paperboard and corrugated fiberboard) and three other containers investigated were clamshells or punnets made of polyethylene terephthalate (PET) and recycled PET (rPET). Pillow wraps made of rPET and polylactide (PLA) were also included for all punnet/tray style containers. The scope of the study ranged from the extraction of raw materials, their processing and formation for all packaging components, product filling and distribution followed by their end-of-life scenarios. The scope includes energy inputs/credits and greenhouse gases in CO₂ equivalents followed by the end-of-life disposal. The functional unit selected was 0.45 kg of packaged strawberries delivered to institutional customers (on-site users) and retailers within 402 kilometers from the processing and packing plant with a minimum of one week of shelf life at delivery. When compared to the traditional PET clamshell style containers, the ten alternative packaging systems provide better energy usage/credit and GHG results. Molded pulp trays outperformed all alternates studied in this regard, while the paperboard and corrugated fiberboard systems provide very practical and environmentally feasible alternatives. Scenario I for the end-of-life, which reflects a close approximation of the MSW treatment rates in the US, the paperboard and corrugated fiberboard based systems had a 3–4% and 12–17% improved performance towards the energy usage/credit and GHG emissions respectively.

1.0 INTRODUCTION

FRESH strawberries rank amongst the most perishable fresh fruits. Unlike most other fruits, strawberries are harvested and packed in a fully ripened state in the field. Due to their high susceptibility to

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water loss and mechanical damage, they require special attention to all aspects of postharvest handling [1]. Immediately upon harvesting, strawberries are often packed in the retail packages (plastic clamshells, baskets, etc.), accumulated in “flats” or trays (plastic or corrugated) and palletized for cold chain distribution. Maintaining the temperature of this fruit between 0–1°C, while in staging for cooling, storage at cooler, distribution through refrigerated trucks as well as stocking for display at retail, is important to prolong its shelf life [1].

Strawberry production has been on the rise over the past two decades with approximately 36% increase between 1990 and 2007 and a global production of 3.82 million metric tons in 2007 [2]. California is the leading producer of fresh strawberries in the US, with over 88% of all shipments followed by Florida with approximately 11% [2]. Figure 1 shows the top ten countries in relation to strawberry production for 2007.

This study aimed at evaluating and comparing the manufacturing, product filling and distribution related environmental impacts of eleven primary container and pillow wrap combinations for the distribution of fresh strawberries. Three of the primary containers studied were paper based (fiber pulp, paperboard and corrugated fiberboard) and three other containers investigated were clamshells or punnets made of polyethylene terephthalate (PET) and recycled PET (rPET). The pillow wraps studied were made of rPET and Polylactide (PLA). A life cycle inventory (LCI) analysis was conducted for comparing the environmental outputs of these containers. LCI quantifies material use, energy use, environmental discharges, and wastes associated with each stage of a
product system over its life cycle, from raw material extraction through material processing, product fabrication, use, reuse or recycling, and ultimate disposal [3].

Very few past studies have researched the environmental issues related to packaging for strawberries. An LCI analysis study compared reusable plastic containers (RPC) to single-use display ready paper corrugated trays (DRC) for packing and shipping of ten categories of fresh fruits and vegetables. Based on the scope of the study, it was reported that overall the RPCs required 39% less energy, produced 95% less total solid waste and generated 29% lesser greenhouse gases (GHG) [4]. Figure 2 shows the energy, solid waste and GHG results for the distribution of strawberries for the two types of containers. The average values reported for DRCs were based on the reported weights of the folded boxes and those for RPCs were based on the average reuse and loss rates reported. The conservative scenario for RPCs involves 75% of average reuse rate, twice the average loss rate and maximum backhaul distance and that for DRCs includes 10% lightweighting. Results for RPCs were also reported assuming a 20% reduction in backhaul distance of empty containers.

Several other studies have focused on the environmental impacts of cultivation and transportation of strawberries. It is estimated by one that, on a broad level, approximately 50% of food GHGs are emitted during the agriculture stage, with the remaining GHGs associated with
the phases after farming [5]. A study looked at the carbon footprint as part of a life cycle assessment (LCA) of strawberries grown in Spain for consumption in Western Europe, using Germany as an example. Using a 500 gram fresh strawberry PET punnet as the functional unit, the study accounted for the three most common GHGs emitted from agricultural activities—carbon dioxide (CO₂), nitrous oxide (N₂O) and methane (CH₄). The findings concluded that the largest part of the carbon footprint was attributed to transportation to consumer and packhouse (205 g CO₂ eq.) and consumer shopping (65 g CO₂ eq.) and strawberry cultivation (60 g CO₂ eq.) while agrochemicals (40 g CO₂ eq.) played a minor role [6].

A different research conducted a comparative study of the CO₂ emissions associated with fresh vegetables and fruits produced locally in Austria versus imported. Among the five products included in this study, strawberries imported from Spain and those grown domestically in Lower Austria were evaluated. The scope of this project was based on the transport associated emissions related to road, sea and air distribution. The CO₂ emissions for the domestic strawberries (6.9 g CO₂ eq.) were found to be approximately 3% as compared to those associated with the Spanish imports (264.4 g CO₂ eq.) [7].

A similar study as above was conducted in Spain to evaluate the energy saved and emissions avoided due to sourcing of fruits and vegetables from local farmers (within 200 km radius) rather than distant sources. Long stem strawberries did not have any impact due to unavailable local climate for their cultivation and these numbers were reported as 169 tons of oil equivalent and 425 tons of CO₂ equivalents for the energy and emissions respectively [8].

2.0 GOAL, SCOPE AND BOUNDARIES

2.1 Goal, Scope and Functional Unit

The goal of this study was to conduct an LCI analysis based comparison of eleven primary container and pillow wrap combinations for the distribution of fresh strawberries. Three of the primary containers studied were paper based (molded pulp, paperboard and corrugated fiberboard) and three other containers investigated were clamshells or punnets made of PET and rPET (Figure 3). Pillow wraps made of rPET and PLA were also included for all punnet/tray style containers. The scope of the study ranged from the extraction of raw materials, their process-
ing and formation for all packaging components, product filling and distribution followed by their end-of-life scenarios. The scope includes energy inputs and credits and greenhouses gases in CO₂ equivalents followed by the end-of-life disposal. The functional unit selected was 0.45 kg of packaged strawberries delivered to institutional customers (on-site users) and retailers within 402 kilometers from the processing and packing plant with a minimum of one week of shelf life at delivery.

Figure 4 shows two of these containers with the strawberries. While the PET/rPET clamshells do not require any more packaging, the rPET and paper based punnets were assumed wrapped in rPET or PLA film “pillow”. The paperboard and corrugated fiberboard punnets provide a large “billboard”, for promoting the product carried within, at retail. This study investigated display ready corrugated containers (DRCs) as the transportation unit (Figure 5)
2.2 Methods

The framework of this study was adopted from ISO 14040 guidelines [1]. SavvyPack® 2.0 software system (Allied Development Corp., Burnsville, MN, USA), an LCI software program, and CAPE PACK v2.04 (Cape Systems Group, Inc., Piscataway, NJ, USA) pallet optimization software were used for this study. The SavvyPack® system measures energy usage and recovery and GHG emissions (CO₂ equivalent), through each step of the supply chain, including resin and other raw material production, raw material transport, package manufacture, product filling, and delivery to the retailers or institutional customers. The “United States 3” data set option offered by the LCI software was selected for this study. This data set is based on production processes in the United States and includes biomass energy credits. The CAPE PACK design software consists of pallet pattern optimization tools. Its features include the ability to build pallet patterns, create new case sizes, design new product packages and consolidate case sizes.

The raw material data required for the inventory analysis for the following was obtained from the SavvyPack® software: PET/rPET (clamsHELLS/punnet); paper fiber pulp, paperboard and corrugated fiberboard (punnets), corrugated fiberboard (DRCs); rPET and PLA film (pillows); band straps (PET) and wood (pallets). This software sources the data and keeps it updated to within three months from the Canadian Raw Materials Database, European Aluminum Association, European Commission, Finnish Environment Institute, International Iron and Steel Institute, National Renewable Energy Lab, Environmental Defense Fund Paper Calculator, Plastics Europe, and Sustainable Product Information Network for the Environment.

A scorecard methodology to provide a comparison between the three
packaging systems studied was also incorporated in this study. This is particularly beneficial to all suppliers and retailers that are presently using scorecards to judge packaged products in terms of different metrics of sustainability. A scorecard may be construed as a document reflecting, in summary form, the strategic objectives, measures, performance targets and any explanatory narrative. Wal-Mart’s packaging scorecard was introduced in the US in 2006 as a measurement tool that allows suppliers to evaluate themselves relative to other suppliers, based on specific metrics [9]. In the packaging scorecard system, the suppliers are required to enter information regarding the packaging of each product supplied to Wal-Mart. Each product packaging is then judged in terms of different metrics of sustainability that include GHG emissions produced per ton of packaging, size of packaging, use of raw materials, use of renewable energy, recycled content, transportation impacts, innovation, etc [9].

SavvyPack® software allows users to create a similar scorecard where the inbuilt matrices are populated during data input for the LCI analysis. The scorecard results for the eleven packaging systems studied were created with the following matrices and the weighted average for each based closely to that utilized by Wal-Mart:

- 15% based on Purchased Material GHG
- 15% based on Sustainable Material
- 15% based on Package to Product Ratio
- 15% based on Cube Utilization
- 10% based on Transportation Distance
- 10% based on Recycled Content
- 10% based on Recovery
- 5% based on Renewable Energy
- 5% based on Energy Innovation

This scorecard provides valuable input to any supplier who may have to meet mandates by retailers and can allow them to compare different packaging options for any product category.

2.3 Allocation

According to ISO 14040, allocation is defined as partitioning the input or output flows of a unit process to the product system under study [3]. During the performance of LCA, allocation may be necessary when
a process yields more than one product, i.e., a multifunctional process [10]. This study focused primarily on the fresh strawberry related packaging manufacturing, product filling, unitizing, and distribution components as related to the six primary containers (and pillow wraps where applicable) as well as the distribution packaging involved. Strawberry production, harvesting, and packing was excluded in this study. Allocation was not used in this study since there was no more than one input or output in each unit process.

2.4 System Boundaries

The system boundaries are illustrated in Figure 6. Strawberry production, harvesting, and packing were not included in this study. It was assumed that any loss of product was the same for all eleven packaging systems studied. GHG in CO₂ equivalents and energies were analyzed based on materials (used to manufacture the packaging components, packaging of the product and the secondary packaging), processes (production facility and manufacturing processes for packaging components and packaging of the product) and transportation (raw materials, raw material packaging, finished product packaging from their point of origin to the production facility and transporting the finished product packaging from the production facility to the customer).
2.4.1 Primary Packaging

The primary package designs studied are shown in Figures 3 and 4 and contain three paper based (molded pulp, paperboard and corrugated fiberboard) and three plastic clamshells or punnet (PET and rPET). While the three plastic clamshells/punnets and the molded pulp trays are presently used widely in the U.S., the paperboard and corrugated fiberboard punnets are not. The latter forms of soft fruit containers are popular in Europe and in contrast to the other containers, provide a larger billboard for graphics. The different overall weights of the primary packages are provided in Table 1.

2.4.2 Secondary (Distribution) Packaging

As shown in the system boundary (Figure 5), the secondary packaging used for this study was primarily corrugated fiberboard DRcs, PET band straps and reusable wooden pallets. Table 1 provides details of the palletizing configurations for all eleven packaging systems studied. The palletizing configurations were based on the existing or recommended methodologies.

3.0 DATA AND DATA QUALITY REQUIREMENTS

3.1 Production of Raw Materials

The LCI data for production of all raw materials namely, PET and rPET (clamshells, punnet, pillow wrap and band straps), paper based substrates (molded pulp, paperboard and corrugated fiberboard), PLA (pillow wraps) and wood (pallets) was obtained from the SavvyPack® software. Details of the databases sourced by this software are provided in section 2.2. The following post consumer recycled content values were adopted for the raw materials used in all packaging systems: corrugated fiberboard, paperboard and pulped fiber (punnets and trays)—76.6%, PET (band straps)—27.2%, PET (clamshells)—0%, rPET (clamshells, punnets and pillow wraps)—50%, PLA (pillow wraps)—0% and wood (pallets)—14.8% [11]

3.2 Production of Packaging Components

The cradle-to-gate energy consumed or credited and CO₂ equiva-
<table>
<thead>
<tr>
<th></th>
<th>PET</th>
<th>rPET</th>
<th>rPET</th>
<th>Paperboard</th>
<th>Paperboard</th>
<th>Molded</th>
<th>Molded</th>
<th>Corrugated</th>
<th>Corrugated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clamshell</td>
<td></td>
<td>Clamshell</td>
<td>Punnet/</td>
<td>Punnet/</td>
<td>Tray/rPET</td>
<td>Tray/PLA</td>
<td>rPET</td>
<td>Punnet/</td>
</tr>
<tr>
<td>Weight of PET (kg)</td>
<td>0.027</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Weight of rPET (kg)</td>
<td>N/A</td>
<td>0.027</td>
<td>0.025</td>
<td>0.025</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Weight of paper-based material (kg)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.040</td>
<td>0.040</td>
<td>0.040</td>
<td>0.040</td>
<td>0.040</td>
</tr>
<tr>
<td>Weight of wrapper (kg)</td>
<td>N/A</td>
<td>N/A</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>Secondary packaging</td>
<td>DRC</td>
<td>DRC</td>
<td>DRC</td>
<td>DRC</td>
<td>DRC</td>
<td>DRC</td>
<td>DRC</td>
<td>DRC</td>
<td>DRC</td>
</tr>
<tr>
<td>Containers per pallet</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
<td>840</td>
</tr>
<tr>
<td>Total weight of palletized load (kg)</td>
<td>574</td>
<td>574</td>
<td>675</td>
<td>675</td>
<td>762</td>
<td>762</td>
<td>804</td>
<td>804</td>
<td>776</td>
</tr>
<tr>
<td>Product weight per pallet (kg)</td>
<td>361</td>
<td>381</td>
<td>381</td>
<td>381</td>
<td>381</td>
<td>381</td>
<td>381</td>
<td>381</td>
<td>381</td>
</tr>
<tr>
<td>Packaging weight per pallet (kg)</td>
<td>193</td>
<td>193</td>
<td>294</td>
<td>294</td>
<td>381</td>
<td>381</td>
<td>423</td>
<td>423</td>
<td>395</td>
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<tr>
<td>Number of pallets per truck (kg)</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
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<tr>
<td>Product weight per truck (kg)</td>
<td>8382</td>
<td>8382</td>
<td>8382</td>
<td>8382</td>
<td>8382</td>
<td>8382</td>
<td>8382</td>
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<tr>
<td>Packaging weight per truck (kg)</td>
<td>4246</td>
<td>4246</td>
<td>6468</td>
<td>6468</td>
<td>8382</td>
<td>8382</td>
<td>9306</td>
<td>9306</td>
<td>8680</td>
</tr>
<tr>
<td>Total weight per truck (kg)</td>
<td>12628</td>
<td>12628</td>
<td>14850</td>
<td>14850</td>
<td>16764</td>
<td>16764</td>
<td>17688</td>
<td>17688</td>
<td>17072</td>
</tr>
</tbody>
</table>
lents generated to produce all packaging system components as well as associated with the disposal were available from the LCI software database. All plastic sheets/films were assumed manufactured using the extrusion process and the clamshells and punnets were thermo-formed.

### 3.3 Consumption Stage

The filling of primary containers with freshly harvested strawberries was assumed identical for all eleven packaging systems and was excluded from this study. Unitization and storage prior to and during distribution of filled containers to institutional customers (on-site users) and retailers within 402 kilometers from the processing and packing plant were assumed to result in similar impacts. Automated cartoners, case packers, pillow form-fill-seal packers for all punnets and palletizers were included in this study. The details of the packaging configurations for all packaging systems are provided in Table 1. The pallet dimensions were assumed to be 102 cm × 122 cm × 15 cm and the truck dimensions were 2.4 m × 16.2 m × 2.8 m with a weight capacity of 19800 kg. Wooden pallets were assumed to have a useful life of 30 trips [4].

### 3.4 Distances and Transportation

Distance from all resin (PET, rPET and PLA) suppliers to the manufacturing centers averaged at 4828 km and included truck and train as the modes of transport. The labels were assumed to be shipped from 520 km to the primary packaging manufacturing sites. All finished packaging components including paper based packages, wooden pallets and PET band straps were assumed to be shipped to the farms from an average of 402 km. The overall cradle-to-gate energy and GHG ratios that converted energy use and GHG emissions to cradle equivalents for the truck and railcar transportation were available through the SavvyPack® LCI software.

### 3.5 End-of-Life

The following end-of-life scenarios in terms of landfill, incineration and recycling for all packaging components used in the eleven systems studied were considered. Both scenarios assumed that no packaging
was being retained by the institutional and retail customers and that all packaging materials underwent the waste treatment process.

- Scenario I—(40R/30I/30L)—40% recycling/30% Incineration/30% Landfill
- Scenario II—(30I/50L)—50% Incineration/50% Landfill

Scenario I is close to the municipal solid waste treatment rates in the U.S when observed across all materials used in the eleven systems studied [11]. Growing climate, energy and environmental concerns coupled with technological developments and regulatory changes have triggered a renewed interest in MSW as an energy source with the potential to provide renewable energy while reducing GHG emissions and the need for landfill space [12]. MSW-to-energy technologies being employed today include landfill gas capture (biogas made of approximately 50% CO2 and 50% methane) [13], combustion (burning waste at approximately 980°C) [14], pyrolysis (MSW heated in absence of oxygen at approximately 290–700°C) [15], gasification (MSW heated with small amount of oxygen at 390–1650°C) [16] and plasma arc gasification (superheated plasma technology used to gasify MSW at approximately 5540°C) [17]. Landfill gas capture has achieved the widest acceptance amongst these technologies with bio-energy programs in place at 485 landfills in U.S. in December 2008 [18]. Waste combustion has not grown in acceptance since 1996 and presently there are 88 waste-to-energy plants in operation in 25 states [19]. Gasification and plasma arc technologies are still facing challenges towards commercial scale-up [14]. Considering the increasing impact of landfill and incineration technologies, Scenario II was used in this study.

4.0 RESULTS

The main purpose of this study was to provide a relatively simple methodology to serve as a decision making tool when more than one packaging solution could be available to a user. For this reason, we provide environmental emissions of the packaging systems studied (LCI) and not the burdens (LCA). A full LCA needs to be undertaken to understand the impacts of the environmental burdens. Also due to recent mandates from retailers that use scorecards to judge packaged products in terms of different metrics of sustainability, this study incorporated it as a technique for comparing the eleven packaging systems studied.
4.1 Discussion

Based on the data collected, GHG output (kg CO₂ eq) and energy use/credit (MJ) per functional unit, and the scorecard results from the analysis were tabulated (Table 2 and Figures 6 and 7 show the GHG output and energy uses for the two end-of-life scenarios considered). Table 3 shows the results in a scorecard format.

4.1.1 Energy Usage Results

The energy usage/credit was studied for the eleven 0.45 kg strawberry packaging systems. Figure 7 shows the percentage difference in

Table 2. Greenhouse Gases and Energy Consumption.

<table>
<thead>
<tr>
<th>Container/Wrapper</th>
<th>Energy (MJ/FU) 40R/30/30L</th>
<th>50L/50L</th>
<th>GHG (kg CO₂ eq/FU) 40R/30/30L</th>
<th>50L/50L</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET Clamshell/(N/A)</td>
<td>102.77</td>
<td>96.62</td>
<td>6.95</td>
<td>7.37</td>
</tr>
<tr>
<td>RPET Clamshell/(N/A)</td>
<td>99.09</td>
<td>91.17</td>
<td>6.35</td>
<td>6.90</td>
</tr>
<tr>
<td>RPET Punnet/RPET</td>
<td>91.06</td>
<td>84.99</td>
<td>5.86</td>
<td>6.29</td>
</tr>
<tr>
<td>RPET Punnet/PLA</td>
<td>89.99</td>
<td>83.52</td>
<td>5.84</td>
<td>6.27</td>
</tr>
<tr>
<td>Paperboard Punnet/RPET</td>
<td>98.66</td>
<td>97.65</td>
<td>5.92</td>
<td>6.01</td>
</tr>
<tr>
<td>Paperboard Punnet/PLA</td>
<td>99.04</td>
<td>97.83</td>
<td>6.14</td>
<td>6.22</td>
</tr>
<tr>
<td>Molded Paper Tray/RPET</td>
<td>97.79</td>
<td>96.56</td>
<td>4.18</td>
<td>4.27</td>
</tr>
<tr>
<td>Molded Paper Tray/PLA</td>
<td>96.71</td>
<td>95.51</td>
<td>4.16</td>
<td>4.25</td>
</tr>
<tr>
<td>Corrugated Punnet/RPET</td>
<td>99.76</td>
<td>98.55</td>
<td>6.19</td>
<td>6.27</td>
</tr>
<tr>
<td>Corrugated Punnet/PLA</td>
<td>99.04</td>
<td>97.83</td>
<td>6.14</td>
<td>6.22</td>
</tr>
</tbody>
</table>

Figure 7 Percentage Difference in Energy Usage Compared to PET Clamshell
Table 3. Packaging Scorecard Results.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Max Score</th>
<th>PET Clamshell</th>
<th>rPET Clamshell</th>
<th>rPET Punnet/Tray</th>
<th>Paperboard Punnet/PLA</th>
<th>Molded Pulp Tray/rPET</th>
<th>Corrugated Punnet/PLA</th>
<th>Corrugated Punnet/PLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased Material GHG</td>
<td>15</td>
<td>10.36</td>
<td>10.65</td>
<td>12.38</td>
<td>12.38</td>
<td>14.33</td>
<td>14.33</td>
<td>14.33</td>
</tr>
<tr>
<td>Transportation Distance</td>
<td>10</td>
<td>4.39</td>
<td>4.39</td>
<td>9.08</td>
<td>9.08</td>
<td>10.00</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Package to Product Ratio</td>
<td>15</td>
<td>6.05</td>
<td>6.05</td>
<td>12.80</td>
<td>12.80</td>
<td>12.80</td>
<td>12.80</td>
<td>12.80</td>
</tr>
<tr>
<td>Cube Utilization</td>
<td>15</td>
<td>7.50</td>
<td>7.50</td>
<td>7.50</td>
<td>7.50</td>
<td>7.50</td>
<td>7.50</td>
<td>7.50</td>
</tr>
<tr>
<td>Recycled Content</td>
<td>15</td>
<td>7.10</td>
<td>6.45</td>
<td>10.00</td>
<td>10.00</td>
<td>9.08</td>
<td>9.03</td>
<td>9.03</td>
</tr>
<tr>
<td>Recovery</td>
<td>15</td>
<td>6.22</td>
<td>6.55</td>
<td>7.98</td>
<td>7.97</td>
<td>8.48</td>
<td>8.46</td>
<td>8.46</td>
</tr>
<tr>
<td>Renewable Energy</td>
<td>5</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Energy Innovation</td>
<td>5</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>53.40</td>
<td>78.36</td>
<td>78.35</td>
<td>79.25</td>
<td>79.23</td>
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</tr>
</tbody>
</table>

GHG: Greenhouse Gas Emissions
PLA: Polylactic Acid
Max: Maximum
energy usage for all systems studied in comparison to the PET clamshells. When compared to the traditional PET clamshells, all ten alternate packaging systems had lower energy usage for Scenario 1. The RPET punnets wrapped in PLA or rPET pillows showed the lowest energy use with approximately 14% and 13% debit respectively in comparison to the PET clamshells. The paper based alternatives overall had a decreased energy usage in the range of approximately 3–6% by comparison. Scenario I reflects an approximate representation of the municipal solid waste treatment rates in the U.S [18]. In Scenario II, the RPET punnets wrapped in PLA or rPET pillows showed the lowest energy use with approximately 14% and 13% respectively in comparison to the PET clamshells. All paper based alternatives were approximately at par.

4.1.2 Greenhouse Gas (CO\textsubscript{2}e) Results

Figure 8 shows the percentage difference in GHG emissions (CO\textsubscript{2}e) for all systems in comparison to the PET clamshells. It was observed that all alternate systems contributed significantly lower GHG emissions for both end-of-life scenarios when compared to the traditional PET clamshells. For Scenario I, while the rPET punnets wrapped in either PLA or rPET pillow had a reduced GHG emission of approximately 19%, the paperboard and corrugated fiberboard punnets had a

![Figure 8. Percentage Difference in Greenhouse Gases (CO\textsubscript{2}e) Compared to PET Clamshell](image-url)
debit ranging between 13–17%. The molded pulp trays had a dramatic reduction in GHG emissions of approximately 67% by comparison. For Scenario II, while the rPET punnets wrapped in either PLA or rPET pillow had a reduced GHG emission of approximately 17%, the paperboard and corrugated fiberboard punnets had a debit ranging between 18–23%. The molded pulp trays had a dramatic reduction in GHG emissions of approximately 73% by comparison.

4.1.3 Scorecard Results

Table 3 and Figure 9 show the results in the SavvyPack® scorecard format. It may be seen that when compared to the PET clamshells, the rPET clamshell and both corrugated fiberboard systems were only slightly better. The rPET punnet, paperboard punnet and molded pulp trays, on the other hand, scored 47–49% higher by comparison.

5.0 CONCLUSIONS

The main purpose of this study was to provide a relatively uncomplicated methodology to serve as a decision making tool when more than one packaging solution is available to a user. It conducted a LCI analy-
sis, and as related to a complete LCA study, the outcomes are limited. A full LCA needs to be undertaken to understand the impacts of the environmental burdens. Through the investigation of the eleven packaging systems in this study, it was shown that several viable material and packaging options exist for fresh strawberry distribution. It was also shown that using LCI and scorecards as tools for "sustainable" package design can be accomplished and can assist in uncovering overlooked aspects of a packaging system.

While the three plastic clamshells/punnets and the molded pulp trays are presently used widely in the US, the paperboard and corrugated fiberboard punnets are not very popular yet. The latter forms of soft fruit containers are popular in Europe and in contrast to the other containers, provide a larger billfold for graphics. It may be noted here that the plastic based clamshells or punnets typically are decorated using labels and the molded pulp trays typically do not get decorated. The advantage of paperboard or corrugated fiberboard punnets is the integrated decoration in the form of on-package printing achievable using a traditional container forming process such as flexo-folding-gluing.

When compared to the traditional PET clamshell style containers, the ten alternative packaging systems provide better energy usage/credit and GHG results. Molded pulp trays outperform all alternates studied in this regard, while the paperboard and corrugated fiberboard systems provide very practical and environmentally feasible alternatives. Scenario 1 for the end-of-life, which reflects a close approximation of the MSW treatment rates in the U.S., the paperboard and corrugated fiberboard based systems had a 3–4% and 12–17% improved performance towards the energy usage/credit and GHG emissions respectively.

As shown through the scorecard results, it may be seen that when compared to the traditional PET clamshells, the rPET clamshells and both corrugated fiberboard systems were slightly better. The rPET punnet, paperboard punnet and molded pulp trays, on the other hand, scored 47–49% higher by comparison. This information would be very beneficial to organizations who must comply with these kinds of recent mandates.

The optimum choice for the packaging systems for fresh strawberry distribution must rely on several issues. Some of these include any regulatory issues related to packaging materials in direct contact with food products, protection from distribution related hazards including the ambient and physical abuse, cost, environmental impacts and performance on scorecard type grading systems.
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REFERENCES


