Abstract

**Background:** The majority of receipts printed on thermal paper contain high levels of Bisphenol A (BPA), a xenoestrogen that is a suspected developmental and reproductive toxicant (NTP 2008). BPA is associated in animal tests and/or human studies with the disruption of thyroid function, neurological function, some cancers (including breast and prostate cancer), and infertility (Vandenberg 2007). Thermal receipts pose unique concern because the levels of BPA are 250-1000 times the amount found in plastic (EWG, 2010), and secondly, the BPA in thermal receipts is not bound to a polymer, making it easily transferred to one’s skin where it can then be dermally absorbed (Zalko et al. 2010).

**Objectives:** In order to investigate the potential relationship between frequent handling of thermal receipts and increased exposure to BPA, we analyzed data from the National Health and Nutrition Examination Survey (NHANES). Secondly, we analyzed the life cycle of thermal receipts. Finally, we ranked alternative receipt technologies according to Green Chemistry principles.

**Results:** A look at the life cycle of thermal receipts reveals potentials for resource depletion and environmental pollution and contamination with chemicals besides BPA. Thermal receipts have the potential to affect human and environmental health through chemical pollution and contamination during the production, recycling and disposal stages. Alternatives to the current direct thermal printing technology include thermal transfer technology, possible photochromic UV technology, and electronic receipts.

**Conclusion:** We recommend taking a precautionary approach and switching the current practice of using thermal paper for receipts to an electronic receipt system.
BPA: what level is safe?

Both Japan and the United States (under the EPA) have set cutoff values for protection against reproductive harm:

- Japan established safe intake level of 0.5 mg/kg/day
- U.S. EPA established a range of 0.05-0.5 mg/kg/day

Yet, a literature review performed by Vandenberg et al. (2007) analyzed 150 published studies regarding BPA toxicity and demonstrated that 40 of these studies demonstrate developmental and reproductive harm in levels less than the 0.05 mg/kg/day dose (Vandenberg et al., 2007).

Conclusion: It appears that the current safety level of BPA is not accurately reflected in the regulatory standards set in both Japan and the U.S. Given the research findings where low-dose exposure is associated with developmental and reproductive harm, examining the current set cutoff level for protection is recommended.
Pathways of BPA exposure

Ingestion

Food and drink has been thought to account for 80-90% of aggregate BPA exposure.

This percentage is now under question: A study analyzed urinary concentration of BPA in fasting individuals. No significant decrease in BPA urinary excretion was demonstrated. Absence of a decline in BPA excretion over the fasting time period suggests that there may be other significant sources of exposure (Stahlhut et al., 2009).

Dermal absorption

Until recently, dermal absorption was not thought to significantly contribute to one’s aggregate exposure.

The first study analyzing BPA absorption using viable human skin found that 46% of dermally-applied BPA is absorbed (Zalko et al., 2010).
Analysis of NHANES data

915 individuals in the 2003-2004 cohort had data on occupational status, BPA excretion levels, and creatinine levels (used to adjust for urinary concentration). These individuals were grouped into exposed (sales workers, retail and personal services, and waitstaff) and unexposed (all other workers).

Individuals who were occupationally exposed are more likely to have BPA detected in their urine. Individuals who were occupationally exposed have higher concentrations of BPA in their urine.
Potential source of BPA dermal exposure: thermal receipts

Direct Thermal Technology

• Thermal paper, containing the color former and color developer is fed through a platen roller.
• Image is formed when heat applied by the thermal head activates the chemical reaction between the former and developer.
• Additives enhance the image quality and printability of thermal receipts.
BPA as Color Developer

BPA donates protons that attack the lactone ring of the color former.

BPA is the common choice for color developer because of:
• high color contrast
• stable image
• low acidity
• low cost
• easy availability
Additives in Thermal Receipts

- **Binders**: Adheres coating to the base paper. Cellulose, polyvinyl alcohols, long chain aliphatic compounds.

- **Sensitizers**: lower the melting temperature. Fatty acids or aromatic compounds with melting points near 100°C.

- **Stabilizers**: move equilibrium point towards colored species. Hindered phenol derivatives.
  - Protect image against plasticizers and oil. Aromatic carboxylic acid metal salts.
  - Protect image against UV. Benzophenone and triazole type compounds.

- **Lubricants**: prevent the coating from sticking to the thermal head. Metallic salts of fatty acids.

- **Fillers**: absorb melted components. White pigments and inorganic compounds.
Advantages of Direct Thermal Technology

- No consumables at point of sale besides paper
- Low cost
- Reliable
- Compact & portable
- Quick printing speed
- Simple to use & maintain
- High resolution
- Quiet operation
Alternative 1: Improving Current Direct Thermal Technology (DTT)

• Maximize recycled fiber content and use wood fiber from environmentally and socially responsible sources in base paper. Use renewable feed stocks (GC 7)
• Use electricity from renewable sources during thermal paper manufacturing. (GC 7)
• Substitute oxygen-based compounds for chlorine compounds in pulping and bleaching processes, and work towards totally effluent free mills. Prevent pollution (GC 1)
• Use intrinsically thermally sensitive compound, cutting the need of auxiliary reagents. Increase atom economy (GC 2)
• Replace the ‘necessary’ non biodegradable auxiliary reagents with biodegradable reagents. Design for degradability (GC 10)
• Use closed systems to minimize worker exposure.
Alternative 2: Thermal Transfer Technology (TTT)

- Heat is transferred from thermal head to the ribbon, which is a polyester coated with wax or resin ink.
- The heat melts the ink, which diffuses, is absorbed and becomes part of media.

**Advantages of TTT**
- Extremely durable images
- High printing speed
- High resolution images
Alternative 3: Photochromic paper using UV Light

This reaction is reversible but the reversibility can be controlled by changing the derivitization, temperature and solvents.

The “Photochromic Paper” has light sensitive compounds which change color on exposure to UV Lamp.

Advantages of Photochromic technology compared to current DTT

• faster reaction; faster printing
• longer receipt life, thermally irreversible reaction
Alternative 4: Electronic Receipts

- **Digital**: Customers create online account with a company (e.g. allElectronic). All receipts automatically sent to their account by linking the credit card number or phone number used at purchase.

- **Web Based Receipts**: Paperless receipts sent to the customer’s email address, given at time of purchase to cashier (e.g. TransactionTree).

- **Near Field Communication Technology**: Customers can swipe credit cards as payment directly with iPhone6 or Android, using Square (plastic cube fitting into the earplug holes). On swiping the card, reader converts the data from magnetic strip into audio signal and passes it onto the phone software.

**Advantages:**

- Ease of tracking & storing receipts
- Saving trees, oil, emissions
- No new gadgets needed, adding application to existing electronic technology.

# Green Chemistry Ranking of Technologies

<table>
<thead>
<tr>
<th>Green Chemistry Metrics</th>
<th>Direct Thermal Technology</th>
<th>Photochromic UV Technology</th>
<th>Thermal Transfer Technology</th>
<th>Electronic Receipts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atom economy (GC 2)</td>
<td>0.62</td>
<td>1.0</td>
<td>0.14</td>
<td>0.0</td>
</tr>
<tr>
<td># Chemicals main reaction (GC 5)</td>
<td>1.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Toxicity (GC 3)</td>
<td>1.0</td>
<td>0.13</td>
<td>0.13</td>
<td>0.0</td>
</tr>
<tr>
<td>Carcinogenicity (GC4,5)</td>
<td>1.0</td>
<td>0.33</td>
<td>0.67</td>
<td>0.0</td>
</tr>
<tr>
<td>Estrogenicity (GC 4,5)</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Biodegradability (GC10)</td>
<td>1.0</td>
<td>0.25</td>
<td>0.25</td>
<td>0.0</td>
</tr>
<tr>
<td>Chemical waste (user level) (GC 1)</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Energy consumption (user level) (GC 6)</td>
<td>0.5</td>
<td>1.0</td>
<td>0.75</td>
<td>0.1</td>
</tr>
<tr>
<td>Average</td>
<td>0.93</td>
<td>0.60</td>
<td>0.42</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Ranking</strong></td>
<td><strong>4</strong></td>
<td><strong>3</strong></td>
<td><strong>2</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>

* Lower number means that the technology follows the green chemistry principle

1 Toxic Release Inventory List
2 OSHA Carcinogens List
3 Terasaki, Shiraishi, Makino, 2007, Occurrence and estrogenicity of phenolics in paper recycling process water: Pollutants originating from thermal paper in waste paper, Environmental Toxicology and Chemistry
We recommend changing the current DTT. In the meantime, the following actions should be taken to minimize BPA exposure from thermal receipts.

• Decline receipts whenever possible.
• Do not touch receipts with wet or greasy hands.
• Store receipts separately in an envelope and away from children.
• Do not crumple receipts.
• Do not recycle thermal receipts.
• Wash hands with cold water after handling receipts.
Do not use alcohol-based hand cleansers.
Conclusion

BPA is a suspected human reproductive and developmental toxicant that causes biological harm in low doses that are environmentally relevant. Individuals working in occupations with high levels of exposure to thermal receipts have higher levels of BPA in their urine compared to individuals who do not have high occupational exposure to thermal receipts. Failure to account for non-food exposure to BPA may underestimate actual BPA exposure, particularly for highly exposed occupations. Besides exposing workers and consumers to BPA, thermal receipts use chemicals that have downstream effects on human and environmental health that result from ineffective waste management. Most chemicals used in thermal receipts lack safety data. Under TSCA, chemicals in production are not required to be proven safe, so BPA-free receipts may contain other compounds that pose hazard. Due to the uncertainty regarding safe level limits of BPA exposure and the safety of other chemicals, we recommend taking a precautionary approach and using safer receipt technologies. After assessing the current direct thermal technology and the alternate thermal transfer, photochromic UV, and electronic receipt technology, according to Green Chemistry Principles, we identified electronic receipts as following the most number of GC principles.
References


Michinori Takeshita, Takehiko Yamato,2001, Synthesis and photochromic properties of 1,2, dicyano[2,n] metacyclophan, Science Direct


www.Allelectronic.com

Direct Thermal and Thermal Transfer Book, www.upmraflatac.com