Policy Forum

Paper Versus Polystyrene: A Complex Choice

MARTIN B. HOCKING

As today's public and governments become more environmentally conscious we are increasingly concerned about the environmental component of product and service options available in our affluent society. Our choices are often made instinctively, from necessity, since a detailed analysis of the relative environmental merits of using canned versus fresh versus frozen foods, or glass versus paper versus steel versus aluminum packaging would simply be too time consuming for each purchase. If, however, the environmental merit question is restricted to a small enough purchase sector it is possible to conduct a complete analysis of relative merit from the initial resource through the manufacturing stages, use attributes, and recycle options through to final use or disposal of the item. Many environmentally appropriate choices of products can only be made after such an analysis. An outline of one such analysis, that of paper versus polystyrene foam as the material of construction for hot drink containers in fast food or other single use applications, is given here.

The major raw material for a paper cup is wood, a renewable resource. However, acquisition of wood for pulp-making has visible negative impacts on the landscape from the construction of road access and typical clear-cutting practices. When the clear-cut area occupies an extensive proportion of a watershed it increases maximum flows and decreases minimum flows of streams draining the watershed, increasing the likelihood of flood and drought in the area served by these streams (*1*).

A polyfoam cup is made entirely from hydrocarbons (oil and gas). Impacts from petroleum exploration and recovery are significant, from the former particularly in sensitive northern ecosystems and from the latter predominantly from accidental spills during drilling, production, or delivery, which can cause widespread direct and indirect harm to affected areas as well as resident plants and animals. But since production of a paper cup consumes as much hydrocarbon as a polyfoam cup (Table 1), acquisition of the raw materials for its production includes both the wood acquisition and the hydrocarbon acquisition requirements necessarily causing the greater environmental impact.

Paper cups are made from bleached pulp, which in turn is obtained in yields of about 50% by weight from wood chips (*2*). Bark and some wood waste are also burned to supply a part of the energy requirements of the papermaking process. Thus an average of some 33 g of wood plus, for additional energy requirements, an average of about 4 g of residual fuel oil or natural gas, is consumed per paper cup with a finished weight of 10.1 g. More petroleum than this would be needed if the paper cup had a plastic or wax coating, but this option is excluded in the estimate given here.

Inorganic chemicals are also required for the papermaking process. Relatively small amounts of sodium hydroxide or sodium sulfate are needed for chemical pulping makeup requirements, since the recycle of these in the kraft pulping process is quite efficient. But larger amounts of chlorine, sodium hydroxide, sodium chlorate, sulfuric acid, sulfur dioxide (or sulfur which is burned to produce this), and calcium hydroxide (or limestone, from which calcium hydroxide may be produced by "burning" and slaking) are used on a once-through basis to the extent of 160 to 200 kg per metric ton of pulp. The total non-recycled chemical requirement thus works out to an average of about 1.8 g per cup.

The superior properties of polystyrene over wood pulp in this application allow the use of only 1/6 as much material to produce a cup. Chemical requirements for the polystyrene foam cup are small because several of the chemical conversion stages employ solid-phase catalysts capable of many thousands of conversions per active site before catalyst replacement is necessary. Alkylation of benzene with ethene (ethylene) also uses aluminum chloride catalytically to the extent of 10 kg per metric ton of ethylbenzene produced. The aluminum chloride is later neutralized with roughly the same amount of sodium hydroxide. Further small amounts of sulfuric acid and sodium hydroxide are consumed, principally for cleanup of the hydrocarbon streams at intermediate stages, which total about a further 10 kg per metric ton of polystyrene. This gives a total chemical requirement of about 33 kg per metric ton of polystyrene, 0.05 g per cup; or 3% of the chemical requirement of the paper cup.

Because 6 times as much wood pulp as polystyrene is required to produce a cup, the paper cup consumes about 12 times as much steam, 36 times as much electricity, and twice as much cooling water as a polystyrene foam cup. About 580 times the volume of waste water is produced for the pulp required for the paper cup as compared to the polystyrene requirement for the polyfoam cup. The contaminants present in the wastewater from pulping and bleaching operations are removed to a varying degree depending on site-specific details but the residuals present in all categories except metal salts would still amount to 10 to 100 times those present in the wastewater streams from polystyrene processing.

The wholesale price of a paper cup is about 2½ times as much as polyfoam since its consumption of raw materials and utilities are both greater. But their respective purchase prices are not so closely linked to the environmental costs of production and recycle or final disposal. Emissions to air total some 22.7 kg per metric ton of bleached pulp to about 53 kg per metric ton of polystyrene. But on a per cup basis this comparison becomes 136 kg from paper versus 53 kg from polyfoam.

On a mass basis, the 43 kg of pentane employed as the blowing agent for each metric ton of the foamable beads used to make polystyrene foam cups is the most significant single emission to air from the two technologies. Its atmospheric lifetime is estimated to be 7 years or less, about a tenth that of the chlorofluorocarbons formerly used in some foamable beads (*3*). Unlike the chlorofluorocarbons, pentane would tend to cause a net increase in ozone concentrations, both at ground level and in the stratosphere (*4*). However, its contributions to ozone and as a "greenhouse effect" gas are almost certainly less than those of the methane losses generated from post-use disposal of paper cups in landfill sites.

If the 6 metric tons of paper equivalent to a metric ton of polystyrene does completely biodegrade anaerobically in a landfill theoretically it could generate 2370 kg of methane along with 3260 kg of carbon dioxide. Since methane is a "greenhouse gas" roughly equivalent to pentane it would only take 2% of the theoretically possible biodecomposition of paper to equate to the effect of the pentane loss from one metric ton of polyfoam cup production.

The technical side of recycle capability with the polystyrene foam is also straightforward. The restriction that recycled resin may not be used in food applications only partially limits the many possible end uses for recycled polystyrene such as in packaging materials, insulation, flotation billets, patio furniture, drainage tile, and so forth. Recycle operating problems have largely been solved. An improved

The author is an associate professor of chemistry at the University of Victoria, Victoria, British Columbia, Canada V8W 3P6.

infrastructure is all that is required to make this option a more significant reality and convert this perceived negative aspect of polyfoam use to a positive one (*5*). Paper cups, which use a non-water soluble hot melt or solvent-based adhesive to hold the parts together, are for this reason technically excluded from paper recycling programs because the adhesive resin cannot be removed during repulping. If the paper is coated with a plastic film or wax barrier to improve its properties in use this, too, prevents recycling of the fiber.

Polystyrene is relatively inert to decomposition when discarded to landfill. However, there is also increasing evidence that disposal of paper to landfill does not necessarily result in degradation or biodecomposition, particularly in arid regions (*7*). Even when anaerobic decomposition of the paper cup after disposal to landfill does proceed, methane and carbon dioxide (both "greenhouse gases") are produced in a roughly 2:1 mole ratio, which is worse than incineration because this would convert virtually all of the carbon content to carbon dioxide. Depending on the greenhouse model chosen, a molecule of methane has from 5 to nearly 20 times the warming effect of a molecule of carbon dioxide (*4*). Water-soluble fragments of cellulose from the decomposition also contribute biochemical oxygen demand (BOD) to leachate from the landfill. Leachate may be treated to remove contaminants to control environmental impact on discharge, or it may be lost to surface waters or underground acquifers to exacerbate the oxygen demand in these raw water sources.

It can be seen from this extensive but not exhaustive analysis that a resource utilization to final disposal consideration of even the relatively restricted question of paper versus polyfoam for hot drink containers is complex. This analysis assumed that one-use hot drink cups are appropriate for the convenience and hygiene of certain situations, and considered only the relative merits of the two choices for this particular application.

The analysis did not consider the relative environmental merits of china, glass, or other materials used for hot drink cups which also have their place but would be more costly and difficult to manage, wash, and so on, in many of the situations where one-use cups are used appropriately. To do so would require consideration not only of the resource and energy consumption and emissions produced in their manufacture, but also the consumption of water, energy, and detergent plus the impact of waste water discharges when they are cleaned for reuse. So this analysis too becomes a complex one. It is probably safe to say that if the multi-use cup survives over a sufficient number of use cycles its environmental impact per use would be less than found for either type of single-use cup analyzed here. But for single-use applications it would appear that polystyrene foam cups should be given a much more even-handed assessment as regards their environmental impact relative to paper cups than they have received during the last few years.

Table 1. Raw material, utility, and environmental summary for hot drink containers. Full details of sources of data and the calculations involved in the entries are to be published separately (*21*).

Item	Paper cup*	Polyfoam cup†
	Per cup	
Raw materials:		
Wood and bark (g)	33 (28 to 37)	0
Petroleum fractions (g)	4.1 (2.8 to 5.5)	3.2
Other chemicals	1.8	0.05
Finished weight (g)	10.1	1.5
Wholesale cost	2.5×	×
	Per metric ton of material‡	
Utilities		
Steam (kg)	9,000 to 12,000	~5000
Power (kWh)	980	120 to 180
Cooling water (m^3)	50	154
Water effluent		
Volume (m^3)	50 to 190	0.5 to 2
Suspended solids (kg)	35 to 60	Trace
BOD (kg)	30 to 50	0.07
Organochlorines (kg)	5 to 7	0
Metal salts (kg)	1 to 20	20
Air emissions		
Chlorine (kg)	0.5	0
Chlorine dioxide (kg)	0.2	0
Reduced sulfides (kg)	2.0	0
Particulates (kg)	5 to 15	0.1
Chlorofluorocarbons (CFCs)	0	0§
Pentane (kg)	0	35 to 50‖
Sulfur dioxide (kg)	~10	~10
	Recycle potential	
To primary user	Possible, though washing can destroy	Easy, negligible water uptake
After use	Low, hot melt adhesive or coating difficulties	High, resin reuse in other applications¶
	Ultimate disposal	
Proper incineration (*6*)	Clean	Clean
Heat recovery, (MJ/kg)	20	40
Mass to landfill (g)	10.1	1.5
Biodegradable	Yes. BOD to leachate, methane to air	No, essentially inert

*Made from fully bleached kraft pulp. Information from British Columbia pulp mill and Paprican contacts, and (*2, 8*). †Made from molded polystyrene foamable beads. Information from (*9–12*) and sources cited therein. ‡For equitable comparison of these data the figures given under the paper cup heading should be multiplied by 6, since that is the ratio of pulp to polystyrene required to produce a cup. §See (*14*) for details of the phasing out of CFCs as a result of the Montreal Protocol of May 1987. Many producers of foamable beads have never used CFCs. The present position is given in (*15*) and (*16*), true since 1988. ‖Blowing agent usage reported in (*14, 17*). Some blow molders have adopted air handling systems to capture and burn pentane from blow molding in a gas turbine, for energy recovery (*18*). ¶Examples of recycle details available from (*19–21*).

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