Reusable and Disposable Cups: An Energy-Based Evaluation

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ABSTRACT / A group of five different types of reusable and disposable hot drink cups have been analyzed in detail with respect to their overall energy costs during fabrication and use. Electricity generating methods and efficiencies have been found to be key factors in the primary energy consumption for the washing of reusable cups and a less important factor in cup fabrication. In Canada or the United States, over 500 or more use cycles, reusable cups are found to have about the same or slightly more energy consumption, use for use, as moulded polystyrene foam cups used once and then discarded. For the same area paper cups used once and discarded are found to consume less fossil fuel energy per use than any of the other cup types examined. Details of this analysis, which could facilitate the comparative assessment of other scenarios, are presented.

Conventional wisdom suggests that multiple uses of a reusable cup produce a lower overall environmental impact per use than a single use of a disposable cup. Disposable cups have a place in applications where breakages and losses of other types of cup are unacceptably high, or where washing and sanitizing of reusable cups is awkward, such as in hospitals, in the entertainment and transportation sectors, and for occasional use by large numbers of people. These circumstances make the convenience and the much lower unit cost of disposable cups attractive.

Our previously published study of the life cycle environmental impacts of paper and polystyrene foam cups (Hocking 1991a,b) evoked a lot of interest, most notably in its conclusion that adverse resource and pollution externalities of these cup types were at least similar. Some readers mistakenly interpreted these papers to be recommendations in favor of disposable over reusable cups, which was not the case. However, these misinterpretations, plus evidence of increasing concern about the overall environmental impact of cup selection (van Eijk and others 1992, Fenton 1992, Hocking 1991c, d, 1993) prompted the energy-based evaluation presented here.

The basic question is, considering the resource consumption and the total resulting waste stream during use, how many uses of a reusable cup are necessary before its overall impact per use is less than that of a disposable cup? Decision-making by food service operators, legislators, environmental groups, and the public would be served by the answer to this question.

KEY WORDS: China; Glass; Hard plastic; Paper; Polystyrene foam cups

This is not an easy question to answer because of the widely differing nature of the materials used and the conditions required to make reusable and disposable cups, e.g., pottery clays, glass, plastics, and paper. The fundamental property common to each of these cup types is the total energy required to produce the cup or mug ready for use, which is a well-established criterion for the comparison of disparate materials (e.g., Boustead and Hancock 1979, Kindler and Nikles 1979, 1980, Ringwald 1982). Available background information from previous studies of the merits of cup options are individually and collectively incomplete. The study carried out in the Netherlands did not consider polystyrene foam cups (van Eijk and others 1992), the Winnipeg Packaging Project did not examine ceramic (earthenware/stoneware) cups (Fenton 1992), and our own previous contribution did not review reusable cups (Hocking 1991b). Furthermore, the frameworks used in these assessments were sufficiently different to make it difficult for direct comparisons to be made between them.

This paper examines the fabrication energy for five of the common hot drink cup types applying the same methodology to each and tabulates the energy required for various widely used commercial washing and sanitizing methods employed for the reusable types. The combined information is then integrated to determine the energy requirements per use for various service scenarios of each cup type and to determine the break-even energy requirements for each of the reusable–disposable cup pairs. Brief consideration is given to the effects of various disposal options. Finally, a few tests are applied to determine the sensitivity of the energy requirements and break-even points to alterations in the input data using the same methodology.

Methods

The boundaries taken for the detailed energy evaluation include: the total energy required for the extraction of crude oil on site to the final product for the plastic cup types; the total energy required to produce a finished paper cup from a standing forest; and all the processing energy required from raw materials in the ground to finished glass and ceramic cups. For the output side, the energy consumption during use for the cup life cycle is evaluated to the point of discard for both the cup types, disposable and reusable. For the reusable cups, account is taken of the total operating energy of various commercial dishwashers. No account is made of the energy or materials requirement to make a commercial dishwasher, because this energy component per cup use cycle over the life of the dishwasher will be small relative to the operating energy component.

The energy parameters of interest for each type of cup were compared on a common basis. The total energy consumption per use for each of the reusable cups was determined using equation 1. This reflects the usual practise to wash new cups of this type before use.

$$\text{Total energy consumption per use of reusable cup} = \frac{A + EB}{E} \qquad (1)$$

where A is the energy required for the manufacture of one reusable cup, B is the energy required for one hygienic wash, and E is the number of single uses of the reusable cup followed by a wash.

To accommodate the influence of refills on the energy consumption per use requires the introduction of an additional term (equation 2). By way of

$$\text{Total energy consumption per use of reusable cup (accommodating refills)} = \frac{A + EB}{E + F} \qquad (2)$$

where F is the number of refills of the reusable cup without intermediate washes.

example, for wash/use cycles WUWU, WUUWUU, and WUUUWUUU, E and F are assigned values of 2 and 0, 2 and 1, and 2 and 2, respectively. In the limiting case with no refills, $F = 0$, and equation 2 reduces to equation 1.

The energy required per use of a disposable cup is the energy required to make the cup, C, divided by the number of uses before discard, D, as given by equation 3.

$$\text{Total energy consumption per use of disposable cup} = \frac{C}{D} \qquad (3)$$

To determine the break-even number of uses of the reusable cup relative to the disposable cup from an energy consumption perspective is straightforward for single uses of the reusable cup between washes and only one use of the disposable cup before discard, determined by equation 4.

$$\frac{A + xB}{x} = C \qquad x = \frac{A}{C - B} \qquad (4)$$

where x is the break-even number of uses of the reusable cup before the energy consumption per use equates to that required to manufacture the disposable cup.

Break-even evaluation becomes more complex when assuming more than one use before washing or discard of either cup type, as is common (equation 5). In the limiting case, when the number of uses of each cup type before washing or discard is 1 (i.e., $D = E = 1$, and $F = 0$), equation 5 reduces to equation 4.

$$\frac{A}{x} + \frac{B}{(E + F)} = \frac{C}{D} \qquad x = \frac{A}{\frac{C}{D} - \frac{B}{E + F}} \qquad (5)$$

Finally, the break-even energetics of various disposal options for both cup types and accommodating a variety of usage scenarios were determined by equation 6.

$$x = \frac{(A - G)}{\frac{(C - H)}{D} - \frac{B}{(E + F)}} \qquad (6)$$

where G is the energy recoverable from the reusable cup on discard and H is the energy recoverable from the disposable cup on discard.

Again in the limiting case, if no energy recovery is practiced for either cup type at the end of its useful life (i.e., $G = H = 0$), this equation reduces to equation 5.

The published energy requirements for each of the four cup technologies were collected without regard to their relevance to cups or to whether the reported value was for part of the process or for the whole process. Operating details were also obtained for several commercial dishwashers with particular refer-

Table 1. Energy costs to produce ceramic tableware

kJ/g	Remarks	Reference
7.91	Firing only, teapots, mugs, etc., >1985	Holmes (1987)
8.40	Glazing only, hotel porcelain, 3 tonne/day	Becker (1980)
16.8	Firing only, teapots, mugs, etc., <1985	Holmes (1987)
21.4	Average for 19 UK earthenware factories, 1989[a,b]	Energy Efficiency Office (1990)
48.2	Firing and glazing, Dutch experience, total energy required from materials in the ground[c]	van Eijk and others (1992)
53.2	Average for 12 UK china/porcelain factories, 1989[b,d]	Energy Efficiency Office (1990)
58.8–88.2	18th, 19th century experience, coal firing, Staffordshire and Pakistan	Rice (1987)
180.5	Small scale (1 m^3, 35 ft^3) gas-fired, downdraft kiln, 400 mugs/cups per batch[b]	Dexter (personal communication)

[a]Range reported for earthenware was 2.53–54.6 kJ/g.

[b]Drying, firing, and glazing energy only.

[c]Includes 9.1 kJ/g as electricity.

[d]Range reported for china/porcelain was 26.5–85.1 kJ/g.

Table 2. Energy costs to produce glassware

kJ/g	Remarks	Reference
9.1	Glass melting only	Berry and Makino (1974)
9.15	Cornelius furnace[a], melting only	Thorpe and Whitely (1947)
9.18	Container glass, electricity, 3.06 GJ/mg, × 3	Harper and others (1982)
11.8	Container glass and containers	Heather (1992b)
12.6	Container glass, electricity × 3	Boyd and Thompson (1980)
10.5–17.8	Glass melting	Miller (1983)
13.3	Container glass making, gas fired	Boyd and Thompson (1980)
14.5	UK glass industry overall, 1982	Bevan and Deakin (1985)
17.9	1 ton/day electric, from 1500 kWh/ton, × 3	Tooley (1974)
18.0	Glass containers, 4534 kWh/ton	Berry and Makino (1974)
19.3	Glassware, melting only, 20 tonne/day scale	Kriz (1981)
20.2	UK glass industry overall, 1970	Bevan and Deakin (1985)
21.0–25.1	Total energy, from raw materials in the ground, generic glass	Boustead and Hancock (1979)
25.0	Glass bottles, ca. 1980 data	Ringwald (1982)
27.7	Glass tableware, includes raw material recovery, transport, +40% cullet	Fenton (1992)
27.7	Gas–oxygen firing, specialty glass, melting only	Klingensmith (1986)
46.5	Specialty glass, UK, overall (includes tableware)	Bevan and Deakin (1985)
79.1	Gas-air firing, melting only	Klingensmith (1986)

[a]Estimated primary fuel requirement from an electrical requirement of 1 kWh per 1.18 kg of glass

ence to their water, energy, detergent, sanitizer, and rinse agent requirements. Published values were all converted to common units of kilojoules per gram of material processed (Tables 1–5). This enables comparison of values within a technology and between technologies. It also provides the raw data in a form that may be readily compared with other fabrication energies, other cup weights, and other types of tableware, such as plates or bowls. The data and methods presented make it straightforward to evaluate any alternative cup type, production energy, or service scenario other than those considered here.

Results and Discussion

Energy of Manufacture

Energy requirements from within a technology and between technologies was found to vary widely. Low values generally coincide with very large or very recently built production facilities, or with reports of the energy requirements for a primary part rather than for the whole process. Glass-making facilities for volume production of containers employ furnaces with a melting capacity as large as 150 tonnes per day (Turton and Argent 1988). Smaller scale production

Table 3. Energy costs to produce polystyrene (PS) ware

kJ/g	Remarks	Reference
50.1–106.1	Range, value depends on system boundary	Bery and others (1975)
67.6[a]	Does not include energy content of feedstock oil	van Eijk and others (1992)
70.2	Polystyrene resin pellets	Berry and Makino (1974)
71.3	Ready-formed polystyrene foam meat trays, 1974	Berry and Makino (1974)
82	Polystyrene foam	Kindler and Nikles (1980)
85	Generic "plastic" packaging	Heather (1982a)
92.1	Single service 9 oz. cola cups	Gaines (1981)
106.6[b]	Raw material, shipping, processing, + ½ electricity	Hocking (1991b)
106.9	Solid polystyrene	Environment Canada (1984)
108.5	Main process only, <1979 UK data	Boustead and Hancock (1979)
111.5	Polystyrene foam ware	Environment Canada (1984)
111.9[c]	Polystyrene foam cups, 1967–1980 data	Hocking (1991a)
132.4	Polystyrene resin, ca. 1980	Ringwald (1982)
138.4	Single service plastic cups, <1974 data	Hunt and Welch (1974)
138.3–149.4	PS foam; main process + capital + transport + services; 1974 data	Boustead and Hancock (1979)

[a]If intrinsic energy (since processing energy requirements are already included) content of feedstock oil is included at 42 kJ/g, would give a gross energy requirement of 109.6 kJ/g.

[b]Estimated in the following way: [oil (4.3 g × 45.6 kJ/g) + other chemicals (5.0×10^{-2} g × 10^{-6} tonne/g × 1400 kWh/tonne(Cl_2 + NaOH) × 3.6×10^3 kJ/kWh × 100/57.3 (Canadian electric efficiency)] × 1.0/1.9 cups/g polystyrene + power (0.28 Wh/g × 0.5 (outside generated) × 3.6 kJ/Wh × 100/57.3 (Canadian electric efficiency) = 104.32 kJ/g polystyrene. Breakdown: oil (processing + feedstock), 103.21 kJ/g; other chemicals, 0.23 kJ/g; outside power, 0.88 kJ/g, using data from reference given.

[c]Estimated in the same manner as footnote b except that energy content of oil was taken as 52.1 kJ/g (Boustead and Hancock 1979) to reflect the additional processing stages not included in the referenced study.

units for specialty glassware employ furnaces with a melting capacity as small as 0.9 tonne per day and consume about twice the energy per tonne because of proportionately larger heat losses (Tooley 1974). When a small kiln is used for the production of ceramic tableware, it is subject to larger heat losses per kilogram of product because the required periods of heating for drying, biscuit firing, and glazing are much longer than for the equivalent melting, forming, and annealing stages of glass-making. Therefore, the higher energy values listed for the ceramic and glass technologies generally correlate with smaller scale units, with older operating units, Third World facilities, and with evaluations of the energy requirements of the whole process rather than isolated parts.

The published energy values for each technology selected for Table 6 represent the best available for the purposes of this study; they take the best estimate of the total energy requirement from raw materials in the ground to a finished cup, including transportation. Production breakage rates in the glass and ceramic sectors, when reported, were usually less than <1% (Boyd and Thompson 1980, Heather 1982a,b). The selected values for these technologies reflects the smaller-scale operation that tableware fabrication usually entails. Tile production, brick-making, or production of glass containers or flat glass tend to be on a much larger scale and more thermally efficient, which is reflected in the primary data for these technologies. Our own information is used for the calculation of the energy requirements of the polystyrene foam and pa per technologies for Table 6 (Hocking 1991b). These values are consistent with the temporal trends in the energy requirements for these technologies (Fenton 1992).

The values selected in all cases are at the upper end of the tabulated range for the reasons described, but none are extreme values. These selection criteria give the highest energy requirement to the two types of polystyrene, 104.3 kJ/g for the foamed material and 106.6 kJ/g for the reusable polystyrene varieties. Paper (66.2 kJ/g), and ceramics (48.2 kJ/g), required much less energy per gram. Glass, at 27.7 kJ/g, required only about one quarter of the energy per gram as the plastics.

An arbitrary range of available samples of each of the cup types of 8- to 9-oz nominal capacity and manufactured in Canada, China, the United States, and the United Kingdom was weighed, and a median weight sample of each type was taken for calculating the total energy of manufacture for each cup type. On this basis, the very low mass of the molded polystyrene (PS) foam cup required the least total energy to produce, 198 kJ/cup, and the ceramic cup the most, at 14,088 kJ/cup.

Table 4. Energy cost to produce paper tableware

kJ/g	Remarks	Reference
7.65	Paperboard pulp	Berry and Makino (1974)
25.3–78.3	From standing timber, 1972–1976 data	Boustead and Hancock (1979)
45.9	Paper and board, ca. 1980	Ringwald (1982)
46.6	Kraft paper, US data, <1974	Berry and others (1975)
47.7	Paper sanitary food containers	Berry and Makino (1974)
58.1	Products from fully bleached kraft paper	Chum and Powers (1992)
61.9	Process energy only, 1989	American Paper Institute (1989)
65.1[a]	Total, excludes intrinsic energy of feedstock wood	van Eijk and others (1992)
66.2[b]	From fossil fuel, wood, additional chemicals + ½ required electricity.	Hocking (1991b)
87.2	Paper cups, bleached kraft, including energy of wood	Gaines (1981)
89.0[c]	Paper cups, 1974–1980 Canadian data	Hocking (1991a)
90.3	Paper cups	Hunt and Welch (1974)
105.5[a]	From ref. total + energy of feedstock wood	van Eijk and others (1992)
124.3	Corrugated boxes	Berry and Makino (1974)

[a]If intrinsic energy content of feedstock wood of 2.059 g wood/g paper at 19.6 kJ/g dry wood is included, it gives a total of 105.5 kJ/g paper. Use of intrinsic energy is appropriate because processing and transport energy is already included in this study.

[b]Estimated in the following way: [wood (21 g × 20.6 kJ/g) + oil (1.8 g × 45.6 kJ/g) + other chemicals (1.0 g × 10^{-6} tonne/g × 1400 kWh/tonne(Cl_2 + NaOH) × 3.6 × 10^3 kJ/kWh × 100/57.3 (Canadian electric efficiency)] × 1.0/8.3 cups/g pulp] + power (0.98 Wh/g × 0.5 (outside generated) × 3.6 kJ/Wh × 100/57.3 (Canadian electric efficiency) = 66.15 kJ/g bleached pulp. Proportion of oil or alternative fossil fuel used is close to current U.S. data given by Wells (1991) and McCubbin (1991). Intermediate figure used here for the energy content of oil accommodates use of other possible fossil fuels, e.g., natural gas, and processing energy requirements but not transport. Breakdown: wood, 52.12 kJ/g; oil, 9.89 kJ/g; other chemicals, 1.06 kJ/g: outside power, 3.08 kJ/g. Cogenerated power estimate of 3.08 kJ/g pulp is not included to avoid double counting.

[c]Estimated in same manner as given in footnote b.

Table 5. Energy equivalencies and conversions used in calculations[a]

	Energy content			
Primary energy source	Intrinsic, fuel itself	Processing, Transport	Total	Notes
Coal (kJ/g)	28.0	1.4	29.4	1[b]
Natural gas				
BTU/ft^3	1050	52.5	1102.5	2,3[c,d]
MJ/m^3	37.2	1.86	39	
Light fuel oil (kJ/g)	43.20	8.9	52.1	1[b]
Dry wood (kJ/g)	19.6	1.0	20.6	2[c]

[a]Secondary energy, examples of average electricity conversion efficiencies, %: Canada, 57.3; Germany, 36.9; Netherlands, 33.0; Norway, 69.9; UK, 35.2; USA, 38.0. Electricity production efficiencies of 33%, 40%, and 70% for thermal, nuclear, and hydroelectric generation, respectively, were adopted from Boustead. The 40% figure is raised slightly from the cited 35% to accommodate anticipated improvements (Boustead and Hancock 1979). Using these efficiencies and the values for the proportion of electricity generated by each of these methods given by the OECD (1993) enabled calculation of the overall efficiencies given. The 33% efficiency for conversion of fossil fuels to electricity is close to the current actual value achieved by many countries, e.g., Canada, 32.0; France, 32.6; Germany, 33.2; Japan, 36.4; UK, 32.6; and USA 32.7 (World Resources 1990–1991).

Energy of Reuse

To assess the overall impact per use for the reusable cup types in a public service setting also required a compilation of the energy requirements of cleaning and sanitizing (Table 7). Most of the electrical energy requirement for dishwashing is for heating the water, required hot for efficient cleaning. The electricity required per cycle for the more energy-efficient commercial dishwashers was similar, in the range of 70–83 kJ/cup. The energy requirements of some models are offset to an extent by reuse of the hot rinse water as the wash water for the next cycle; even so, two of these require about 130 kJ/cup/wash (Table 7). However, electricity is a secondary energy source. To compare dishwashing energy with the energy for the manufacture of each of the cup types, the energy equivalent to the required electricity has to accommodate the additional expenditure of primary energy from which it is

Table 6. Energy required to make typical hot drink cups[a]

Cup type	Mass range (g)	Selected cup (g)	Energy requirement kJ/g (ref.)	kJ/cup
Ceramic	227–337	292.3	48.2 (van Eijk and others 1992)	14,088
Heat-proof glass	166–255	198.6	27.7 (Fenton 1992)	5,501
Reusable polystyrene	27–109	59.1	106.6 (Fenton 1992)	6,300
Uncoated paper	6.3–10.2	8.3	66.2 (Hocking 1991b)	549
Moulded PS foam	1.4–2.4	1.9	104.3 (Hocking 1991b)	198

[a]See Tables 1–5 for details of methods used to derive kJ/g figures quoted here.

derived. The efficiency of electricity generation varies country by country, according to the proportions of thermal, hydro, nuclear, and other methods used to produce it. Thus Canada, with a higher proportion of hydroelectricity than the United States, has an average electrical generating efficiency of 57.3%, while the value for the United States is 38%. The former values are used in the present study for calculating total energy and the break-even points. The corresponding figures for Germany and the Netherlands, both with lower proportions of developed hydroelectricity, are 36.9% and 33.0%, respectively; Norway, with 99.6% hydroelectricity has the highest efficiency of about 70%. While these differences would marginally influence the figures they would not substantially alter the conclusions.

Figure 1 illustrates the energy consumption in kilojoules per serving for each of the reusable cup types used only once before washing, calculated using 184 kJ/cup primary wash energy requirement (for Canada) from Table 7 and equation 1. For the disposable cup types used only once before discard, the energy consumption per use is the energy required to manufacture the cup. All three types of reusable cups have a much larger energy consumption per use than either of the disposables at ten servings. Energy consumption of any reusable cup drops to less than the paper cup only at about 100 servings. Only at some point between 100 and 1000 servings does the energy consumption per use of the reusable cups drop to less than that of either paper or polystyrene foam disposables.

Another interesting feature emerges from this portion of the study. Using the same energy data for an economical commercial dishwasher but the lower average generating efficiency of the United States, the primary energy required to wash a reusable cup is 278 kJ. This is somewhat more than the 198 kJ of primary energy required to make a polystyrene foam cup, but not significantly more bearing in mind the weight range of foam cups and the generalizations in the source data. In other words, for a single use of both cup types in a country with low average electrical generating efficiency, there will be no point at which a reusable cup would consume less energy per use than a polystyrene foam cup. Only if the reusable cup were used twice between washes, to one use before discard for the disposable (not a "level playing field") could any of the reusable cups eventually come out ahead.

In the comparison with paper cups, the 278 kJ required to wash a reusable cup with an efficient dishwasher in the United States is still less than half of the energy required to make a paper cup, so a glass reusable cup would use less energy after 15 uses, reusable plastic after 17 uses, and ceramic after 39 uses, calculated using equation 4. Considering dishwashers of lower energy efficiency, the 340–360 kJ of primary energy used by two of the high temperature dishwashers in the United States is more than half of the 549 kJ total energy required to make a paper cup. However, the per cup energy used by any dishwasher exceeds the 82 kJ (for 8.3 g/cup) of fossil fuel required to make a paper cup. Considering only fossil fuel consumption, therefore, a single use of a paper cup consumes less than a single use of any of the other cup types examined.

The number of uses of the reusable cup types where the total energy consumption per use is equivalent to that required to manufacture a disposable cup is calculated for each of the cup pairs, again using the conservative (Canadian) primary energy requirement of 184 kJ/cup/wash. The results, on the basis of one use for each cup type before washing or discard, are given in Table 8. Depending on which cup pair one wishes to compare, anything from 15 to 1000 uses of the reusable cup are needed before the inclusive energy consumption per use of the reusable cup drops to the energy required to make the disposable cup. The Winnipeg Packaging Project obtained break-even values of about 20–115 uses of the reusable cup, and the Dutch study concluded that 294–640 uses of the reusable cup were required for break-even energy

Table 7. Energy requirements for commercial cleaning and sanitizing of cups[a]

Washer type	Electrical energy per cup (kJ)[b]	Primary energy required (kJ per cup)[c]		Reference
		Canada	USA	
Hobart under-counter, model not known, 4.55 liters per cycle	69.7[d]	122	183	Fenton (1992)
Blakeslee UC-1 high temp., 1.5 hp drive	67.6–78.9[e] (73.3)	128	193	Blakeslee (1993)
Rhima, high temp., 5 cycle	82.9[d,f]	145	218	van Eijk (1992)
Hobart WM-5C under-counter, low temp., 0.5 hp	105.5[g]	184	278	Hobart (1993a) Smith (1991)
Moyer-Diebel, under-counter, high temp.	129.2[d,h]	225	340	Moyer Diebel (1993) Fenton 1992
Hobart AM-14, high temp., ca. 8.2 liters rinse water per cycle, 1 hp	122–151[i] (136.5)	238	359	Hobart (1993b) McGinnis (personal communication) Smith (1991)

[a]Calculated on the basis of the electrical energy required for hot water consumed to wash full racks of cups (usually 20), heating from 10°C to 83°C (180°F) for the high-temperature and to 60°C (140°F) for the low-temperature washers. Assumes 100% efficiency of electric water heater. If standing losses are included, electric water heaters are about 90% efficient, and gas about 50%. Lower three machines are in common current use in Canada and the Unites States.

[b]Ranges given correspond to 20 and 40 wash cycles before discard of wash water estimated for those washers using recycled rinse water for washing as an energy conserving measure. For the 20 wash cycle calculation, 50% booster heat was added to the original hot water requirement to allow for slower cycling times.

[c]Average electrical generation efficiencies of 57.3% in Canada and 38.0% in USA were calculated from the respective primary sources of power of the two countries for 1990 (Table 5).

[d]Not known whether the energy required to operate the dishwasher, and to produce the detergent mixture were included. Temperature sufficiently high to not require sanitizer. Could not verify water volume information.

[e]New model, 1993 specifications. Includes an estimate of 3.6 kJ/cup required to operate the 1.5-hp drive and 1.8 kJ/cup required to produce the detergent.

[f]Conversion to Dutch electrical generation efficiency of 33% would require 240 kJ of primary energy (van Eijk and others 1992).

[g]Requires use of sanitizer (0.5 kJ/cup). Sales and service representatives estimate high-temperature models of commercial dishwashers outsell low-temperature models by 10:1 or more. High-temperature model of this machine, WM-5H, is estimated to require 136 kJ/cup, which includes 5.1 liters of 66°C wash water, 6.6 liters of 82°C rinse water, operating power, and detergent.

[h]Specifications for 1993 model (Moyer-Diebel/Champion model 501) require an estimated 94.4–95.9 kJ/cup including operating power and detergent.

[i]Rinse water (8.2 liters, 83°C) is recycled to 60 liters, 66°C wash water holding tank together with added detergent, for reuse as wash water. Includes 2.4 kJ/cup for operating power, and 1.8 kJ/cup required to produce detergent plus caustic. New high-temperature and low-temperature models of this machine are estimated to consume 73–103 kJ/cup and 52–74 kJ/cup, respectively.

consumption (Fenton 1992, van Eijk and others 1992). Lower values in the former evaluation are from a combination of a lower wash energy (electrical energy only) and slightly higher fabrication energy for the polystyrene foam cup. The closer but still lower values in the Dutch study arise partly because the dishwasher required 240 kJ of primary energy per cup and partly because the intrinsic energy content of the feedstock apparently was not included in the fabrication energy required for the two disposable cups.

Table 8 also gives the energy costs per use for the scenario of two uses between washes of the reusable cup types compared to two uses before discard of the disposables. This scenario evidently requires twice as many uses of each of the reusables, ranging from 30 to 2000 uses per 15–1000 washes, before the reusables reach break-even energy consumption relative to the disposable cups.

Another way to consider the break-even servings is in terms of the return rate required for each of the reusables relative to each of the disposables for equal gross energy expenditure. A return rate of 99.7% or better, i.e., 997 returns out of 1000 uses, is required from each of the reusables relative to polystyrene foam for equal or lower energy expenditure (Table 8). Usage of the reusable cups relative to paper cups

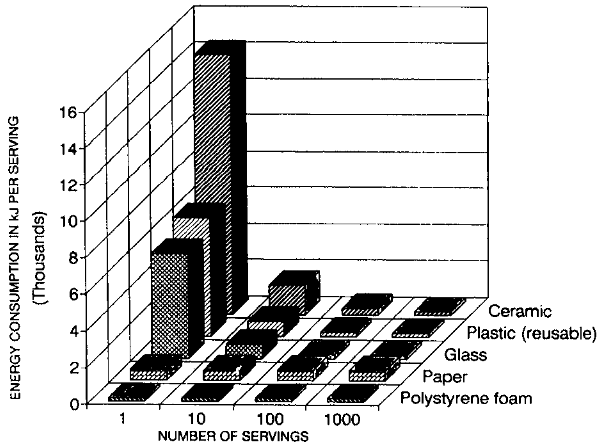

Figure 1. Energy consumption by reusable and disposable cups in kilojoules per serving. Assumes one use before washing for reusable cups, one use before discard of disposable cups.

requires return rates of 93.8%–97.5% for equal energy consumption per use.

To keep the scope of this paper manageable, it has focused on the energy aspects of reusable and disposable cups. The cited comprehensive Dutch survey also conducted a detailed assessment of other environmental factors involved in the manufacture and use of a porcelain cup and saucer relative to solid (not foam) polystyrene and paper disposable cups, and expressed their results in environmental break-even terms. For one use per wash for the porcelain versus one use for the disposable before discard they obtained break-even values for porcelain–polystyrene and porcelain–paper pairs of 1800 and 48 for impact on air, 125 and 99 for landfill volume, and 640 and 294 (as already mentioned) for energy consumption, respectively (van Eijk and others 1992). They could find no point where the impact on water by the porcelain cup would be lower than use of either of the disposables. Thus, environmental factors other than energy consumption give quantitatively different break-even points for the reusables as compared to the disposables, but still require very high return rates for the reusable cup to come out ahead of disposables in three out of the four environmental factors examined.

Net energy expenditure of the disposables and plastic reusable cup types could be further reduced by recycling or energy recovery instead of landfill disposal. The reduction would be equivalent to the intrinsic energy content of the material from which they are made, less the energy required to collect these materials for recycle. This would, of course, also shift the energetic break-even value compared to reusable cups. A discarded ceramic cup has no recycle value except as fill, and the energy required to reuse the material of the glass cup as cullet is almost as much as required in the initial making of glass from raw ingredients (Boustead and Hancock 1979, Berry and Makino 1974, Miller 1983). Thus, no energy is recoverable from ceramic cups and negligible energy from the glass cups, but the intrinsic energy recoverable by recycling the reusable polystyrene, the polystyrene foam, and the paper cup types is about 2364 kJ/cup (40 kJ/g), 76 kJ/cup (40 kJ/g), and 166 kJ/cup (20 kJ/g), respectively (Hocking 1991b), minus the energy expenditure required to accumulate these materials for recycling. Doing this reduces the net energy expenditures to 3936 kJ/cup for the reusable polystyrene, 122 kJ/cup for polystyrene foam, and 383 kJ/cup for paper. Any energy expenditure incurred to recycle or recover energy from these materials must be added to these figures.

Trash collection and plastics recycling operations have been estimated to have energy costs of 0.28–0.40 kJ/g and 26.7 kJ/g, respectively (Berry and Makino 1974). If it is assumed that there is a similar energy cost to recycle paper, recycling the material of the three cup types gives net energy costs of 5532 kJ/cup [3936 kJ/cup + (59.1 g/cup × 27 kJ/g)] for the reusable polystyrene cup, 173 kJ/cup [122 kJ/cup + (1.9 g/cup × 27 kJ/g)] for the polystyrene foam cup, and 607 kJ/cup [383 kJ/cup + (8.3 g/cup × 28 kJ/g)] for the paper cup. If energy costs of recycling (collection and sorting, transport, reprocessing) can be kept low, and the grade of end use of the recycled material kept high to maintain the high intrinsic energy content of these materials, then this is an energetically attractive option. Otherwise, recycling becomes a less attractive option and energy recovery from these materials is energetically preferable.

Sensitivity Tests

A series of tests was run altering one variable at a time to determine the sensitivity of the conclusions reached here to changes in the input manufacture and wash energy requirements. Reducing the assumed fabrication energy requirements of the reusable cups by 25%–50% is feasible within the weight ranges of cup types considered. Decreasing the fabrication energy required to make only the reusable cup types by 25% or 50% decreases the number of uses required from the reusable cups for break-even with the disposables by about the same percentages, to the ranges of 11–755 uses and 8–503 uses, respectively (Table 9). On the other hand, decreasing the fabrica-

Table 8. Break-even analysis of energy requirements for reusable and disposable cup pairs[a]

Cup pairs compared	One serving per wash/discard[b]		Two servings per wash/discard[c]	
	Break-even servings	Required return rate (%)[d]	Break-even servings	Required return rate (%)[d]
Glass/paper	15	93.8	30	96.8
Glass/PS foam	393	99.7	786	99.9
Plastic (reusable)/paper	17	94.4	35	97.2
Plastic (reusable)/PS foam	450	99.8	900	99.9
Ceramic/paper	39	97.5	77	98.7
Ceramic/PS foam	1006	99.9	2013	99.9

[a]Using 184 kJ per cup primary energy requirement, the calculated value obtained using the Canadian average electrical generating efficiency for 105.5 kJ (29.2 Wh) per cup electrical demand, see Table 7.

[b]One use between washings of reusable cups, one use before discard of disposable cups.

[c]Two uses between washings of reusable cups, two uses before discard of disposable cups.

[d]Calculated as (break-even servings) ÷ (break-even servings + 1) × 100.

Table 9. Sensitivity of break-even servings to changes in fabrication and wash energy requirements

Cup pairs compared	Baseline Canadian experience[a]	25% less fabrication energy for only		50% less fabrication energy, reusables	Wash energy per cycle[b]	
		Reusables	Disposables		50% less (92.0 kJ/cup)	50% more (276 kJ/cup)
Glass and paper	15	11	24	8	12	20
Glass and PS foam	393	295	none[c]	196	52	none[d]
Plastic (reusable) and paper	17	13	28	9	14	23
Plastic (reusable) and PS foam	450	338	none[c]	225	59	none[d]
Ceramic and paper	39	29	62	19	31	52
Ceramic and PS foam	1006	755	none[c]	503	133	none[d]

[a]Baseline cup fabrication energies from Table 6, wash energy of 184 kJ/cup from Table 7, calculated using equation 5.

[b]Covers somewhat wider range than Canadian primary energy requirements, and well below to mid range of American primary energy requirements.

[c]This manufacturing energy requirement for the polystyrene foam cup is less than the energy required to wash a reusable cup once, so there is no break-even point for this scenario.

[d]This wash energy requirement is greater than the fabrication energy for the polystyrene foamcup, so there is no break-even point for this scenario.

tion energy of the disposable cups by only 25% dramatically increases the break-even number of uses required from the reusable cups by 60%, relative to the paper cup, and to less than the wash energy for the polystyrene foam cup. That is, it costs more energy to wash any reusable cup than it costs to make the lightest polystyrene foam cup.

Decreasing the energy required to wash the reusable cups by 50% decreases the number of uses required for break-even energy by 18%–87%, to the 12–133 range. Increasing the wash energy requirement to 50% more than the Canadian baseline energy requirement, to 276 kJ, is about the same as the economical baseline primary wash energy requirement of 278 kJ in the United States (Tables 7 and 9). This increases the break-even uses of the paper disposable cup types by about 30%, to the 20–52 use range. Since the energy requirement for this wash scenario is somewhat more than the energy required to make a polystyrene foam cup, the reusable cup types are somewhat more energy intensive, use for use, than this type of disposable.

Conclusions

In carrying out this analysis, completeness and appropriateness of the secondary source input data selected were all important. The range of correct values for some of the energy inputs considered in this analysis is particularly broad for the manufacture of ceramic and glass cups, but the analysis reveals that the break-even points are not as sensitive to changes in this parameter (the fabrication energy of the reusable cup types) as to the energy required for washing and sanitizing of the reusable cups and to the fabrication energy for the disposable cups. The methods used are presented in sufficient detail that comparisons using any other input data may be entered readily and evaluated relative to the conclusions reached here.

The high fabrication energy required for the reusable cups becomes unimportant over enough uses, say 500 or more, compared to the energy required to wash and sanitize them for reuse. The wash energy alone is as much or more than that required to make a polystyrene foam cup in the United States and more than half that required to make a paper cup. From an energy standpoint, therefore, use of these disposable cups is thus appropriate, especially in situations where the return rate of a reusable cup is likely to be low. Selection of disposable cups is also indicated by the fact that the break-even points with respect to the environmental pollution parameters are also high.

Nevertheless, most of us prefer to use a ceramic, glass, or hard plastic cups over the disposable varieties. For regular use in the home and in most cafeteria and restaurant settings where a reusable cup life of 500 or more uses can be expected, their use makes sense. From an energy consumption criterion, however, there is good reason to use the disposable cup types when the return rate is likely to be low or for situations of one-time use such as for large parties, because their total energy requirement for manufacture is less than, or so close to, the energy required to clean a reusable cup that there is not much to choose between them.

Reuse of either cup type by the original user before washing or discard of course reduces the energy cost and environmental impact per use in direct proportion to the number of such reuses, over a large enough number of wash cycles of the reusable cups. Encouragement to do this with disposables here at a recent conference, was met with interest and some cooperation. As the significance of this factor becomes more widely realized, motivation and participation should improve.

This analysis provides the tools for a fresh consideration of practical options. Food service facilities that cater to on-site and take-out meals and beverages could encourage on-site users to use the reusable tableware and also provide convenient disposables for take-out use. This would reduce costs to replace broken or nonreturned ceramic ware and would also reduce net energy and resource requirements. Since wash energy is a high and sensitive factor, reducing the energy required for the operation of a commercial dishwasher could be an important goal. However, it is hard to see how this could be done without adding to operating complexity, which could increase labor costs or jeopardize public hygiene. Tables 7 and 8 show that efficient commercial dishwashers use only about 1.3 cups of hot water per cup to wash, rinse, and sanitize a tray of 24 cups. Hand washing to equivalent standards would be hard pressed to beat that, but domestic use of the same cup many times without washing remains as an option for those deeply concerned with saving energy.

Finally, this analysis confirms that to have a diversity of cup types available, appropriate to the required end use has environmental as well as convenience and cost merit. To eliminate disposable cups entirely could cost more resources and cause more environmental impact than achieved through the options available by the status quo. Thus, one's choice of cup may be freely based on aesthetic and convenience criteria rather than environmental or energetic ones.

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