EXECUTIVE SUMMARY

INTRODUCTION

Bottled water offers consumers a clean, portable supply of drinking water for consumption at home or away from home. Some disposable water bottles are recyclable, and lightweighting of bottles and bottled water packaging have reduced the amount of packaging waste associated with bottled water consumption. However, bottled water is frequently consumed at away from home locations where access to container recycling may be limited. In addition, while recycling of postconsumer bottles and packaging reduces consumption of virgin material resources, other resources are used and wastes created when packaging is manufactured and bottled water is transported.

Consumers have other drinking water options that do not involve disposable containers. These include consumption of tap water from a container that can be washed and reused many times, or consumption of water from a home/office delivery system with the water dispensed into a reusable drinking container. However, while reusable systems require less use and disposal of material, these systems require washing of containers between uses, and in the case of HOD systems, transportation of the containers to and from the filler. These processes incur environmental burdens that may be higher or lower than the burdens for disposable container systems.

Life Cycle Assessment (LCA) has been recognized as a scientific method for making comprehensive, quantified evaluations of the environmental benefits and tradeoffs for the entire life cycle of a product system, beginning with raw material extraction and continuing through disposition at the end of its useful life. This LCA evaluates the environmental burdens for disposable and reusable systems for delivering drinking water.

PURPOSE OF THE STUDY

This LCA was commissioned by the Oregon Department of Environmental Quality (OR DEQ) to evaluate the environmental implications of various systems for delivery and consumption of drinking water, including bottled water, tap water consumed from reusable containers, and home/office delivery (HOD) water consumed from reusable containers. The analysis includes water processing, production of containers and packaging materials, filling, transport, and end-of-life management of containers and packaging. The analysis also looks at transportation of bottled water imported from several foreign locations.

This study uses container weight and packaging data obtained by weighing purchased samples of various brands of bottled water and reusable drinking containers,[1]

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[1] Supplemented with information from a published article about bottle weight trends: Bauerlein, Valerie. "Pepsi to Pare Plastic for Bottled Water." Wall Street Journal. March 25, 2009.

and import distances are estimated based on the locations of several countries where popular brands of imported water are bottled. The companies producing these brands of bottled water did not participate directly in this study, and their specific operations may be significantly different from the data sets and modeling assumptions used in this report. **The results presented in this report are not intended to be used to represent specific brands of bottled water or reusable containers available in the marketplace.** For example, a scenario shown for water imported from Fiji is one of several import scenarios developed using purchased container weights and estimates of transportation distances from bottling location to Oregon; however, the results for this scenario are **not** intended to be used to represent the specific products or operations of FIJI Water Company LLC, since no data from FIJI were collected for this study.

INTENDED USE

The primary intended use of the study results is to inform DEQ about the environmental burdens and tradeoffs associated with various options for providing drinking water to consumers and behavioral choices of consumers. DEQ is also interested in better understanding the environmental burdens and tradeoffs of end-of-life management options (recycling, composting, landfilling, etc.).

This analysis contains comparative statements about the drinking water subscenarios analyzed. These statements are supported by the data presented in this report and apply to the systems analyzed in this study. Because DEQ will make the results of this study, including comparative statements, publicly available, this report is being peer reviewed in accordance with ISO standards for life cycle assessment.[2]

SYSTEMS STUDIED

The following types of drinking water systems are analyzed in this study:

- Bottled water packaged in and consumed from individual disposable bottles:
    - Virgin polyethylene terephthalate (PET) bottles (16.9 ounce, 8 ounce, and one liter)
    - PET bottles with a mix of virgin and recycled content (16.9 ounce)
    - Bottles made of virgin polylactide (PLA) resin derived from corn (16.9 ounce)
    - Glass bottles with a mix of virgin and recycled content (12 ounce)
- Tap water consumed from reusable containers:
    - Virgin aluminum bottle with plastic closure (20 ounce)
    - Virgin steel bottle with plastic closure (27 ounce)
    - Virgin plastic bottle with plastic closure (32 ounce)

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[2] International Standards Organization. ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework, ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

    - Drinking glass with a mix of virgin and recycled content (16 ounce)
- Home/office delivery (HOD) water consumed from reusable containers
    - Virgin polycarbonate bottles
    - Virgin PET bottles
    - Same reusable containers listed under the Tap system.

Within these three general drinking water scenarios, a number of subscenarios were analyzed to evaluate the results for variations in container sizes, weights, transportation distances, recycled content and recycling rates, and many other variables. Forty-eight subscenarios were evaluated in all: 25 bottled water subscenarios (20 for PET bottles, 4 for PLA, 1 for glass), 12 subscenarios for tap water consumption using a variety of reusable drinking containers, and 11 subscenarios for HOD water consumed from reusable containers. Of the bottled water subscenarios, 5 evaluated long-distance transport of water from another country or the Eastern U.S. to Oregon.

FUNCTIONAL UNIT

In a life cycle study, systems are evaluated on the basis of providing a defined function (called the **functional unit**). The function of each system analyzed in this report is to deliver drinking water to consumers. The functional unit selected for this analysis is delivering 1,000 gallons of drinking water to a consumer, including use of a bottle or reusable drinking container, and end-of-life management of the containers and packaging. To provide some perspective, 1,000 gallons is the amount of water a person would consume in about 5.5 years if they drank eight 8-ounce servings of water a day.

The functional equivalence is based on delivering drinking water that meets water quality standards set by the Food and Drug Administration (FDA), EPA, and state governments. The scope of the analysis does not include evaluating other differences in the quality of the water (e.g., taste, fluoride or mineral content, etc.) or temperature of the water, or any potential health impacts that may be associated with the use of specific water container materials. Each subscenario evaluated clearly indicates whether the results included chilling of the water, and if so, the chilling method used. No carbonated or flavored waters were evaluated.

SCOPE AND BOUNDARIES

This study is a complete life cycle assessment (LCA) as defined in the ISO standards 14040 and 14044. As such, the study includes definition of goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation of results.

The analysis includes all steps in the production of each drinking water container system, from extraction of raw materials through production of the materials used in the containers, fabrication of finished containers and closures, and transport to filling locations. Treatment of municipal drinking water and additional processing steps used to purify bottled municipal water and natural water such as spring water are included in the analysis. Bottle filling and washing operations are included, as is production of secondary packaging used for shipment of filled containers, distribution of filled containers, washing of reusable containers, and end-of-life management of containers and associated packaging components. Various options for chilling water are also included in the model, including home refrigeration, use of ice, and HOD chiller units.

All washing of reusable personal drinking containers in this study is modeled based on use of a residential dishwasher, which is expected to be the most common method used by consumers for washing of these containers. Containers may also be hand-washed; however, water and detergent use for hand washing can vary widely based on the practices of individual consumers. As a result, hand washing of containers can be either more or less burdensome than machine washing.

The scope of the study did not include analysis of scenarios for HOD and tap water consumed from disposable cups, nor did the study include any scenarios in which disposable drinking water bottles sold filled with water were refilled by consumers and used as a reusable drinking container. Additional at-home purification of tap water, such as use of tap water filters, was not included in the scope of the analysis. The scope of the analysis did not include greenhouse gas effects of direct and indirect land use changes that may be associated with corn growing for PLA production.

In Oregon, municipal solid waste (MSW) that is not recovered for recycling or composting is managed 93 percent by weight to landfill (LF), 6 percent by weight to waste-to-energy (WTE) combustion, and 1 percent by combustion without energy recovery, as documented in Appendix J. An energy credit is given for material that is managed by WTE combustion, based on the amount of each material burned, its heating value, and the efficiency of converting the gross heat of combustion to useful energy.

The end-of-life emissions results take into account the effects of combustion, decomposition, and energy recovery, including estimates of release of carbon dioxide from combustion of materials and methane from decomposition of degradable landfilled material, emission credits for avoided grid electricity displaced by electricity generated from WTE operation and from landfill gas combustion, and carbon sequestration in landfilled biomass-derived material that does not decompose. The end-of-life modeling and recycling methodologies are described in Chapter 1. The LCI results are presented in Chapter 2.

In the scoping phase of this study, the U.S. EPA's TRACI methodology was selected as the impact assessment methodology to be used, since it was developed to represent U.S. conditions (e.g., for fate and transport of chemical releases). Details of the LCIA are presented in Chapter 3.

DATA

Detailed descriptions of the data and assumptions used in the life cycle assessment are provided in the Appendices, a separate document. Wherever possible the study used Oregon-specific data and assumptions, including the following:

- Mix of fuels to produce electricity used for processes that occur in Oregon, including processing and filling operations for bottled water processed in Oregon; operation of pumps to deliver municipal tap water to Oregon homes or to pump well water; molding of plastic water bottles produced in Oregon; operation of home dishwashers used to clean reusable containers between uses, electricity use in washing operations for HOD bottles that are filled and circulated in Oregon;
- Transportation distances for bottled water;
- Mix of residential water from wells and municipal water supplies;
- Recycling rates for PET bottles, glass bottles, and corrugated packaging;
- Percentages of landfilling, waste-to-energy combustion, and combustion without energy recovery for municipal solid waste management of containers that are not recycled;
- Modes and distances for transport of postconsumer solid waste to landfill and combustion facilities;
- Management of landfill gas.

MAIN CONTRIBUTING FACTORS FOR EACH SYSTEM

The primary factors contributing to the results for the bottled water system include the following:

- Production of bottles accounts for the majority of energy consumption for all subscenarios except those involving long-distance transport. Scenarios for trucking water cross-country showed higher energy requirements than scenarios where water was transported longer distances by ocean and a shorter distance by truck.
- The energy requirements for bottled water delivered in the 8-ounce bottle (scenario 5) are higher than the energy to deliver water in larger bottles because the smaller bottle has a higher ratio of bottle weight to weight of water in the bottle.
- In addition to the bottles themselves, the bottle lids and secondary packaging make significant contributions to the energy results. On average across all subscenarios, production of caps and secondary packaging each accounted for 12 percent of total energy.
- The choice of recycling allocation methodology for LCI analysis also can have a significant effect on the results. Use of an open-loop recycling allocation divides the burdens for material production and disposal between the product uses of the material, while alternative "cut-off" recycling allocations assign material production and disposal burdens to

either the system first using the virgin material or to the system using the recycled material.

For tap water consumed from reusable containers, results are driven by washing of the container (including energy use for heating the water) and variations in the use of the container that affect the frequency of washing.

- The number of drinking container washings per thousand gallons of water consumed varies inversely with the size of the containers, the number of times the container is filled before washing, and the number of days the container is used before washing. The drinking glass system (scenario 18) has the lowest energy use for container manufacture but has the highest washing requirements because it is smaller than the other reusable containers so that the container must be filled (and washed) more times per 1,000 gallons consumed.
- Doubling the number of container fills between washings or washing the container every other day instead of daily reduces the washing requirements by half.
- Efficient use of the dishwasher is also important. The highest results for the tap water system are for the scenario in which containers are washed daily in a dishwasher with a high water consumption rate that is run when it is half full.

For HOD water consumed from reusable containers, the three life cycle stages that consistently making the largest contributions to overall energy use are transportation of HOD containers (delivery of filled HOD containers and backhauling of empty containers to be washed and refilled), home washing of the reusable drinking containers, and chilling of the HOD water using a chilling base unit.

- Distribution of HOD containers includes transportation of filled containers from bottler to HOD distributor, dropping off filled bottles and picking up empties on delivery route, and backhauling empties to filling location for refilling. Distribution accounts for about 25 percent of total energy requirements for the subscenarios evaluated.
- Observations for washing of the reusable drinking container are the same as described above for the tap water system. Industrial washing of the HOD bottles makes a much smaller contribution to the overall results than does home washing of the individual drinking container.
- Chilling of drinking water is not required in order to maintain the quality of drinking water. While chilling of bottled water and tap water is done at the discretion of the consumer, HOD water is most commonly dispensed from a base unit that chills the water, so chilling energy use was included in all the HOD scenarios. This is a difference from the modeling of the bottled water and tap water scenarios, where most of the subscenarios did not include chilling. Energy for chilling of HOD water ranges from 20 to 40 percent of total energy for HOD systems and accounts for around 30

percent of total energy for most HOD subscenarios. Chilling results are shown separately in the results tables so that results for HOD systems without chilling can be compared to results for unchilled bottled and tap water.

OBSERVATIONS AND CONCLUSIONS

Some general observations and conclusions can be made based on the results for the full range of subscenarios evaluated, which include combinations of parameters selected to represent "best" and "worst" cases for each system. It should be noted that the "best" and "worst" case subscenarios include future lightweighting and increased recycling scenarios. The full range of results also includes some subscenarios that account for a small percentage of total Oregon bottled water consumption (e.g., imported water packaged in glass bottles). The reader is encouraged to refer to the figures in Chapters 2 and 3 for results for individual scenarios for each system and the figures in Chapter 4 for the ranges of results for individual impacts across all subscenarios evaluated.

Energy Results

Energy comparisons between the different drinking water systems can be summarized as follows:

- All tap and HOD scenarios show lower energy than all long-haul water scenarios.
- The "best case" results for Oregon bottled water (excluding long-haul water) are for a future lightweighted bottle not currently in the marketplace, combined with 100% bottle recycling. When *existing* Oregon bottled water subscenarios are compared to tap subscenarios, the energy for tap subscenarios is lower in all cases.
- When existing Oregon bottled water subscenarios are compared to HOD subscenarios, there is overlap in many cases so that neither system can generally be considered to have lower energy results.
- Assuming a consumer's container washing practices are not influenced by the type of water served in the container, tap water systems have lower energy requirements than HOD water systems.

Solid Waste Results

As would be expected, the HOD and tap water systems do not produce much solid waste compared to the majority of the bottled water scenarios, since the tap and HOD systems utilize drinking water containers that are used many times over their useful life. The HOD bottles are also refilled and reused multiple times before they are retired from service and recycled; however, the solid waste results for the HOD systems do include the weight of disposed HOD plastic caps that are assumed to be replaced after each use cycle of an HOD bottle.

The choice of recycling allocation method has a significant influence on the solid waste weight and solid waste volume comparisons. The majority of subscenarios used an open-loop recycling methodology (designated method 1), in which half of the disposal burdens for the recycled bottles are allocated to the bottle system and half to the next system using the recycled material. The other recycling methods evaluated (designated methods 2 and 3) allocate *all* disposal burdens for recycled material to the next system using the recycled material, so the subscenarios using methods 2 and 3 show lower solid waste results than the subscenarios using method 1. A detailed description of the recycling methodologies can be found in the Postconsumer Recycling Methodology section of Chapter 1.

The following solid waste observations can be made:

- In nearly all solid waste comparisons, both the tap and HOD systems have lower solid waste than the bottled water systems (long-haul and Oregon bottled water), although there are a few exceptions. The HOD worst case scenario overlaps with several Oregon bottled water solid waste subscenarios. Excluding the HOD worst case, the only other comparisons where bottled water solid wastes are lower than tap and HOD solid wastes are for the PLA bottle at 100% composting and the future lightweighted PET bottle at 100% recycling.
- Assuming a consumer's container washing practices are not influenced by the type of water served in the container, tap water systems have lower solid waste requirements than all HOD subscenarios except when compared to the HOD best case scenario.

Impact Categories

Rather than describing each impact category individually, this section describes general trends observed in the impact figures in Chapter 4. The reader is encouraged to refer to Chapter 4 to view results for individual impact categories. Environmental impact results can be summarized as follows:

Comparison of Long-haul Bottled Water and Oregon Bottled Water Systems. Within the bottled water subscenarios evaluated, the ranges of impact results for long-haul bottled water and Oregon bottled water overlap or show small gaps for most impact categories. It should be noted that differences in impacts for long-haul and Oregon bottled water are due not only to differences in transportation but also to differences in the types and weights of bottles used for domestic and imported water.

Comparison of Tap and Bottled Water Systems. For the subscenarios evaluated in this study, all tap subscenario results are lower in all impact categories compared to all long-haul bottle subscenarios. When comparing tap system results to Oregon bottled water results, the tap system subscenarios evaluated all have lower impacts than *existing* Oregon bottled water scenarios. The *future* lightweighted PET bottle combined with very high bottle recycling rates has the potential to compare favorably with tap scenarios with inefficient container washing practices.

Comparison of HOD and Bottled Water Systems. For the subscenarios evaluated in this study, all HOD subscenario results are lower in all impact categories compared to the long-haul bottle subscenarios. When comparing HOD subscenario results and the Oregon bottled water subscenario results, there are many subscenarios where there is overlap between HOD and Oregon bottled water results, even when the best and worst case scenarios are excluded for each system. Therefore, no general statements can be made about which of these systems has lower environmental impacts.