Briefing Paper:
Potential for Additional Material Recovery

November 2011

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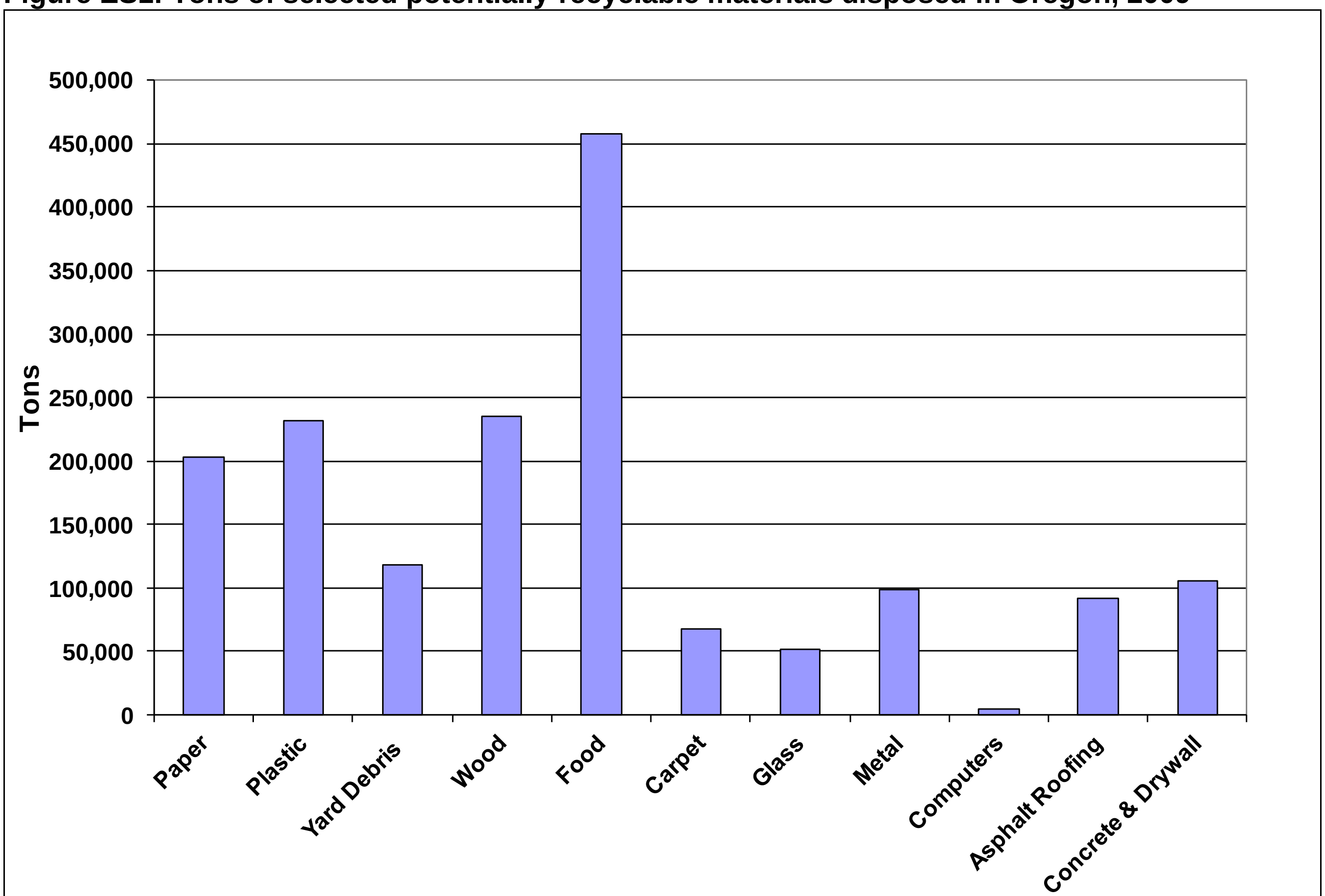
Executive Summary

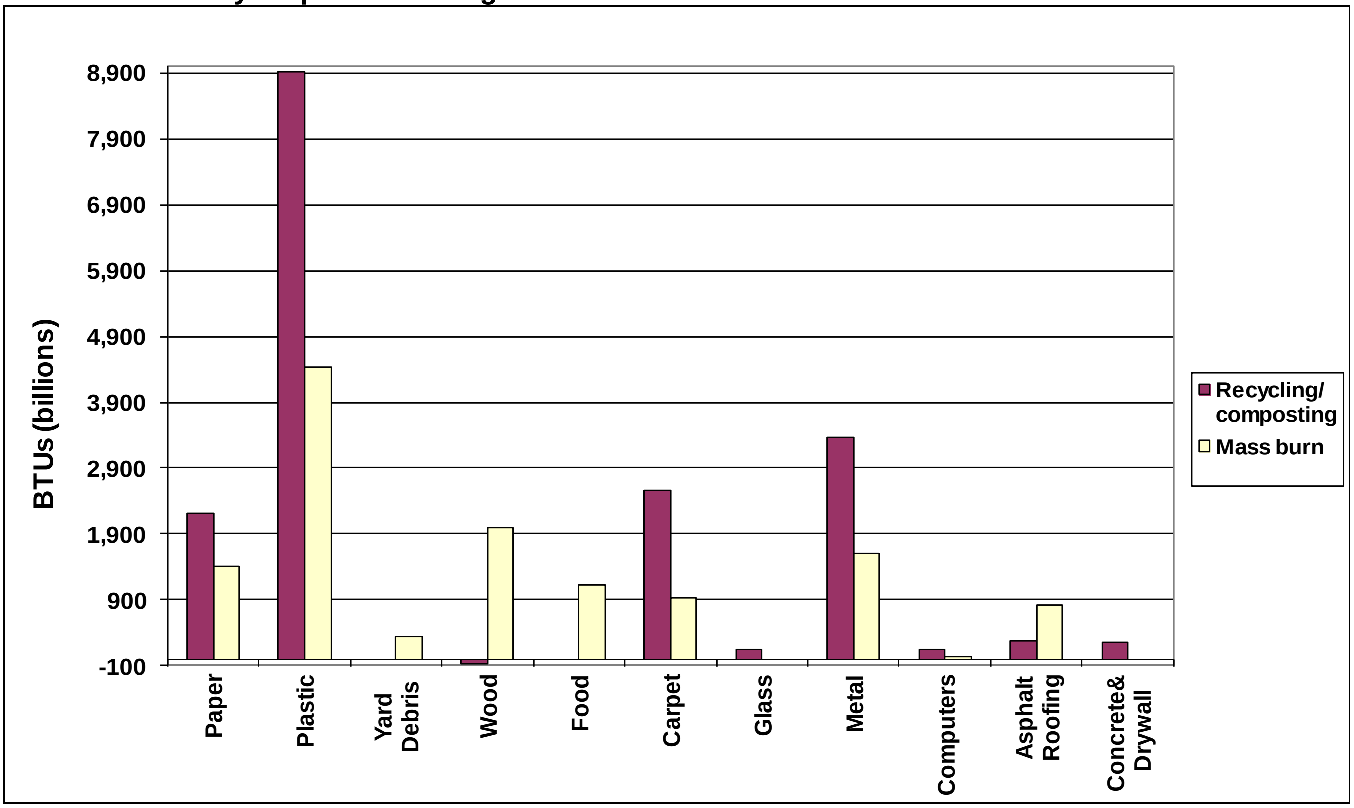
This paper examines current recovery rates for materials in Oregon and evaluates several potential environmental impacts if recovery could be increased. When compiling information on existing material recovery, DEQ uses units of weight, because that is how most materials are measured. When considering priorities for additional material recovery, though, other measures that directly affect humans and the environment should be considered. Factors such as potential greenhouse gas reductions, energy savings, land use, toxicity reduction and material depletion may be more relevant than weight. However, data are not readily available for all these measures and considerable uncertainties exist about how much of different types of materials are feasible to recover. This paper evaluates energy and greenhouse gas savings that would result from collecting and recycling in Oregon additional potentially-recyclable material that is currently being disposed (landfilled or mass-burned as solid waste). The wastes considered in this paper are only municipal wastes and construction/demolition waste included in Oregon's material recovery survey and waste composition studies, and represent 64 percent of all tons disposed. Industrial and agricultural wastes and inert materials are not evaluated here.

Figure ES1: Tons of selected potentially-recyclable materials disposed in Oregon, 2009



Evaluating potentially recyclable or compostable materials disposed only by weight (Figure ES1), food waste, wood, paper and plastics rank highest.

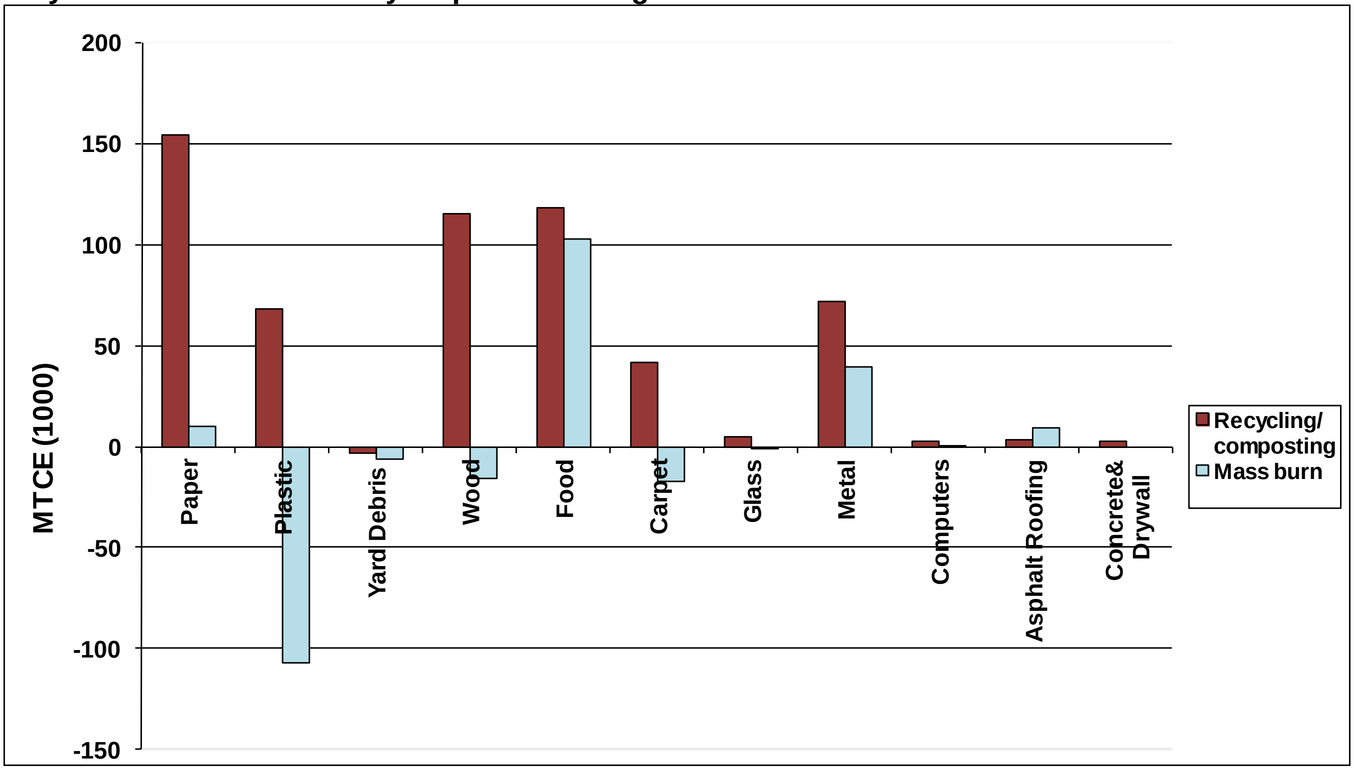
Figure ES2. Potential energy savings from recycling/combustion of potentially recyclable material currently disposed in Oregon



However, looking at materials from an energy conservation viewpoint (Figure ES2) gives substantially different results. From a potential energy savings standpoint, plastics recycling ranks highest, partly due to the energy embodied in the plastic. Metal recycling is the next highest category, but carpet recycling is also high, again partly due to the energy embodied in the carpet. Significant potential energy savings are also seen for paper, although the existing recycling rate for recyclable paper is already quite high (about 75 percent). Wood, food waste, yard debris and asphalt roofing material provide relatively little energy benefit when recycled but can provide some benefits when burned for energy recovery.

Examining materials from a greenhouse gas perspective (Figure ES3) also provides a very different viewpoint. Paper and wood recycling provide significant greenhouse gas benefits when compared to sending materials to a landfill. This benefit is based mainly on the U.S. Environmental Protection Agency's modeling of forest sequestration of carbon. Reducing tree harvest by recycling paper or wood keeps carbon stored longer in a growing forest. Either composting or burning food waste for energy recovery can also provide net greenhouse gas benefits. In this case, the reduction is almost entirely due to the reduction in methane production that would otherwise happen if that food waste were placed in landfills. The value of the food waste itself is very small either for composting or for energy recovery. Metal recycling provides strong greenhouse gas reduction benefits. The positive value of metal burned in mass-burn facilities stems almost entirely from the fact that metal is recovered from burner ash and then recycled. The metal itself has little fuel value in mass-burn facilities.

Figure ES3. Potential greenhouse gas reductions from recycling/combustion of potentially recyclable material currently disposed in Oregon



Plastic and carpet both provide strong greenhouse gas benefits when recycled, but not when burned for energy recovery in mass-burn facilities. Both of these materials are derived mainly from fossil fuel sources, and all that carbon gets converted to carbon dioxide when the plastic or carpet is burned. Mass-burn energy recovery facilities will use some of the energy from the plastic or carpet to produce electricity, and this reduces the need to burn fossil fuel elsewhere in the electricity grid. These mass-burn facilities are not as efficient as other power plants in turning fuel to electricity, so the carbon dioxide released when the plastic or carpet is burned exceeds the carbon dioxide reduced by needing to produce less electricity at power plants. The situation is substantially different, though, if the plastic or carpet is used as a fuel directly in an industrial boiler, furnace, or cement kiln to replace coal or other high-carbon fuels. In those cases, substantially reduced emissions of carbon dioxide will occur.

Many other factors could be evaluated, including toxicity, land use, and air and water pollution. However, data on these other impacts are not readily available for all the materials discussed above.

Conclusion

Based on these results, it appears that plastic, metal, carpet and paper recycling all provide strong energy and greenhouse gas savings, and more effort should be devoted to increasing the collection and recycling of these materials. Glass recycling and yard debris composting and energy recovery provide relatively little energy or greenhouse gas benefit. The situation for wood is mixed. By EPA's model, recycling wood provides no net energy benefit, since it takes relatively little energy to produce new lumber from trees. Burning wood for energy recovery does provide a fair amount of energy. For greenhouse gases though, the situation is reversed. Recycling wood provides substantial greenhouse gas savings, according to EPA's modeling, but burning wood for energy recovery results in a net increase in greenhouse gas emissions when compared to landfilling.

Overall, markets for paper, metal and most plastics are strong, and anyone who has well-prepared material will have no problem marketing it. The main problem facing plastics recycling is that there are many types of plastics in the market, varying by resin type, additives and fillers, and it is difficult to identify and separate a number of these types of plastics from each other. If techniques to better separate and recycle the plastics were developed, substantial energy savings and greenhouse gas reductions could result. Finally, carpet recycling is sparsely developed in Oregon and the rest of the nation, and increased efforts to recycle carpet could lead to substantial energy and greenhouse gas savings.

Introduction

This paper examines current recovery rates for materials in Oregon and evaluates several potential environmental impacts if recovery could be increased.

Table 1 shows overall disposal and recovery results for Oregon, including estimates of material-specific recovery rates. Recovery information is from the 2009 Oregon Material Recovery and Waste Generation report, which includes municipal waste and most construction and demolition wastes, but excludes inert materials, automotive and major construction scrap metals, and industrial wastes. Disposal information is derived from Oregon's 2009-10 solid waste composition study.

For each material or group of materials, this paper examines:

- Are markets available to accept additional material for recycling (or energy recovery or composting)?
- Is collection of additional materials feasible?
- What would be the energy and greenhouse gas implications of recovering additional material?

Some of the above information is not currently be available for certain materials. In addition, it would be valuable to look at other criteria when evaluating additional material recovery, such as the creation of and exposure to toxics, land-use effects and other impacts described in the Material Impact Criteria paper. For example, a meta-analysis of more than 50 life cycle studies published by the WRAP program in the United Kingdom found almost all studies demonstrating environmental benefits from recycling (relative to landfilling) across multiple environmental criteria (toxics, smog, acidification, eutrophication, resource extraction, etc.). However, a thorough and quantitative evaluation of all these criteria is beyond the scope of this paper, which just contains an initial evaluation, limited to energy and greenhouse gases.

Energy and greenhouse gas impacts are derived primarily from data from the Environmental Protection Agency's WARM model. The Waste Reduction Model does not have data for many materials - particularly products that are composed of different materials (with the exception of computers and carpet). In some cases DEQ has used factors for some of the missing materials based on similarity to materials for which EPA does publish factors. Table 2 shows energy and greenhouse gas impacts of recycling and mass combustion of different materials, with and without energy recovery in the case of mass burn. For a few organic materials, Table 2 also shows greenhouse gas impacts of composting the material using aerobic composting. In all cases, the numbers shown in Table 2 are based on the difference between recovering the material (for recycling, mass burn or commercial composting) and landfilling that same material. Negative values mean energy or greenhouse gas saving based on recovering rather than landfilling the material. Positive values mean an increase in energy use or greenhouse gas emissions if materials are recovered rather than landfilled.

Table 1: Disposal and Recovery for 2009

	2009 Tons Disposal	2009 Tons Recovery	% Recovery
All paper	**339,486**	**626,984**	**64.87%**
Recyclable paper	205,235	626,984	75.34%
Non-recyclable paper	134,251	0	0.00%
All plastic	**255,200**	**45,826**	**15.22%**
Rigid plastic containers	38,093	23,377	38.03%
Film plastic	89,171	11,327	11.27%
Other plastic	127,936	11,122	8.00%
Other miscellaneous organics	**1,309,047**	**855,479**	**39.52%**
Yard debris	118,009	475,386	80.11%
Wood	273,223	311,846	53.30%
Food	457,382	34,802	7.07%
Tires/rubber	52,040	23,264	30.89%
Carpet	68,456	515	0.75%
Textiles and mixed	88,256	958	1.07%
Asphalt roofing	101,189	8,708	7.92%
Other organic (carbon-containing)	150,491	0	0.00%
All glass	**52,132**	**109,193**	**67.68%**
Container glass	30,749	108,084	77.85%
Other glass	21,383	1,109	4.93%
All metal	**146,490**	**372,458**	**71.77%**
Aluminum	6,618	30,673	82.25%
Tin and aerosol cans	18,139	9,004	33.17%
Other scrap metal***	121,733	332,782	73.22%
Computers, TVs, brown goods	**26,674**	**15,174**	**36.26%**
Other miscellaneous inorganics	**294,220**	**3,949**	**1.32%**
Brick and concrete	33,965	*	*
Gypsum wallboard	75,247	3,359	4.27%
Other inorganics	185,008	590	0.32%
Medical	**21,132**	**0**	**0.00%**
Hazardous total	**11,701**	**59,165**	**83.49%**
Paint**	3,171	1,308	29.21%
Oil/fuels**	1,477	40,658	96.49%
Lead acid batteries	1,321	13,794	91.26%
Dry cell batteries	1,519	218	12.56%
Antifreeze/solvents/other chemicals**	4,213	3,187	43.07%
Water/residue	152,832		
Total	**2,608,915**	**2,088,229**	**44.46%**

* Brick and other inert material recovery is not measured in the Oregon Material Recovery Survey
** Liquids and powders that are not containerized are for the most part missed in the waste composition study and end up in the "residue" category or as contaminants in other materials. Thus, the disposal numbers for these materials are low.
*** Scrap metal recovery does not include vehicles or major demolition scrap tonnage.

Table 2. Energy and greenhouse gas Factors per ton for different management methods relative to landfilling.

Material	Energy Net Recycling Million BTU	Energy Net Combustion Million BTU Energy Recovery	GHG Recycle MTCE	GHG Burn No Energy Recovery MTCE	GHG Burn-Northwest Energy Recovery MTCE	GHG Compost MTCE
Corrugated containers	-15.20	-6.99	-0.87	0.00	-0.12	NA
Office paper	-9.98	-6.50	-1.15	-0.36	-0.47	NA
Textbooks	-0.93	-6.50	-1.22	-0.36	-0.47	NA
Newspaper	-16.89	-8.16	-0.50	0.28	0.15	NA
Phonebooks	-12.33	-8.16	-0.46	0.28	0.15	NA
Magazines/Third-class mail	-1.07	-5.41	-0.72	0.13	0.05	NA
PET (Polyethylene terephthalate)	-53.36	-10.07	-0.42	0.55	0.40	NA
HDPE (High density polyethylene)	-51.43	-19.18	-0.39	0.76	0.46	NA
LDPE (Low density polyethylene)	-56.54	-19.18	-0.47	0.76	0.46	NA
Grass	NA	-3.00	NA	-0.06	-0.10	-0.13
Leaves	NA	-3.00	NA	0.16	0.12	0.09
Branches	NA	-2.87	NA	0.20	0.15	0.13
Dimensional lumber	0.26	-8.45	-0.49	0.20	0.07	NA
Medium-density fiberboard	0.53	-8.45	-0.49	0.20	0.07	NA
Food scraps	NA	-2.46	NA	-0.19	-0.23	-0.26
Carpet (factors used here)*	-37.98	-13.82	-0.62	0.47	0.26	NA
Carpet (original EPA #s)	-96.82	-13.82	-1.98	0.47	0.25	NA
Asphalt shingles	-2.99	-9.03	-0.04	0.18	-0.10	NA
Glass	-2.66	0.00	-0.09	0.00	0.00	NA
Aluminum cans	-206.95	0.11	-3.72	0.00	0.00	NA
Copper wire	-83.12	0.04	-1.37	0.00	0.00	NA
Steel cans	-20.50	-17.63	-0.50	-0.44	-0.43	NA
Personal computers	-31.01	-6.82	-0.63	-0.02	-0.05	NA
Concrete	-0.64	NA	NA	NA	NA	NA
Drywall	-3.18	NA	NA	NA	NA	-0.03

* See discussion under Carpet for why different factors instead of EPA's are used here.

GHG is measured in metric tons carbon equivalent (MTCE) per ton of material. Carbon equivalent is converted to carbon dioxide equivalent by multiplying by 44/12 (the molecular weight of carbon dioxide divided by the atomic weight of carbon).
Negative values represent a savings in energy or reduction in greenhouse gases relative to landfilling (recovery better than landfilling). Positive numbers represent an increase in energy or greenhouse gases relative to landfilling (recovery worse than landfilling).

Subsequent tables (beginning with Table 4) and tables in the executive summary report potential energy and greenhouse gas impacts if recovery rates – either by recycling, mass burn and/or energy recovery – were increased to 100 percent for selected materials. Recovery rates, of course, rarely approach 100 percent due to limitations in participation, sorting and markets. As such, the projected energy and greenhouse gas impacts in this paper give a very crude sense of relative potential benefit (or impact) between materials, but generally overstate the actual potential benefit (or impact). Also, these analyses apply hypothetical 100 percent recovery rates to 2009 disposal tonnages. As the waste stream in the future continues to change, actual recovery potential will change with it. Finally, the tables below treat all disposed waste as if it were landfilled. In fact, in 2009, about 7.1 percent of Oregon's waste was burned in an energy-recovery mass-burn facility, and another 0.8 percent was burned in a mass burn facility without energy recovery.

Paper

Oregon and Washington are both paper-making states and have well-developed facilities for manufacturing new paper from recycled fiber. Currently, about 65 percent of all paper used in paper products (excluding toilet paper) is recycled. Of the paper currently being disposed as garbage in Oregon, nearly 40 percent is paper tissue, paper towel or other non-recyclable paper. Excluding these, about 75 percent of Oregon's recyclable paper is currently being recycled. Oregon has fairly detailed data on the types of paper being disposed, based on the 2009-10 Oregon waste composition study. However, with commingling, individual paper grades are not well-distinguished in the annual material recovery survey. Material sold as "newsprint" commonly has more of other grades of paper (office paper, magazines, junk mail) than actual newspaper, and "cardboard" often contains significant amounts of boxboard. Thus, it is not possible at this time to calculate accurate recovery rates for individual paper grades.

Table 3 shows a breakdown of disposed paper by type.

Table 3: Disposed paper tonnage

Paper type	Tons disposed	Examples
Recyclable:	**202,807**	
Cardboard and brown bags	70,447	corrugated cartons
Low-grade paper not compatible with newsprint	41,239	boxboard, cereal boxes
Milk cartons / aseptic drink boxes	3,472	
High-grade paper	22,763	white and colored ledger paper
Newspaper	18,603	
Magazines	15,008	
Low-grade paper compatible with newsprint	28,506	junk mail
Hardcover books	2,770	
Not recyclable:	**136,679**	
Waxed corrugated cardboard	2,611	
Other compostable nonrecyclable paper	77,728	paper tissue, towel
Polycoated paper excluding cups	2,428	freezer boxes, multiwall bags
Other non-compostable, non-recycl. paper	53,911	mixed paper/materials, foil/paper laminates, photos

Oregon has a number of large mills that recycle cardboard, newspaper and office paper. The only large commodity grade that is not manufactured in Oregon is boxboard, but a substantial amount of boxboard is recycled into corrugated medium. These mills require more recycled paper than is available in Oregon, and thus must import paper from many other states. In addition to these Oregon mills, there are many mills in Washington that accept almost all grades of recycled paper. Within the past decade, though, paper mills have been experiencing increasingly difficult economic times, and a number have closed, including large cardboard mills in Albany and in Coos County and a newsprint mill in Oregon City. Reasons for these closures include reduced paper use in the United States, increased production capacity in Asian companies, and lack of clean recycled paper fiber at affordable prices. There is not any lack of capacity for paper recycling worldwide, although concerns have been expressed about the general low quality of waste paper (high contamination) from U.S. commingled recycling programs. As long as contamination remains at acceptable levels, any additional recyclable paper collected in Oregon is likely to find good markets, although if more Oregon paper mills close, those markets may then be in Asian countries.

More corrugated cardboard is used in Oregon than any other paper grade, and it probably has the highest recycling rate too, coupling high recovery in the commercial sector with good recovery in household curbside programs. In spite of the high recovery rate, it is also the recyclable paper grade with the highest disposal tonnage.

Greenhouse Gas and Energy Impacts of Paper Recovery

Table 4 shows the results of EPA's modeling of greenhouse gas and energy recovery of paper, applied to the tons of each grade of paper disposed in 2009. By EPA's model, much of the GHG savings for recycling paper comes from reduced harvest of wood, yielding higher storage of carbon in standing trees. Paper with lignins removed (office paper, cardboard) decomposes more quickly and releases more CO2 and methane than do papers such as newspaper which still contains lignins (which degrade very slowly). These papers with lignins removed produce much more methane (a potent greenhouse gas) in landfills than do newspaper and other papers that still contain lignins. That is why office paper and textbooks have substantial GHG savings when recycled and even when burned with no energy recovery, since it is reducing the generation of methane that would occur if that paper were landfilled.

Modeling of energy and GHG savings depend strongly on the type of paper being produced by recycling. Newspaper, junk mail and magazines are commonly recycled into newsprint in Oregon but into boxboard in other parts of the country, so the factors used here might not accurately reflect the common use of these papers in Oregon. It should also be noted that milk cartons and aseptic drink boxes have a substantial yield loss due to non-recoverable layers of plastic (and aluminum too in aseptics). This yield loss is not accounted for in Table 4, and so potential recycling benefits are lower than shown.

Waxed cardboard and paper tissue and towel can be composted along with food waste. However, EPA does not provide emission factors for composting paper. DEQ has not yet applied energy recovery (mass burn) factors to the non-recyclable paper grades.

Table 4. Energy and greenhouse gas impacts of paper recovery instead of landfilling

Material	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	Energy Net Combustion (Billion BTUs)	GHG Net Recycling MTCE (1000s)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)
Recyclable paper	**202,808**		**-2,204**	**-1,405**	**-154.5**	**11.9**	**-10.4**
Cardboard	70,447	Cardboard	-1,071	-492	-61.1	-0.2	-8.1
Low grade paper - unbleached	41,239	Phonebooks	-508	-337	-19.0	11.6	6.4
Milk cartons/drink boxes	3,472	Office paper	-35	-23	-4.0	-1.2	-1.6
High-grade paper	22,763	Office paper	-227	-148	-26.3	-8.2	-10.6
Newspaper	18,603	Newspaper	-314	-152	-9.3	5.2	2.9
Magazines	15,008	Mags./junk Mail	-16	-81	-10.9	2.0	0.7
Low-grade - bleached	28,506	Mags./junk Mail	-31	-154	-20.6	3.7	1.4
Hardcover books	2,770	Textbooks	-3	-18	-3.4	-1.0	-1.3
Non-recyclable paper	**136,678**						
Waxed cardboard	2,611						
Other compostable non-recyc. paper	77,728						
Polycoated paper excluding cups	2,428						
Other non-compost. non-rec. paper	53,911						

Plastics

Oregon's recent material recovery surveys classify plastics into three main categories: rigid plastic containers, film plastic and other plastic. Of these three, only rigid plastic containers are currently included in curbside recycling programs throughout most of Oregon. Film plastic recycling is available to large generators of film plastic such as warehouses (pallet wrap and polyethylene bags) and dry-cleaners. Limited residential recycling of film plastic is provided by some grocery stores that will accept back old plastic shopping bags. Recycling of other plastic items is generally limited to certain generators who produce large amounts of a limited number of types of plastic, and to processors who sort out large recyclable plastic items from mixed garbage or mixed recyclables.

Table 5 shows tons of plastic disposed of in 2009, plus the estimated impact on energy use and on greenhouse gas production if those tons of plastic were recovered instead of being disposed of in a landfill.

Table 5. Disposed tons, energy and greenhouse gas impacts of plastic recovery instead of landfilling

	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	Energy Net combustion (Billion BTUs)	GHG Net Recycling MTCE (1000s)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)
TOTAL PLASTIC	**255,200**		**-8,909**	**-4,429**	**-68.1**	**175.7**	**106.8**
Rigid Plastic Containers (RPCs)	**38,093**		**-1,965**	**-704**	**-14.8**	**28.3**	**17.4**
Deposit plastic bottles	1,255	PET	-67	-13	-0.5	0.7	0.5
Plastic deposit water	1,641	PET	-88	-17	-0.7	0.9	0.7
No-deposit plastic beverage bottles	5,904	HDPE	-304	-113	-2.3	4.5	2.7
Other plastic bottles	9,727	HDPE	-500	-187	-3.8	7.4	4.5
Plastic tubs, curb-OK 8oz to 5gal	8,707	HDPE	-448	-167	-3.4	6.6	4.0
Other RPCs - tubs, trays, etc.	10,859	HDPE	-559	-208	-4.2	8.2	5.0
Other rigid plastic packaging	20,851	HDPE	-1,072	-400	-8.0	15.8	9.6
Other rigid plastic products	84,165	HDPE	-4,329	-1,614	-32.5	63.9	38.8
Plastic film - recyclable	27,294	LDPE	-1,543	-524	-12.8	20.7	12.6
Plastic film - non-recyclable	61,877	LDPE		-1,187		47.0	28.5
Mixed plastic / materials	22,920						

There are many plastic resins, but just a few dominate plastics products and packaging used in Oregon. Table 6 shows the make-up of rigid plastic containers disposed in Oregon's garbage in 2009. Just four resins, polyethylene terephthalate (PET), high density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS) make up 96 percent of all rigid plastic containers disposed in Oregon.

With juice, tea and some non-alcoholic beverage containers being added to the Oregon bottle bill effective Jan. 1, 2018, Oregon should see another bump up in beverage bottle recycling. However, a substantial amount of plastic beverage containers not currently being recycled are plastic HDPE milk jugs, which are not covered under the law. These, along with "other plastic bottles" (which include detergent and shampoo bottles) and tubs, plant pots and pails made from HDPE or PP are all collected mainly through curbside recycling, and showed big increases in recent years as more and more collection programs switched to using large roll carts for collection. Currently, markets are strong for all these plastic resins, and recycling processors will have no problem selling any additional tonnage of these that might be collected.

Table 6. Rigid plastic containers by resin and container type statewide 2009

Resin	Bottle	Tub	Total
1 PET	25.02%	7.92%	32.94%
2 HDPE	28.50%	11.29%	39.78%
3 PVC	0.27%	0.05%	0.33%
4 LDPE	0.14%	0.00%	0.14%
5 PP	0.62%	9.36%	9.98%
6 PS (solid)	0.00%	8.24%	8.24%
6 PS (foam)	0.00%	5.15%	5.15%
7 Other	1.53%	0.67%	2.20%
U Unknown	0.09%	1.16%	1.25%
Total	56.17%	43.83%	100.00%

The Oregon Waste Composition Study divided plastic film into two categories, "recyclable" and "non-recyclable.” The "recyclable" category includes only those low density polyethylene (LDPE), HDPE and PP plastics that are relatively easy for businesses and households to identify and separate out for recycling. The bulk of the material is commercial, including materials such as dry cleaner bags, pallet wrap and furniture bags. Some residential material such as plastic grocery bags and newspaper delivery bags are also included, although households have to make a special effort to find places that will accept these plastics for recycling. For 2009, about 27,000 tons of disposed film plastic fit this "recyclable” film category, but a much larger tonnage was labeled "non-recyclable." In fact, though, much of this "non-recyclable" film plastic is actually recyclable, but potential difficulty in identification or potential contamination makes it less likely for collection programs to include it. In addition, any plastic used as a garbage bag was classified as "nonrecyclable" since it was disposed as a consequence of its use, even though the plastic itself is usually highly recyclable. A fair amount of the "nonrecyclable" plastic film consisted of other resins, though, such as polyvinyl chloride (PVC or vinyl), acetates and other resins for which no general recycling collection programs currently exist.

DEQ does not have much information about what makes up the remaining major plastic categories: "other rigid plastic packaging" and "rigid plastic products." A fair amount of "other rigid plastic packaging" includes bottle caps and lids. Recently, plastics processors throughout the United States have been requesting that consumers leave the caps on bottles when they recycle the bottles, because the caps are easily separated from bottles by the plastics recyclers/processors, and that could lead to an increase in the recycling of this material. However, some collectors and commingled recycling processors are not in favor of asking people to leave caps on bottles, because doing so reduces the amount of compaction in collection and also reduces the density of bottles in plastic bales.

There has been increasing attention by the Association of Post-Consumer Plastics Recyclers and the American Chemistry Council to increase the recycling of large rigid plastic products and packaging. APR has been developing bale specifications for these plastics, looking at case studies and identifying domestic recyclers willing to buy rigid plastics that meet these bale specifications. Export buyers are also very willing to purchase this material. Examples of these large plastic products include such things as laundry baskets, plastic roll-carts, lawn furniture, large buckets and other large plastic items made of HDPE, PP or LDPE. Objects made of other plastics or of mixes of plastics and other materials are not allowed under these specifications. DEQ does not have information to indicate how much of the 125,000 tons of other rigid plastic products and packaging would fit these specifications.

A significant percentage of plastics collected for recycling in Oregon are exported, primarily to Asian countries. This has led some critics to suggest that these plastics are not actually recycled, but rather are burned for energy. DEQ has not inspected Asian importers of waste plastics from Oregon, but the evidence strongly suggests that most of these exported plastics do, in fact, get recycled. For example, DEQ recently evaluated the price per pound that Asian importers pay for waste PET plastic from Oregon, and converted this into a price per recoverable BTU if the waste plastics were burned. This price per BTU was found to be approximately six times higher than the equivalent price per BTU for domestic Chinese coal. Put differently, Chinese firms buying waste plastic from Oregon for the purpose of combustion and energy recovery could generate an equivalent amount of energy using domestic coal at roughly one-sixth the price. Thus, while some (difficult to recycle) waste plastics may be burned, it seems highly unlikely that most are.

Energy and greenhouse gas impacts of plastics

The estimates for energy and greenhouse gas savings given in Table 5 are upper limits based mainly on using the factors for high-energy plastics such as the polyethylenes. Polyesters such as PET and chlorinated plastics such as PVC have much lower BTU value per pound of material, so would yield less energy when burned for energy recovery. In addition, substantial amounts of rigid plastic products may have multiple resins in the same product, making separation difficult and reducing the yield of plastic for recycling.

The energy savings from recycling plastic are large compared to recycling many other materials, in large part due to the embodied energy in the plastic itself. Recycling plastic is a fairly low-energy process that just involves cleaning the plastic and either chipping it into flakes or extruding it into pellets Making plastic from virgin petroleum or natural gas is a much more energy-intensive chemical process. Not only is energy needed to drive that process though, but additional petroleum or natural gas is needed as the raw feedstock for making the plastic itself. At least for polyethylene and polypropylene, the energy embodied in the plastic itself is greater than the additional process energy that was required to make the plastic.

Burning plastic in a mass-burn energy recovery facility results in less energy savings than does recycling plastic. There are two reasons for this. First, burning the plastic only recovers energy that was embodied in the plastic itself. Lost is the net process energy required to make plastic from feedstocks as compared to the low energy required to make plastic from plastic. Second, mass burn energy recovery facilities are not as efficient at producing electricity as are power plants designed to directly burn fuel, so a greater portion of the fuel value of the materials being burned is lost in mass burn facilities when compared to other power generation facilities.

Although energy savings from recycling plastic are large, the greenhouse gas savings are not as large relative to other materials. When you landfill plastic instead of recycling it, all of the energy embodied in the hydrocarbons of the plastic is lost. However, regarding greenhouse gases, there is no difference in the carbon embodied in recycled plastic as compared to the carbon embodied in landfilled plastic. In both cases, that carbon is safely sequestered away where it will not contribute to global warming. The greenhouse gas savings resulting from recycling plastic come mainly from avoiding the net process energy needed to convert petroleum or natural gas feedstocks to plastic.

Regarding the greenhouse gas impact of burning plastic for energy recovery in a mass-burn facility, such energy recovery is actually a net source of additional greenhouse gas when compared to landfilling. This is again because burning plastic (or other hydrocarbons) in a mass-burn energy-recovery facility releases all the carbon from the plastic mainly in the form of carbon dioxide, but such burning is not as energy efficient as burning petroleum directly in a power plant. Other types of plastic burning or pyrolysis should be studied for their energy and greenhouse gas impacts.

EPA's WARM tool does not evaluate pyrolysis of waste plastic, a technology that has attracted much attention in Oregon due in part to the presence of a local vendor of pyrolysis technology. Using data provided by Agilyx and Agilyx's consultant, DEQ estimates that pyrolysis of mixed plastic conserves more energy than mass combustion (approximately 24 million BTU/ton for pyrolysis compared to approximately 15 million BTU/ton for mixed plastic), and that pyrolysis recovers much more energy than landfilling plastic (which produces no energy). However, recycling is still a much better option (approximately 53 million BTU/ton savings). Results for greenhouse gas modeling are somewhat different. Combustion, pyrolysis and landfilling of plastics all contribute to greenhouse gas emissions (with pyrolysis and landfilling having very small emissions relatively to mass burn), while again, recycling remains far and away the most advantageous approach (emissions factors estimated at -0.42 MTCE/ton for recycling mixed plastic, +0.01 MTCE/ton for landfilling, +0.06 MTCE/ton for pyrolysis, and +0.43 MTCE/ton for mass burn with energy recovery). Please note that these values for pyrolysis represent rough estimates and do not carry the same level of quality review as EPA values.

Wood

Substantial amounts of wood are burned in hogged fuel boilers at paper mills and other facilities throughout the Northwest. However, the environmental impacts of recovering wood are substantially different when compared to the impacts of recovering plastic and paper as discussed above. As can been seen in Table 2 above and Table 7 below, the recycling of lumber actually takes slightly more energy than producing wood products directly from trees. However, recycling lumber does result in significant greenhouse gas savings, according to EPA modeling. Recycling lumber results in reduced harvesting of trees, leaving more carbon sequestered for years in the growing forest.

Table 7. Disposed tons, energy and greenhouse gas impacts of wood recovery instead of landfilling

Material	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	Energy Net combustion (Billion BTUs)	GHG Net Recycling MTCE (1000s)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)
All wood	**273,223**		**75**	**-1,987**	**-115.2**	**46.6**	**15.4**
Unpainted lumber	65,446	Lumber	17	-553	-32.0	13.0	4.3
Hogged fuel lumber	51,784	Fiberboard	27	-438	-25.5	10.3	3.4
Painted lumber	38,941	Lumber	10	-329	-19.0	7.7	2.6
Wood pallets and crates	35,612	Lumber	9	-301	-17.4	7.1	2.3
Wood furniture	43,391	Lumber	11	-367	-21.2	8.6	2.9
Chemically-treated lumber	5,345						
Other wood products	10,110						
Mixed wood / materials	22,593						

In contrast, burning recovered lumber has the opposite results from recycling, in that burning wood provides a significant energy gain but leads to increased greenhouse gases (relative to landfilling). The energy gain from burning wood is much less on a per-weight basis than the gain from burning plastics, since wood has a much lower energy density than plastic. Burning wood releases small quantities of greenhouse gases (nitrous oxide), but these are offset by a much larger credit for displacing fossil fuel combustion by electric utilities elsewhere in the system. The carbon dioxide produced from burning the wood is biogenic carbon which does not count towards greenhouse gas emissions. Combustion and energy recovery from wood is viewed by WARM as a net reducer of greenhouse gases, but not as much as landfilling, which benefits from a large credit associated with lost long-term storage of carbon in the landfill.

Yard Debris and Food Waste

By weight, food waste is the largest single material in Oregon's solid waste disposal stream, and a large amount of yard debris is also disposed of each year. For both yard debris and food waste, EPA modeled composting instead of recycling. EPA also modeled burning in a mixed waste energy recovery facility.

For most materials, the major impact of recovery is to reduce emissions and energy use associated with manufacturing the material, and the impact of material in the landfill is relatively unimportant. In the case of both food waste and yard debris, though, the landfilling of these materials do have a significant direct impact on emissions. Both food waste and non-woody yard debris (particularly grass) decompose quickly when landfilled. Landfills quickly use up their oxygen and become anaerobic as garbage builds up and the organic materials in the landfill decompose. Under anaerobic conditions, the organic materials in food and yard debris break down to form roughly equal portions of methane and carbon dioxide. Methane is a greenhouse gas 25 times more potent than carbon dioxide. Although large landfills are now built with gas collection systems that capture methane and either flare it or burn it for energy recovery, a significant portion of the methane from food and grass is produced in the early stages of filling the landfill cell, before final cover is applied to the landfill and the gas collection system is turned on. Even once waste comes under the coverage of gas collection systems, these systems do no collect and destroy all of the methane. Thus, recovery of food and non-woody yard debris have a major effect by keeping these materials out of the landfills where they would otherwise decompose anaerobically and release methane to the atmosphere. That is why both composting or burning of these materials for energy recovery results in reduced greenhouse gas emissions, even though they have low fuel value and release almost all their carbon to the atmosphere on being burned or composted. Because of the very large tonnages involved, the reduction in greenhouse gas by burning or composting these materials is significant. Note that by EPA's model, the greenhouse gas impact for composting or burning woody materials (including old leaves) is significantly different. The lignins in these woody materials strongly delay their decomposition, so relatively little methane is produced in the early stage of the landfill. For these materials, EPA estimates that the long-term storage of carbon in the landfill from these woody materials exceeds the greenhouse gas impact of the relatively small amount of methane released to the atmosphere.

For both food waste and yard debris, the market value of the raw material is generally negative. The value of the products sold (compost or energy) by the processor is not enough to pay for the processing or composting operation, and so facilities that compost these materials have to charge people for dropping off their material, instead of paying for it. There are some places that will accept unprepared woody yard debris for free for energy recovery, but composting is almost always a cost to the generator. However, the markets for both compost and hogged fuel (energy) are very large.

For these two materials, the potential impact on soil fertility should be taken into account. Intensive agriculture tends to degrade soils and causes them to lose their organic matter, which has negative impact on both the water-retention and nutrient-retention characteristics of the soil. Adding compost or directly adding organic matter to the soil can help reverse this loss.

Although this paper concentrates on material recovery, it should be noted that waste prevention can play a much more important role for food waste than is the case for recovery and composting of food. Estimates of the amount of food that is produced in the United States but not eaten range from 27 percent to nearly 40 percent (Hall *et al.* 2009, Kantor *et al.* 1997). Also important are the choices that farmers and consumers make about the types of food they grow or purchase, as recently documented in both the agriculture and materials management sections of the Oregon Global Warming Commission's *Interim Roadmap to 2020 (2010)*

Table 8. Disposed tons and energy and greenhouse gas impacts of food and yard debris recovery instead of landfilling

Material	Tons	Material used for factors	Energy Net combustion (Billion BTUs)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)	GHG Net Composting
Yard debris	**118,009**		**-351**	**11.3**	**6.0**	**2.9**
Grass clippings	40,154	Grass	-120	-2.3	-4.1	-5.2
Leaves / weeds	53,743	Leaves	-161	8.9	6.5	5.0
All prunings and stumps	24,112	Branches	-69	4.8	3.7	3.1
All food	**457,382**	**Food Scraps**	**-1,125**	**-85.6**	**-102.9**	**-118.2**

Glass

Glass generation has been very stable on a per-capita basis in Oregon for the past 15 years, but during this period, the amount of glass being recycled has increased steadily while the amount disposed has correspondingly decreased. Currently, Portland's Owens Illinois glass manufacturing plant only accepts color-sorted glass to be recycled into new bottles. Glass collected under the Oregon bottle bill is almost all color-sorted, either through direct sort or through use of optical sorting machines. However, most glass collected through curbside programs is mixed color, and none of the Oregon commingled recycling processors have the equipment to separate the glass by color. As a result, a large portion of the curbside glass is shipped to California at a significant cost, to be color-sorted for bottle production or used for fiberglass production. In 2009, nearly one-third of the curbside glass was recycled into very low-grade uses such as being used to make temporary roads in landfills or as part of the drainage layer at the bottom of the landfill. Table 9 shows the use of container glass that was recycled in 2009, plus the estimated glass disposal that year.

Table 9. Uses for container glass: 2009 (tons)

Collection source Market ==>	Make Glass	Aggregate	Unknown	Total	Disposed
Bottle Bill distributors	53,008	326		53,334	6,809*
Hauler/other	34,073	16,536	578	51,187	23,940**
Unknown	3,558			3,558	
Total	90,639	16,862	578	108,079	30,749

*6,809 tons refers to deposit glass bottles that individuals disposed of rather than redeeming for deposit or recycling through curbside programs.
** This is all other container glass, excluding deposit container glass, that ended up being disposed of.

Energy and greenhouse gas savings for recycling glass strongly depend on the market. Recycling glass into glass saves moderate amounts of energy because it takes significantly less energy to recycle glass back into glass than it does to manufacture glass from sand, limestone and other minerals. In contrast, recycling glass into aggregate saves very little energy, because it takes so little energy to mine aggregate or to crush rock to produce aggregate.

There are two new developments regarding glass recycling that should help increase the recycling of glass back into glass. First, a new glass processor plans to build a plant in Oregon and will be selling the glass cullet it produces to the local glass plants. Secondly, a new glass bottle manufacturing operation, Bennu Glass, is scheduled to open in Kalama, Wash., by July 2012. Bennu Glass will likely be using green glass to make wine bottles - a color that is rarely used by the Owens Illinois plant in Portland, which makes mainly brown glass bottles.

Table 10 below gives the tons of glass disposed in 2009 for different glass categories and gives estimates of energy and greenhouse gas savings that would result from recycling that glass back into new glass products. Estimates for energy and greenhouse gas savings for "window and other glass" are high because some of these types of glass would be hard to recycle back into glass products or would have much lower yields.

Table 10. Disposed tons and energy and greenhouse gas impacts of glass recovery instead of landfilling

Material	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	Energy Net combustion (Billion BTUs)	GHG Net Recycling MTCE (1000s)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)
GLASS	**52,132**		**-139**	**0**	**-4.5**	**-0.2**	**0.0**
Deposit beverage glass	6,809	Glass	-18	0	-0.6	0.0	0.0
No-deposit glass containers	23,940	Glass	-64	0	-2.1	-0.1	0.0
Window and other glass	21,383	Glass	-57	0	-1.9	-0.1	0.0

Metals

As can be seen in Table 2, metals (particularly aluminum and other nonferrous metals) have some of the highest coefficients for energy and greenhouse gas savings of any single material modeled by EPA. Steel has lower coefficients but still demonstrates considerable savings. Markets for recycling metal are well-developed and worldwide. Oregon has a large steel recycling facility in McMinnville, but much of the actual melting and recycling of other metals takes place in other states or other countries.

Metals generally show high recycling rates. Oregon's material recovery survey shows little detail regarding types of metals recycled, providing separate numbers for aluminum and tinned cans but lumping all other metals into a "scrap metal" category which includes both ferrous and non-ferrous metal. It is likely that some aluminum and tinned cans also are sometimes reported in the more general scrap metal category. Based on the way Oregon's law is written, the recovery numbers for scrap metal do not include industrial scrap, vehicles or scrap metal from major building demolition. These materials all have very high recycling rates, so the total metal recycling rate is higher than reported in Table 1.

Table 11 shows energy and greenhouse gas savings that would result from recovering scrap metal that is currently placed in Oregon landfills. For material categories such as aluminum foil, the Table 11 numbers overestimate the savings that would result, since aluminum foil has a much lower yield than aluminum cans when recycled. The same is also probably true for various other scrap metal categories. On the other hand, the mixed ferrous/nonferrous category, which includes materials such as electric motors, might actually have higher savings, since the EPA numbers for steel rather than high-benefit non-ferrous values were used in calculating these estimates.

The high values in Tables 2 and 11 for energy and greenhouse gas savings from combusting ferrous metal produced in mass-burn facilities might seem confusing, since very little steel actually burns. The numbers actually represent recovery and subsequent recycling of ferrous metal from ash resulting from burning mixed garbage in mass-burn facilities, rather than combustion of the metal itself.

The results show that even though the amount of aluminum and other non-ferrous metal disposed is fairly small, there are still reasonable savings in energy and greenhouse gases that could result from increased recovery. Ferrous metal, due to its much higher disposal quantity, also could provide greater savings if recovery levels improved.

Table 11. Disposed tons and energy and greenhouse gas impacts of metal recovery instead of landfilling

Material	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	Energy Net combustion (Billion BTUs)	GHG Net Recycling MTCE (1000s)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)
METAL	**146,490**		**-3,357**	**-1,606**	**-72.2**	**-39.7**	**-39.4**
Aluminum beverage cans	2,929	alum. cans	-606	0	-10.9	0.0	0.0
Aluminum foil / food trays	2,092	alum. cans	-433	0	-7.8	0.0	0.0
Other aluminum	1,597	alum. cans	-330	0	-5.9	0.0	0.0
Other nonferrous metal	1,439	copper wire	-120	0	-2.0	0.0	0.0
Steel (tinned) cans	16,035	steel cans	-329	-283	-8.0	-7.0	-6.9
White goods	1,219	steel cans	-25	-21	-0.6	-0.5	-0.5
Used oil filters	500	steel cans	-10	-9	-0.3	-0.2	-0.2
Empty aerosol cans	2,105	steel cans	-43	-37	-1.1	-0.9	-0.9
Other ferrous metal	46,431	steel cans	-952	-819	-23.3	-20.2	-20.1
Small appliances-non electronic	13,053	steel cCans	-268	-230	-6.5	-5.7	-5.6
Other mixed ferrous/non-ferrous	11,785	steel cans	-242	-208	-5.9	-5.1	-5.1
Mixed metal / material	47,306						

Computers

Computers were banned from disposal in Oregon beginning Jan. 1, 2010, and thus disposal tonnage from 2009 should be substantially reduced in subsequent years. Because of the low tonnage, the potential for additional savings from recycling computers is fairly small. As was the case with metals, the small energy and greenhouse gas benefits of burning computers in mass burn facilities are mainly associated with metal recovery from the ash of the burner.

As was the case with food, waste prevention can play a much larger role in saving energy and reducing greenhouse gases than recycling or direct energy recovery can play. Computers contain complicated mixes of materials, and some of those materials cannot be feasibly separated for recycling; other materials such as silicon may take significant energy to manufacture but have no recycling market. In contrast, purchasing fewer computers or reducing the frequency of upgrading computers saves all the energy and greenhouse gas impacts of manufacturing that computer. Per EPA's WARM model, the greenhouse gas saved from recycling one ton of computers, relative to landfilling them, is 0.63 MTCE, but the greenhouse gas saved by source-reducing a ton of computers is 15.21 MTCE - some 24-fold higher savings.

Table 12. Disposed tons and energy and greenhouse gas impacts of computer recovery instead of landfilling

Material	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	Energy Net combustion (Billion BTUs)	GHG Net Recycling MTCE (1000s)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)
Computers and monitors	**4,774**		**-148**	**-33**	**-3.0**	**-0.1**	**-0.2**
Computers CPU units	2,038	personal computers	-63	-14	-1.3	0.0	-0.1
Computer monitor CRTs	2,736	personal computers	-85	-19	-1.7	-0.1	-0.1

Carpet

Carpet is a very high-energy material, often composed primarily of nylon, polypropylene, polyesters or other plastic resins, along with adhesives and fillers. Oregon's waste composition studies have consistently documented large amounts of carpet being disposed of in landfills. EPA's numbers for energy and greenhouse gas savings for recycling carpet are also very high. At 96.82 million BTUs and 1.98 MTCE saved per ton of carpet recycled instead of landfilled, only aluminum cans show higher savings per ton. EPA's numbers are somewhat perplexing because they are significantly higher per ton than are the three pure grades of plastic that EPA modeled - PET, HDPE, and LDPE. The savings for those three individual resins range from 51 to 56 million BTU and 0.39 to 0.47 MTCE. Nylon does require more energy to manufacture than the other three resins do, but the carpet modeled by EPA is only 45 percent nylon and 15 percent polypropylene. The rest is a glue (8 percent) and calcium carbonate filler (32 percent), which should not contribute significantly to energy or greenhouse gas savings when the carpet is recycled. Morris (2010) recently completed a study for Seattle Public Utilities looking at greenhouse gas impacts of recycling carpet and burning carpet in a mixed-waste energy recovery facility. Greenhouse gas impacts of recycling carpet were substantially lower in Morris' study, at 0.62 to 0.66 MTCE saving instead of 1.98 MTCE savings per ton determined by EPA. In contrast, Morris and EPA found the added greenhouse gas impacts for mass-burn energy recovery from carpet to be nearly the same - an extra 0.25 to 0.26 MTCE released per ton of carpet burned instead of landfilled. With the large difference in recycling savings, and EPA recently acknowledging that their GHG emissions factors need to be reviewed. As such, DEQ chose to use Morris' values for greenhouse gases rather than EPA's. For energy savings, which were not included in Morris' paper, DEQ estimated per-ton energy savings by taking the per-ton energy savings for mass burn of carpet (from EPA) and multiplying it by the ratio of energy savings (recycling):energy savings (combustion) for plastics (from EPA, derived from Table 5 above).

Table 13. Disposed tons and energy and greenhouse gas impacts of carpet recovery iInstead of landfilling

Material	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	Energy Net combustion (Billion BTUs)	GHG Net Recycling MTCE (1000s)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)
Carpet/ rugs Morris	67,546	Carpet - Morris			-41.8		17.5
Carpet/ rugs DEQs	67,546	Carpet - EPA/DEQ	-2,565	-933		31.4	

Carpet is rarely recycled back into carpet. Nylon car parts, carpet pad and carpet backing are three common products that were included in the recycling models for greenhouse gas and energy impacts.

In 2009, less than 1 percent of Oregon carpet was sent off for recycling. A new company has recently opened to collect and recycle carpet in Beaverton, Oregon, so future carpet recycling numbers should improve. Given large tonnage of carpet disposed and the large energy and greenhouse gas impacts of carpet recycling, even using the lower numbers from the Morris study, increasing carpet recovery could be a high priority for reducing material impacts on the environment.

Asphalt Shingles

Asphalt roofing has even higher disposal tonnage than carpet, but the history of asphalt roofing recycling in Oregon has been mixed. Shingle-to-shingle recycling does not occur commercially in the United States. Most shingles get recycled by being ground and blended at low rates with aggregate and asphalt at hot-mix asphalt plants for road asphalt.

According to EPA, asphalt shingles are mainly aggregate and inert materials, and contain only 22 percent asphalt cement. Because aggregate is a low-energy material, the greenhouse gas and energy impacts of recycling asphalt roofing into hot-mix asphalt is fairly low.

Table 14. Disposed tons and energy and greenhouse gas impacts of asphalt roofing recovery instead of landfilling

Material	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	Energy Net combustion (Billion BTUs)	GHG Net Recycling MTCE (1000s)	GHG Net Burning - No Energy Recovery MTCE (1000s)	GHG Net Burning Northwest Energy Recovery MTCE (1000s)
Asphalt roofing - recyclable	91,778	Asphalt shingles	-274	-829	-3.3	17.0	-9.4
Asphalt roofing – non-recyclable	9,411						

For energy recovery, unlike other materials where mass-burn energy recovery was modeled, asphalt shingles were modeled using a cement kiln as the location of combustion. This allowed asphalt shingles to directly replace other fuels in the cement kiln, instead of the less efficient replacement of fuels used to generate electric power as modeled for other materials burned in mass-burn facilities. This is why the greenhouse gas reduction from burning shingles (in cement kilns) is greater than the greenhouse gas impact of recycling shingles - the only material in EPA's model for which this is true. Morris (2010) similarly modeled burning carpet in cement kilns, replacing coal, and found very large greenhouse gas savings as compared to greenhouse gas losses (extra emissions) from burning carpet in mass-burn facilities.

Concrete and Drywall

EPA models concrete recycling as crushing concrete to produce aggregate. There is very little difference between the energy involved in crushing rock when compared to crushing concrete, so the energy and greenhouse gas benefits were very small.

For gypsum, EPA modeled recycling taking new wallboard scrap (from new construction, not from demolition) and recycling 81 percent into agricultural gypsum and 19 percent into making new gypsum wallboard. As the energy involved from making either drywall or agricultural gypsum from recycled gypsum is nearly the same as the energy involved in making them from virgin materials, the overall benefit of recycling gypsum is fairly small on a per-ton basis. This can be seen in the results in Table 15.

Throughout the nation, gypsum recyclers have been reluctant to accept gypsum from demolition projects due to concerns about asbestos or lead on the demolition drywall. Gypsum causes significant problems in mass-burn facilities due to its sulfate content. Marion County requires that loads containing gypsum be sorted to remove the gypsum before the waste can be sent to the Marion County Energy Facility. Gypsum can also cause problems in landfills or composting operations that become anaerobic, because it forms toxic hydrogen sulfide in the absence of oxygen.

Currently a relatively small amount of drywall is shipped to a drywall recycling facility in Washington, and some is used in agricultural products and compost in Oregon.

Table 15. Disposed tons and energy and greenhouse gas impacts of concrete and drywall recovery instead of landfilling

Material	Tons	Material used for factors	Energy Net Recycling (Billion BTUs)	GHG Net Recycling MTCE (1000s)
Rock, concrete	30,606	Concrete	-20	-0.4
Gypsum wallboard NEW	22,576	Drywall	-72	-0.6
Gypsum wallboard OLD	52,670	Drywall	-167	-1.4

Other Materials and Further Research

DEQ has not yet evaluated a number of materials for potential recovery environmental benefits, either because the WARM model does not include data for those materials (or questions exist about the emissions factors), or because recycling, composting or energy recovery options do not exist for those

Table 16. Disposed tons for miscellaneous materials

Material	Tons
Automotive tires	37,709
Other tires	655
Other rubber products	13,676
Disposable diapers	71,757
Rug pads, not rubber, plastic	911
Other textiles	51,854
Mixed textile / material	36,402
Asphalt roofing - nonrecyclable	9,411
Mattresses & box springs	10,122
Furniture (mixed material)	32,133
Paper composite ceiling tiles	2,014
Compostable other organics	10,695
Non-compostable other organics	23,770
TVs	7,109
Other consumer elect./brown goods	14,792
Brick	3,359
Soil / sand / dirt	37,457

Material	Tons
Pet litter / animal feces	80,463
Fiberglass insulation	14,216
Other miscellaneous inorganics	52,872
"MEDICAL WASTES"	21,132
Lead-acid batteries	1,321
Dry-cell batteries	1,519
Latex paint	3,038
Oil paints	132
Motor oil	884
Other flammables	593
Pesticides / herbicides	1,071
Corrosive cleaners	504
Asbestos	25
Ammunition and fireworks	11
Compressed gas cylinders	371
Other hazardous chemicals	2,174
Unknown hazardous chemicals	57
Total	544,210

materials. Table 16 gives the tonnage of all the materials that were not included in earlier sections of this paper. These total 544,210 tons, or 21 percent of all waste disposed in 2009. For some materials, including textiles, furniture, consumer electronics, tires/rubber and miscellaneous organics, disposal tonnages are fairly large and possible recovery options may exist. Further investigation should be made for these materials. An additional 244,953 tons of non-recyclable paper, wood, metal and mixed plastic/material were also not included in the energy and greenhouse gas analysis.

Most of the energy recovery analysis in EPA's WARM model looks at mass-burn technology, where the main positive impact is in generating electricity that replaces the need to produce electricity in power plants, reducing emissions from those power plants. Other types of energy recovery could also be considered for certain materials, including pyrolysis for plastics, anaerobic digestion for organics, and direct burning of materials in industrial boilers, furnaces and cement kilns to take the place of petroleum, coal or natural gas. Preliminary modeling of some of these options show energy and greenhouse gas benefits, especially when compared to mass-burn energy.

Finally, this paper concentrated on just energy and greenhouse gases impacts. Other impacts should also be considered, including toxicity, resource depletion, land use, and air and water pollution.

Summary and Conclusion

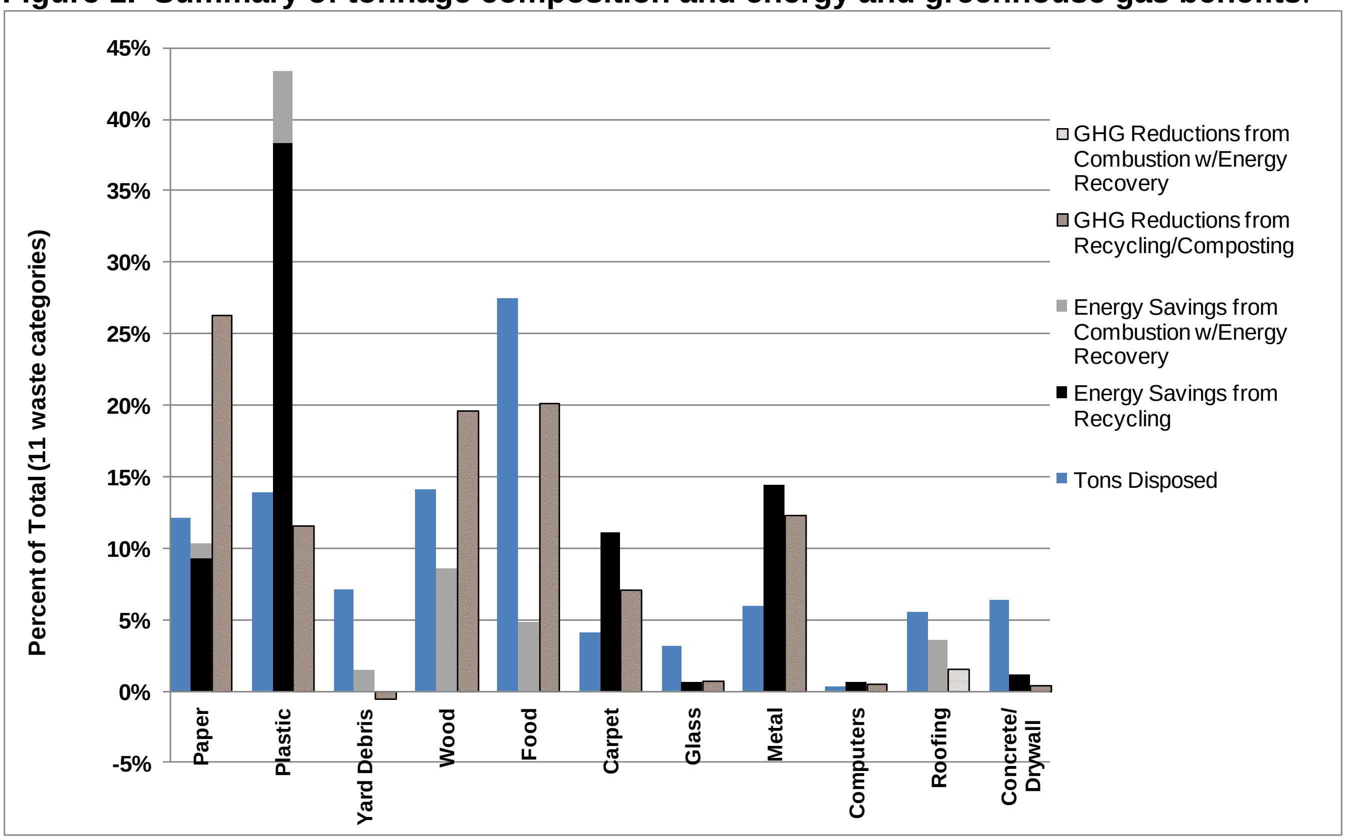
Looking at major categories of materials disposed of in Oregon, it is clear that some materials have much greater potential for positive energy and greenhouse gas benefits from recovery than is the case for other materials. As can be seen in Table 17, plastics, metals, carpet and paper have the highest potential for reducing energy consumption through recycling while paper, food waste, wood and metal have the highest potential for reducing greenhouse gases.

Table 17. Disposed tons and energy and greenhouse gas impacts of recovery instead of landfilling for major material categories

Material	Tons Disposed	Energy Net Recycling Billion BTUs	Energy Net Combustion Billion BTUs	GHG Recycling 1000 MTCE	GHG Burn 1000 MTCE
Recyclable paper	202,807	-2,204	-1,405	-154	-10
Plastic	232,280	-8,909	-4,429	-68	107
Yard debris	118,009	0	-351	3	6
Recyclable wood	235,175	75	-1,987	-115	15
Food	457,382	0	-1,125	-118	-103
Carpet	67,546	-2,565	-933	-42	18
Glass	52,132	-139	0	-5	0
Metal	99,184	-3,357	-1,606	-72	-39
Computers	4,774	-148	-33	-3	0
Asphalt roofing	91,778	-274	-829	-3	-9
Concrete & drywall	105,853	-259	0	-2	0
Non-recyclable paper	136,679	not evaluated			
Mixed plastic/materials	22,920	not evaluated			
Other wood	38,048	not evaluated			
Mixed metal/material	47,306	not evaluated			
Other materials	544,210	not evaluated			
Residue/water	152,832				
Total	2,608,915				

Figure 1 demonstrates this information graphically. For each material the tonnage or environmental impact is displayed as a percentage of the total for all of these material categories. The first column for each material (blue) shows that material's percentage in the waste stream in terms of tons. The second column (black) shows the percentage of total energy savings that would result from recovering that material, while the third column (sand texture with black border) shows the same for greenhouse gases. For both energy and greenhouse gases, if subcategories might be readily separated (for example, different grades of paper or types of plastic), each separate subcategory for a material was examined to see if either recycling or energy recovery provided the greatest benefit. If recycling, a dark color was used. If energy recovery, a light color was used. For example, with plastics, almost all types of plastics showed greater energy savings when recycled rather than when burned for energy recovery, but non-recyclable film plastic, since not recyclable, would show benefit only for energy recover. Thus the solid gray part of the middle bar for plastics represents the benefit from energy recovery for non-recyclable film plastic. In contrast, if subcategories are not easily separated (e.g., branches, leaves and grass) then Figure 1 reports results for the category as a whole, for whichever recovery method (composting or mass burn) provides the greatest benefit. In one instance, recovery is not modeled, and that is the greenhouse gas impact of burning non-recyclable plastic. In this case, recycling is not an option, but energy recovery via mass burn actually increases net greenhouse gas emissions. The energy potential of burning non-recyclable plastics are included in Figure 1, but not the greenhouse gas impacts. Non-recyclable paper, wood and metal are excluded from Figure 1.

Figure 1. Summary of tonnage composition and energy and greenhouse gas benefits.



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