APRIL 7, 2014

2050 CITY

RECYCLING AND END-OF-LIFE

NAVIN RAJ
URB3833, KISS
Final Report

2050 Model

After projecting the recycling data for a current city of 1 million people, the same model can be used to generate data for the 2050 city. Again, the model requires the total US waste generation for 2050; however, the assumption that 100% of the waste will be recycled makes the calculation much simpler. The one variable that must then be accounted for is the change in the amount of energy required to recycle by 2050.

The data that the 2050 model is built upon is based on a United Nations Environment Programme report entitled *Waste: Investing in Energy and Resource Efficiency*, in conjunction with an article by economist Edward S Rubenstein entitled *Solid Waste Infrastructure - Immigration and Infrastructure*. These two articles outlined the amount of waste produced globally in 2050, and the projected US population. This was used to calculate the projected amount of waste produced by the US in 2050.

The UN believes that 13.1 billion tons of MSW will be generated in 2050 by a population of 9.3 billion people (UN 314). Using Rubenstein's number for the 2050 US population, 438.2 million people, we find that the total MSW produced by the US in 2050 will be 617.3 million tons. This number must then be broken down into the waste components that constitute MSW.

Next, using the trends found in *Municipal Solid Waste Generation, Recycling, and Disposal in the United States*, *Tables and Figures for 2012*, released by the EPA, we can find the breakdown of waste production per product. Table 4, below, shows the amount of material generated as a percentage over 10 decades.

	Percent of Total Generation									
Materials	**1960**	**1970**	**1980**	**1990**	**2000**	**2005**	**2008**	**2010**	**2011**	**2012**
Paper and Paperboard	34.0%	36.6%	36.4%	34.9%	36.0%	33.4%	30.7%	28.5%	28.0%	27.4%
Glass	7.6%	10.5%	10.0%	6.3%	5.2%	4.9%	4.8%	4.6%	4.6%	4.6%
Metals										
Ferrous	11.7%	10.2%	8.3%	6.1%	5.8%	6.0%	6.3%	6.7%	6.6%	6.7%
Aluminum	0.4%	0.7%	1.1%	1.3%	1.3%	1.3%	1.4%	1.4%	1.4%	1.4%
Other Nonferrous	0.2%	0.6%	0.8%	0.5%	0.7%	0.7%	0.8%	0.8%	0.8%	0.8%
Total Metals	*12.3%*	*11.4%*	*10.2%*	*7.9%*	*7.8%*	*8.0%*	*8.4%*	*8.9%*	*8.8%*	*8.9%*
Plastics	0.4%	2.4%	4.5%	8.2%	10.5%	11.6%	12.0%	12.5%	12.7%	12.7%
Rubber and Leather	2.1%	2.5%	2.8%	2.8%	2.7%	2.9%	3.0%	3.0%	3.0%	3.0%
Textiles	2.0%	1.7%	1.7%	2.8%	3.9%	4.5%	5.0%	5.2%	5.2%	5.7%
Wood	3.4%	3.1%	4.6%	5.9%	5.6%	5.8%	6.1%	6.3%	6.3%	6.3%
Other **	0.1%	0.6%	1.7%	1.5%	1.6%	1.7%	1.8%	1.9%	1.8%	1.8%
Total Materials in Products	62.0%	68.8%	71.8%	70.3%	73.4%	72.9%	71.9%	70.9%	70.5%	70.4%
Other Wastes										
Food Waste	13.8%	10.6%	8.6%	11.5%	12.6%	13.0%	13.6%	14.3%	14.5%	14.5%
Yard Trimmings	22.7%	19.2%	18.1%	16.8%	12.5%	12.6%	13.0%	13.3%	13.5%	13.5%
Miscellaneous Inorganic Wastes	1.5%	1.5%	1.5%	1.4%	1.4%	1.5%	1.5%	1.5%	1.5%	1.6%
Total Other Wastes	38.0%	31.2%	28.2%	29.7%	26.6%	27.1%	28.1%	29.1%	29.5%	29.6%
Total MSW Generated - %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 4: Percent of Generation for each Material

This chart shows the breakdown of MSW in its constituent materials. Based on the decade-by-decade change, an average percent breakdown can be calculated for the materials. This percentage breakdown can then be used to calculate the weight generated for each material in 2050 based upon the total MSW generated in 2050. Table 5 shows this relationship:

Material	**Weight Generated (million ton)**	**Recovery as Percent**	**Weight Recycled (million ton)**
Paper and paperboard	201.17807	100.00%	201.1781
Glass	38.95163	100.00%	38.95163
Steel	45.92712	100.00%	45.92712
Aluminum	7.22241	100.00%	7.22241
Other nonferrous metals †	4.13591	100.00%	4.13591

Total metals	**297.41514**	**100.00%**	**100.00%**
Plastics	54.01375	100.00%	54.01375
Rubber and leather	17.16094	100.00%	17.16094
Textiles	23.27221	100.00%	23.27221
Wood	32.96382	100.00%	32.96382
Other materials	8.95085	100.00%	8.95085
Total materials in products	**136.36157**	**100.00%**	**100.00%**
Food, other ‡	78.3971	100.00%	78.3971
Yard trimmings	95.80496	100.00%	95.80496
Miscellaneous inorganic wastes	9.19777	100.00%	9.19777
Total other wastes	**183.39983**	**100.00%**	**100.00%**
Total municipal solid waste	**617.3**	**100.00%**	617.3

Table 5: The Composition of MSW and the Recycling Rate of Each Material, 2050

Each of the materials has been determined as a percentage of the total MSW produced, 617.3 million tons. Paper products, glass, and metals contribute to a large portion of the waste. Paper on its own accounted for 201 million tons of the total waste, almost the amount of all metals combined. Given that the assumption for 2050 is that 100% of the waste will be recycled, the recovery of materials is equal to the waste generated.

The next consideration for 2050 is the decrease in process energy required for each recycling process. In the case of the 2050 city, we proposed a decrease in 30% in the amount of energy consumed by recycling processes. This number was used as an assumption of the research for 2050. It is rooted in a Moore's Law-esque belief that as time goes on, processes will become more efficient. This has been reflected in new glass and plastic recycling methods than can break down biodegradable products (Huyhua). The 30% was taken away from the EPA process energy breakdown, as Table 6 shows below:

Praducts/Materials		Process Energy per Short Ton Made	Energy Emissions (MTCOE /Short Ton)	Transportation Energy per Short Ton Made from Recycled Inputs (Million
Asphalt Concrete		0.123	0.03	0.015
Asphalt Shingles		0.012	0	0.024
carpet	Nylon 6 Fiber	22.272	3.96	0.255
	Nylon 6-6 Fiber	0.999	0.18	0.768
	Nylon 6 - 6 Pellet	4.017	0.74	1.101
	PET Fiber	0.372	0.07	0.972
	PP Fiber	3.165	0.58	0.252
Concrete	Recycled Aggregate (Crushed Concrete)	0.012	0	0.027
Drywall	Drywall	0.957	0.18	0.006
	Agricultural Uses	0.036	0.01	NA
	Fly Ash / Cement	0		0.01(MTCO 2 E/Short Ton)
Glass		1.296	0.23	0.102
Metals	Aluminum Cans	10.872	2.02	0.132
	Aluminum Ingot	1.35	0.25	0.066
	Steel Cans	3.534	66	1.209
	Copper Copper No. 1 Scrap	2.367	0.44	0.555
	Copper No. 2 Scrap	6.72	1.44	0.726
Paper	Corrugated Containers	3.519	0.84	0.24
	Magazines/third-class mail	9.591	1.63	0.009
	Newspaper	6.594	1.22	
	Office Paper	6.036	1.33	
	Phonebooks	6.606	1.46	
	Textbooks	10.053	2.03	
	Mixed Paper (general)	3.573	0.67	0.069
	Mixed Paper (primarily	3.573	0.67	0.069
	Mixed Paper (primarily from	15.507	2.64	0.132
PCs	Asphalt	1.647	0.31	0.294
	Steel Sheet	3.759	0.7	0.201
	Lead Bulion	5.85	1.1	1.203
	CRT Glass	2.187	0.42	1.584
	Copper Wire	30.315	5.81	0.651
	Aluminum Sheet	4.977	0.93	0.303
	Copper Copper No. 1 Scrap	2.367	0.44	0.555
	Copper No. 2 Scrap	6.72	1.44	0.726

Table 6: The Energy Consumption for Recycling Process and Transportation by Product, 2050

This data can be taken, and inputted into the below equation to find the total energy for the US recycling waste in 2050.

$$TotalEnergy = \sum \mathrm{Re}cyclesWeight_i \times (\mathrm{Pr}ocessEnergy_i + TransportationEnergy_i)$$

Once we have the US 2050 population, we can calculate the recycling energy used for 1 million people. With the total US 2050 recycling energy, we can calculate the area needed based on the PV energy production rate.

$$Energy_{1Million} = TotoalEnergy \times \frac{1000000}{US2050POP}$$

$$EnergyArea = \frac{Energy_{1Million}}{PVEnergy\,\mathrm{Pr}oductionRate}$$

$$PVEnergy\,\mathrm{Pr}oductionRate = 292\ \mathrm{KWH/M2/YR}$$

Based on the results of the model, the recycling energy consumption for 1 million people is 1511.593605 gWh/year and the energy area needed is 5.176690427 km2.

Technology + Limitations

Technologically speaking, there are many advances in the recycling and waste management field that are important to the growth of recycling globally. Most important is the reuse process and lifespan. The goal of a recycling program should be to minimize the amount of virgin material going into production of the product. In the case of plastic, this means recycling plastic bottles back into bottles instead of small balls of plastic.

One solution for the issue of plastics is biodegradable plastics. These plastics chemically separate the resins in the recycling process, and make sorting and recycling much simpler

(Huyhua). Another advancement in technology is new glass recycling processes used in Scotland. These processes guarantee 97% recovery of input materials at 99% quality (Viridor).

This study has its fair share of limitations that must be overcome or addressed. The greatest limitation is finding accurate results for energy readings. Recycling is most often measured in some form of CO_2. This can make certain conversions difficult or disjointed. However, the advent of the individual material data sheets has solved the issue by breaking down process energy.

Conclusion

Using the model for recycling and energy, a figure for the amount of energy used and footprint required for both current recycling practices and 2050 practices was found. Our data found an increase in the amount of energy needed to recycle 100% of the waste in 2050; however, a projected decrease in the amount of process energy needed sees that the increase in energy is actually quite minimal. The land area required for PV only increases by 1 km^2, whereas the amount of waste produced continues to grow by 2050.

Recycling is a key part of the future practices of energy and conservation. As time goes on, resources will be drained from this planet. Oil is a clear example of a vital resource that is quickly dwindling. These resources are key to the growth of human life. Furthermore, landfills will continue to be filled with waste, and disposal of this waste will become more and more difficult. Useful land will be wasted if society does not make the push for recycling. Finding a way to re-input material back into the production cycle is necessary not just for a self-sustaining future, but for any future of human growth.

Sources

"£25m Scottish glass investment." *Viridor News Blog.* Viridor Limited Inc., 23 Jan. 2014. Web. 1 Apr. 2014. <http://www.viridor.co.uk/news-blogs/show/25-toast-to-scotch-whisky-sector>

Huyhua, Samantha. "Recycling Plastics: New Recycling Technology and Biodegradable Polymer Development." *Illumin* 15.1 (2014). Web. < https://illumin.usc.edu/printer/7/recycling-plastics-new-recycling-technology-and-biodegradable-polymer-development/>

Modak, Prasad. *Waste: Investing in Energy and Resource Efficiency*. United Nations Environment Programme, 2011. Web. < http://www.unep.org/greeneconomy/Portals/88/documents/ger/GER_8_Waste.pdf>

Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012. Rep. N.p.: n.p., n.d. *EPA*. Web. <http://www.epa.gov/waste/nonhaz/municipal/pubs/2012_msw_fs.pdf>.

Rubenstein, Edward S. "Solid Waste Infrastructure - Immigration and Infrastructure." *Social Contract Journal* 19.2 (2008): 74-76. Print.

"Solid Waste Management and Greenhouse Gases." *EPA*. Environmental Protection Agency, n.d. Web. 03 Apr. 2014.