Team #2371

Waste Not, Want Not:

Putting Recyclables in Their Place

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List of Acronyms Used

Acronym	Meaning
MSW	Municipal Solid Waste
GEN	Generation
yr	Year
Reduc	Reduction

Summary

As a solution to the modern society of the 20th and 21st century urban lifestyle, plastic products have provided a convenient means of quick use and quick disposal. As landfills quickly reach maximum capacity, and more litter is found scattered throughout the environment, a stricter and more realistic recycling-reimbursement program needs to be implemented nationwide to combat resource and environmental restrictions that press society.

As time passes, more and more plastic and other environmental pollutants will be produced exponentially. If current trends continue, all aspects of the environment will be stifled and suffocated. By increasing reduction in cities in particular, it will be possible to directly prevent plastics and other recyclables from entering landfills or the environment, as well as being incinerated.

With supplemental information, we have developed not only a model to predict the rate at which plastic waste will be produced and recycled in the United States but also one of reimbursement to fill the niche of the necessary recycling program to prevent further filling of landfills and polluting of the Earth. Through an implied cost on all recyclable goods, we predict that the net cost of the project would only cost the price of installing collection locations in most cities. As we have found, even a 5% pay and return increase would easily increase recycling rates significantly.

Additionally, by applying our model to the three cities on the Western United States, we analyzed its effectiveness in a realistic application. With necessary adjustments, such as size, geographic location, and relative public attitudes towards recycling for each city, the model can be easily adapted to suit local conditions.

Finally, by applying this model on a national level, we levy the benefits the government could gain by implementing our method across all states, making it impossible to cash refunds without having bought said recyclables in the state with the refund.

Restatement of Problem

We were asked to devise a solution to the problem of municipal city waste. As a particular instance, rate of plastic disposal over time

General Assumptions

For the sake of clarity throughout the paper, we here establish the assumptions taken by us:

- A stable political climate will persist
- No natural disasters will significantly cripple any significant geographic region
- Current rates of production and disposition will remain steady
- Incineration of materials counts as reclamation of the material
- All our sources contain accurate information
- Patterns have not recently made any large deviations from trends

Introduction

As according to the EPA in 2010, "Americans generated about 250 million tons of trash and recycled and composted over 85 million tons of this material, equivalent to a 34.1 percent recycling rate. On average, Americans recycled and composted 1.51 pounds out of our individual waste generation of 4.43 pounds per person per day." As a significant note, throughout our scope of American waste, the ratio of recycling to discarding has potential to easily be reduced.

How Big is the Problem?

As plastic production has exploded since the 30's and 40's when it was developed for use in industry, plastic disposal has become an increasingly important issue. Designed as a long lasting material, it most commonly ends up in landfills. To prevent this recycling has increasingly been pushed forward by modern society as an alternative. But to make a significant dent in the plastic problem recycling must seriously pick up from the EPA's 2010 rate of 2550 thousand tons a year, in comparison to 31,040 thousand tons of plastic waste produced in the same year. We were asked to create a mathematical model for the amount of plastic ending up in landfills and use this to predict the rate of plastic waste production and the amount of plastic waste present in landfills in ten years. Unfortunately, our projections based on past productions and reclaiming show that waste continues to grow at a much higher rate than recycling.

To make our projections, we used the following values from the EPA's 2010 Data Tables on Municipal Solid Waste. (Hereafter referred to as MSW) [13]

Year	**Plastics Waste Generated in U.S.** (thousands of ton)	**Plastic Not Recovered**[1] **(Landfills, litter, etc.)** (thouands of tons)	**Plastics Recovered** (thousands of tons)
1960	390	390	0
1970	2900	2900	0
1980	6830	6810	20
1990	17130	16760	370
2000	25530	24050	1480
2005	29250	27470	1780
2007	30740	28630	2110
2008	30070	27930	2140
2009	29830	27690	2140
2010	31040	28490	2550

To find an applicable model for the plastic waste generated, since all data was accounted for, we utilized a line of best fit of quadratic approximation, as represented by

$$W_T(x) = 5.311x^2 + 290.818x + 0.985$$

where x is the number of years since 1950, and f(x) represents the plastics generated per year.

Per contra, to find the amount of plastic not recovered, we had to first find the line of best fit for the recovered plastic, but since data was not available for amount of plastic not recovered, we had to calculate a line of best fit for the plastic recovered, which we then used to create the data for the amount of plastic not recovered. Using a similar quadratic approximation equation, we derived the equation

$$W_R(x) = 1.521x^2 - 55.356x + 274.403$$

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[1] After negotiation on whether or not combustion counts as recovery, we found from an alternate source [18] that the percent of plastic combusted is roughly 7% and the percent of plastic recycled is roughly 6%, adding up to our roughly 12% from the EPA, showing that combustion is indeed included.

To find the amount of plastic waste not recovered, given the data from the EPA and our projections based on said data, we subtracted the amount recovered (recycled) from the total amount:

$$W_T - W_R = W_N$$

W_T = Total

W_R = Recovered

W_N = Not Recovered

Using this equation, we can append our data table with projected values from appropriate years:

2012	38447	35758	2689
2014	40367	37406	2961
2016	42330	39084	3246
2018	44335	40792	3543
2020	46382	42530	3852
2022	48472	44299	4173
2023	49533	45194	4339

To find the rate at which the production of plastic changes at any instant, we find the derivative of the above approximation of total waste generated:

$$f'(x) = 10.623x + 290.818$$

This data can show us how fast the rate of plastic production is increasing.

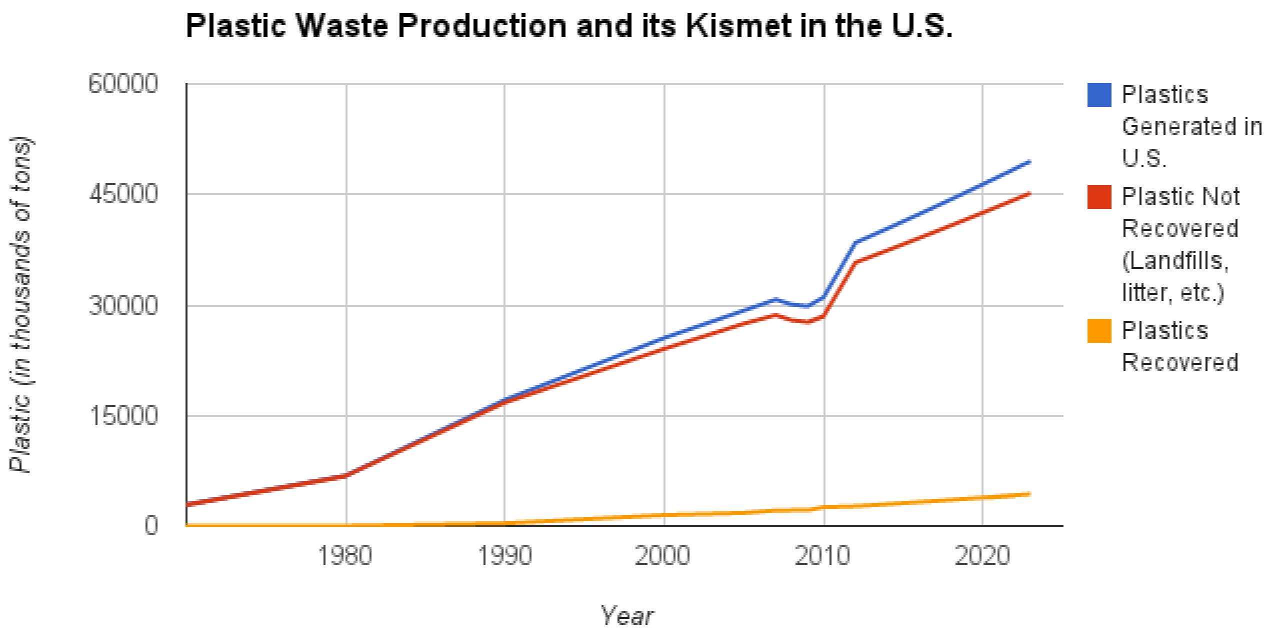
Next, to find the total cumulative amount of waste in landfills, we first had to find the line of best fit for the projected plastic not recovered from the data extracted from the above addition equation:

$$W_N(x) = 7.257x^2 + 125.408x - 2020.259$$

to complete the calculation, we took the integral of the best fit line for W_N from x=0, when plastics were first available to the consumer (1950) to the amount in 10 years, x=73 (2023):

$$\int_0^{73} W_N(x) = 1,127,702.832$$

We consequently expect 1,127,702.833 thousand of tons of plastic to be present in the year 2023. This statistic gives us a baseline comparison for the rest of the report, specifically as a comparison by implementation into cities of interest.



[2]

Making the Right Choice on a Local Scale

As a solution to the problem of municipal waste, we proposed an incentive-based program to encourage the public to recycle. By increasing price by a practically marginal amount and returning about that same amount once a product package is returned, the net cost of a national implementation would only encompass the initial cost of installing refund station and residual electrical costs to run the stations, in addition to making recycling attractive--by offering a cash incentive instead of threatening with a law to deem trash illegal, the consumer is more inclined to prefer recycling to littering or discarding waste.

As most recycling happens on a local level, it becomes crucial to accurately be able to predict the impact and functionality of different program options on a smaller scale. Particularly, we developed a model based on the Western United States cities of Wichita, a large city in Kansas, Fargo, a mid-sized city in North Dakota, and Price, a small town in Utah.

In order to make our models, we first needed to derive roughly how much MSW each city produces annually. As these statistics were specifically unavailable publically online we had to use state MSW statistics and state population to calculate tons of MSW in each city produced per person[3]. To

[2] The dip in the graph is due to an increased sampling rate around 2010; if more samples exist in a small area, that area will consequently become more detailed and seem like a distortion to the rest of the data.
[3] We are making the assumption that the state levels of MSW generation per person are similar to levels in

do so, we used

$$\text{State } W_T/\text{State Pop} = W_T \text{ per person}$$

and

$$W_T \text{ per person*local population} = \text{local } W_T$$

and to calculate 2006 population for both state and local levels (to correspond with our 2006 state MSW data):

$$\text{CensusPop}_{2000}+(6/10)*\text{CensusPop}_{2010}=\text{Pop}_{2006}$$

as shown by the table[4]:

State	2006 State Pop	State MSW gen/yr (In tons)	MSW gen/yr/person (in tons)
KS	2787238	4089591	1.467
ND	661434	660552	0.9987
UT	2551595	2864492	1.123

City	2006 Local Pop	Local MSW gen/yr (in tons)
Wichita, KS	367134	538679.475
Fargo, ND	114519	114366.293
Price, UT	8560	9609.696

We can use these values to approximate the effects of the implementation of recycling initiatives that have been applied in other areas of the country with varying levels of success.

One possibility for implementation in these cities is a "Bottle Bill," As both the production of plastics and the recovery of plastics increase, a stronger program than the current waste management regulations (such as the Resource Conservation and Recovery Act) will become a necessity. Offering only capital to begin the new recycling act, after several years, the federal government would allow the recycling program to become self-sufficient in its instituting programs similar to that of Michigan, wherein the cost of recyclables may increase over time, and the consumers would have to return said recyclables in order to obtain a rebate.

According to a study at the University of Michigan, between 1990 and 2000, recycling rates doubled in the United States [10], and states with incentive programs experienced 34% more overall

the areas in question, as the smallest level of available data is at the state level.

[4] 2000/2010 Census data omitted but available from source [5]

recycling compared to states without an incentive program [10]. Data gathered from states that have enacted such bills can be used to predict an effect on these cities. The percent of overall waste reduction by enactment of a bottle bill can be determined by

$$\text{State Bottle Bill reduc/State } W_T = \text{\% reduc from bottle bill}$$

State	**MSW gen/yr** (In tons)	**Bottle Bill reduc** (In tons)	**Percent reduc** (In tons)
ME	2178339	54000	2.48
MA	9160000	71199	7.77
IA	4341454	50000	1.15
VT	644226	15854	2.46
Average			3.465

which can be applied to the cities in question:

$$\text{State } W_T*(0.03465) = \text{MSW reduc}$$

City	**MSW reduc/yr** (In tons)
Wichita, KS	18616.762
Fargo, ND	3979.947
Price, UT	332.111

Taking into account the population and geography of each state, we can apply and alter as the model as necessary to suit the specific condition of each city. With the different population of each city, different challenges such as scale of implementation must be overcome. Similarly, the geography can either limit or allow specific methods to apply.

Fargo, North Dakota

Fargo, the largest city of North Dakota, contains a population of approximately 100,000. An economic hub of the southeastern portion of the state, Fargo has a median age of approximately 30 years, and has branches of large corporations such as Sanford Health and Microsoft.

Fargo has a normal curbside recycling, along with 27 additional drop off locations in the form of dumpsters and similar bins.

As an alternative to curbside recycling, the reimbursement program can offer an easier method to receiving incentives for recycling. Consumers may not notice a small increase in prices, and even if they do, the incentive of getting tangible currency in return for recycling should motivate the population of Fargo to adopt a recycling-rebate program.

Price, Utah

As relatively small city of about 8000 in, Price survives as a mining town at the center of Coal County, known for its large natural deposit of coal, located in the desert near the 9-mile canyon. As a particularly interesting note, its is comparatively very eco-friendly in contrast to Utah as the 47th best waste management state in America [20]. Because the bottle reimbursement plan has monetary insensitive in addition to an environmental one, it will be the program most likely to be successful in an area with borderline surroundings.

Wichita, Kansas

Wichita, the political and cultural center of Kansas, is a hub of manufacturing and economic activity due to the large presence of aircraft developers and the Arkansas River, which makes large scale imports and exports easy to handle. Wichita is a prime candidate for the the bottle reimbursement program; not only does the aircraft industry make a great buy for recycled products such as aluminum, but it also has the river for large scale exports of recycled goods.

Wichita is not located in a particularly environmentally friendly state. (Kansas ranks second to last on Zero Waste America's waste management performance rankings of the 50 states and Wash. D.C.) However, much like Price, this make it a perfect example of how the bottle reimbursement plan can succeed where other recycling programs fail. In Michigan, for example, (ranked 41st by Zero Waste report) the bottle bill brought beverage container recycling up to amn average of 97%!

How does this extend to the national scale?

In offering an incentive program, the federal government may even be able expand the venture to incorporate fiscal breaks to states with successful initiatives, as well as more local counties and towns.

Although instituting a nationwide recycling rebate program would curb the amount of plastic waste in landfills, creating such a program in major cities across the United States presents a challenging opportunity. Without subsidies--or something similar--a national program may face difficulty in winning a large percentage of American citizens. In order to encourage adoption, especially in the states already using a rebate program, the incentive may have to approach ten or fifteen cents on the dollar, leading to a larger price increase among recyclable goods nationwide.

Like most ventures, the initial startup cost should be recovered relatively soon following the adoption of the program by the increase in prices accompanied by the rebates. If the rebates are not claimed, the states will actually generate a profit.

Conclusion

In creating a national recycling-reimbursement programs, the prospects of a cleaner national environment come alive. The creation of a nationally recognized rebate may create issues between states, especially those that already maintain a rebate system, such as Michigan, California, or Vermont.

States with an established system, however, will still benefit from an improved recycling system by nationalizing the exchange rates, and having the ability to take recycling to other states for higher prices moot.

Quality Assurance

By our reasoning, the rate at which consumers throw away not only plastic, but also all other recyclables can be improved greatly. Additionally, by implementing a recycling incentive program into the country, nationwide rates of recycling can increase by figures even as high as 100% in some products such as glass as it has in states such as Michigan. Consequently, from our model developed on Sunday, March 3, 2013, we conclude that a nationwide recycling program can only benefit.

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Supporting Elements

Appendix of Tables

STATES:	PRE-IMPORT/EXPORT	PRELIMINARY RANK	POST IMPORT/EXPORT	FINAL RANK
South Dakota	(0.400)	2	=0.400	1
Wisconsin (1)	(0.448)	4	=0.580	2
North Dakota	(0.628)	9	=0.628	3
Colorado	(0.649)	11	=0.649	4
Oklahoma	(0.663)	12	=0.663	5
Minnesota	(0.591)	7	=0.679	6
Idaho (2)	(0.732)	16	=0.765	7
Louisiana	(0.769)	20	=0.776	8

Maine(1)	(0.636)	10	=0.784	9
Washington	(0.604)	8	=0.830	10
Connecticut	(0.694)	13	=0.848	11
Dist. of Columbia	(.0427)	3	=0.872	12
Alaska	(0.853)	26	=0.876	13
New Mexico	(0.712)	14	=0.888	14
New Jersey	(0.560)	5	=0.907	15
Nebraska(1)	(0.881)	29	=0.928	16
Rhode Island	(0.372)	1	=0.929	17
Massachusetts	(0.784)	21	=0.958	18
Florida	(0.966)	32	=0.966	19
Kentucky	(0.813)	23	=0.982	20
Maryland	(0.742)	17	=0.988	21
California	(0.976)	34	=0.989	22
Iowa	(0.825)	24	=0.996	23
Illinois	(0.810)	22	=1.005	24
Ohio	(0.893)	30	=1.006	25
Arizona	(1.026)	38	=1.026	26
Alabama	(0.989)	37	=1.036	27
Mississippi	(0.751)	18	=1.044	28
North Carolina	(0.980)	36	=1.045	29
Wyoming	(1.048)	40	=1.048	30
Tennessee	(1.061)	41	=1.106	31
Vermont	(0.713)	15	=1.112	32
Arkansas	(1.087)	44	=1.120	33
Pennsylvania	(0.581)	6	=1.130	34
Virginia	(0.868)	27	=1.1360	35

Texas	(1.118)	42	=1.1364	36
West Virginia	(0.881)	28	=1.156	37
Montana	(1.122)	45	=1.171	38
Oregon	(0.851)	25	=1.185	39
New York	(0.968)	33	=1.195	40
Michigan	(1.035)	39	=1.234	41
Missouri	(0.979)	35	=1.316	42
Georgia	(1.310)	46	=1.333	43
Hawaii	(1.342)	47	=1.342	44
Indiana	(0.941)	31	=1.432	45
New Hampshire	(0.767)	19	=1.471	46
Utah	(1.479)	50	=1.484	47
Delaware	(1.120)	43	=1.491	48
South Carolina	(1.467)	49	=1.588	49
Kansas (1)	(1.457)	48	=1.879	50
Nevada	(2.000)	51	=2.132	51

	Thousands of Tons									
Materials	**1960**	**1970**	**1980**	**1990**	**2000**	**2005**	**2007**	**2008**	**2009**	**2010**
Paper and Paperboard	29,990	44,310	55,160	72,730	87,740	84,840	82,530	77,420	68,430	71,310
Glass	6,720	12,740	15,130	13,100	12,770	12,540	12,520	12,150	11,780	11,530
Metals										
Ferrous	10,300	12,360	12,620	12,640	14,150	15,210	15,940	15,960	15,940	16,900
Aluminum	340	800	1,730	2,810	3,190	3,330	3,360	3,410	3,440	3,410
Other Nonferrous	180	670	1,160	1,100	1,600	1,860	1,890	1,960	1,970	2,100
Total Metals	*10,820*	*13,830*	*15,510*	*16,550*	*18,940*	*20,400*	*21,190*	*21,330*	*21,350*	*22,410*
Plastics	390	2,900	6,830	17,130	25,530	29,250	30,740	30,070	29,830	31,040
Rubber and Leather	1,840	2,970	4,200	5,790	6,670	7,290	7,500	7,590	7,630	7,780
Textiles	1,760	2,040	2,530	5,810	9,480	11,510	12,170	12,710	13,020	13,120
Wood	3,030	3,720	7,010	12,210	13,570	14,790	15,190	15,400	15,590	15,880
Other **	70	770	2,520	3,190	4,000	4,290	4,550	4,670	4,710	4,790

	% Bottles Recycled					
States	**2yr**	**4yr**	**6yr**	**8yr**	**10yr**	**USA average when implicated**
MA	0.79	0.83	0.83	0.72	0.74	0.48
MI	0.99	0.98	0.97	0.96	0.95	0.4
NY	0.79	0.74	0.73	0.76	0.76	0.43
CA	0.7	0.82	0.78	0.75	0.74	0.48