Recycling vs. Energy Efficiency Programs – Which are More Cost-Effective for Reducing GHG?

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ABSTRACT

Jurisdictions across the U.S. are adopting green, or sustainability goals, and are implementing wide-ranging strategies to move toward those goals. Given the traditional information from the U.S. Environmental Protection Agency (Washington) on the sources of greenhouse gas (GHG) emissions, which indicate waste management contributes only about three percent of GHG emission sources, communities and policymakers have tended to focus their efforts and plans on energy- or transportation- related programs that represent much bigger sources of emissions.

However, the size of emission potential is only part of the story. Strategies should be undertaken if they have advantages in terms of one or more of the following:

- Large impact
- Low cost
- Advantageous timing,
- Or other advantages (low risk, etc.).

Traditional EPA figures on emissions sources indicate that solid waste strategies would tend not to have a large impact. However, it is important to look beyond just size of impact. The question arises whether solid waste strategies may be more cost-effective than other strategies, or be quicker to implement. If so, solid waste strategies should potentially be part of the policy arsenal for addressing GHG.

The authors compared information from three main types of landfill diversion programs (recycling, composting, rate incentives) and four key types of energy efficiency investments (commercial lighting retrofit, residential weatherization, wind, and photovoltaics) to explore the question: How does the cost of achieving GHG reductions from solid waste programs compare with the cost of achieving similar GHG reductions from energy strategies?

We gathered information on the costs and typical energy savings from a variety of energy efficiency strategies from around the country. We used a combination of internal and external models to compute the GHG effects from energy efficiency programs. We tried to go beyond the traditional kWh and cost comparisons used in ranking programs, and instead, look at the costs per carbon equivalent reduction for a variety of energy efficiency (EE) programs and recycling / diversion programs to identify their cost-effectiveness in meeting sustainability goals. This involved estimating program impacts (tonnage, kWh) and costs, translating impacts to greenhouse gas (GHG) emissions, and computing – and ranking –cost per carbon equivalent for the program initiatives. In addition, we compared figures on job creation and economic development impacts from the programs. We also examined issues of “certainty / risk”, coverage, control, and timing, and how that impacts relative performance of the carbon

reduction strategies to identify "winning" strategies to include in the climate change program / policy mix for cities.

Our analysis of the costs per metric ton of carbon dioxide equivalent ($MTCO_2E$) of GHG emissions avoided indicated that faster and cheaper progress in reducing GHG could be made if communities, counties, or state agencies include an early focus on solid waste programs. The research also recognized three other considerations related to solid waste programs that provide important policy implications: timing, coverage and authority. Our research indicated:

- Recycling and PAYT initiatives appear to be cheaper per $MTCO_2E$ than the standard types of energy efficiency programs
- These programs can be implemented more quickly than standard energy efficiency programs. When implemented, these programs generally immediately cover all households (or businesses), not just a fraction of the customer base, as found in most energy efficiency programs
- The limited list of solid waste programs we studied are often more directly in the control of communities and jurisdictions.

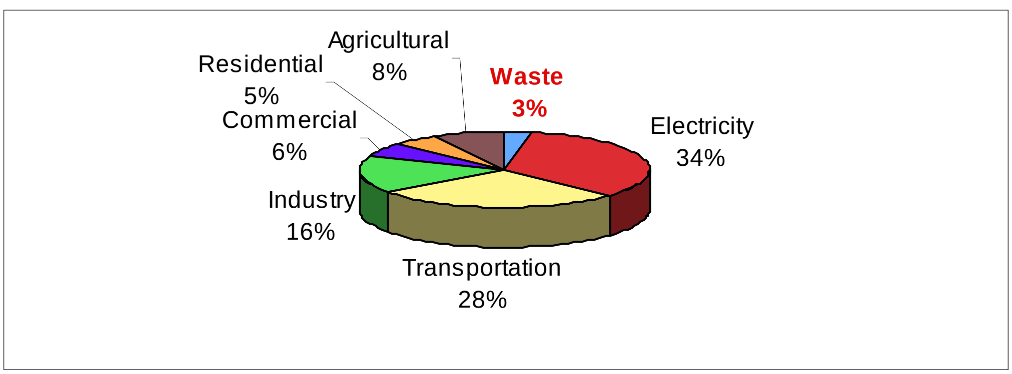
These results indicated that solid waste programs provide quick and substantial reductions in GHG emissions and serve as a bridge to impacts from energy efficiency strategies.

The results provide implications on effective and cost-effective methods of achieving reductions in greenhouse gases, and help guide cities and other agencies to identify the optimal mix (portfolio) of programs and initiatives toward sustainability goals. It provides information useful in constructing a "supply curve", identifying quantities of emission reductions available from energy and solid waste strategies, and their cost per metric ton of carbon equivalent. This paper represents a rare cross-field study, and it provides a unique analytical perspective useful in assessing alternative "green" initiatives – toward a broader sustainability integrated plan.

Introduction

Communities and counties across North America are adopting "green" or sustainability goals, and assessing wide-ranging strategies to move toward those goals. US EPA has published data estimating the sources of greenhouse gas emissions, and the data (Figure 1) indicates that electricity and energy use by buildings is responsible for the lion's share of emissions, and solid waste / waste management is only responsible for about 3% of GHG emissions sources. As a consequence, communities are focusing on energy-related issues, and mainly building energy use and transportation, which appear to represent the largest sources of emissions.

Figure 1: US Greenhouse Gas Emission Sources (Source: EPA, 2005)



Although the EPA figures make it clear that energy efficiency is an important part of the strategy for reducing GHG emissions, prudent planning suggests that it is also useful to examine the relative costs of achieving these reductions in order to put together a well-designed comprehensive plan. This paper addresses this latter question – what are the costs per metric ton of carbon equivalent for different strategies for achieving reductions in GHG and how do they compare? We also examine:

- relative performance in terms of job creation / economic development,
- timing, coverage, and authority issues associated with program delivery, and
- provide information on the implications of recent updates of information revising the accounting of GHG emissions by "source".

Analysis of Solid Waste Programs

Solid waste initiatives – whether strategies, policies, or programs – work to divert materials from disposal in a landfill or other site to "beneficial" uses in three main ways:

- **Recycling**: Recycling reduces use of virgin materials and the emissions generated during their production and transportation, and generally reduces the energy and resource demand, and significantly reduces the processing efforts and costs associated with production of final products. It also specifically preserves trees and other materials that soak up GHGs.
- **Composting**: Composting avoids anaerobic conversion of compostables in a landfill – thus avoiding production of significant amounts of methane. Methane has been shown to be 23 times as "potent" a GHG as carbon dioxide, and has an especially high impact within the first 20 years.[1] Instead, composting uses an aerobic process to produce a usable product, and doesn't produce methane or harmful GHG constituents.
- **Reuse / Waste Prevention / Source Reduction**: Reuse and waste prevention programs reduce the production of new materials, resulting in fewer GHG emissions during mining / input acquisition, production, transportation – and ultimately disposal at end of product life.

Each of these strategies has direct effects in reducing tonnage landfilled. In addition, they help avoid emissions "upstream" in raw material recovery, transport, manufacturing, and other "emitting" activities.

In this initial research project, to explore the viability of our approach, we opted to measure the GHG impacts for three major solid waste programs:

- **Pay as you throw**: PAYT is a system by which residents are charged for trash collection service based on the amount of trash set out for disposal (number of cans, size of cans, number of bags, etc.). Research shows this program has strong impacts on customer behavior, leading to substantial diversion of materials from trash (landfills) into recycling, composting, donations to charities, and so on. The programs are widespread (in place in 7,100 communities in the US as of 2006), and available to 25% of the US population (Skumatz and Freeman 2006). The program usually involves the delivery of new containers or bags, establishment of a new rate structure (and sometimes an enhanced billing system), and associated education / outreach efforts.

[1] Most GHG comparisons assume a 100 year horizon. Source, author interviews with John Armstrong (Fort Collins); David Allaway (OR DEQ)).

- **Residential curbside recycling**: Curbside recycling programs provide opportunities for residents to place recyclables in a separate container from trash, and the materials are collected, processed at a central facility, and baled and sold to market for use as a substitute (or augment) for virgin materials in the production of goods. Implementing the program requires delivery of special collection containers, periodic curbside collection of containers, and access to a convenient reprocessing facility.

- **Residential yard waste / food waste composting collection.** Residents separate their yard waste and food waste and put the material into a special container that is collected weekly or every other week. The material is collected, ground, and placed into windrows (usually) that are monitored for moisture and heat, "turned" periodically, and when the composting process is completed, the material is "screened" to assure an even, high quality product. The materials too large to fit through the screen are added to the next batch and re-composted. The finished product is a high quality soil amendment that improves water use characteristics. Implementing the program usually requires delivery of special collection containers, periodic curbside collection of containers, and access to a convenient processing facility.

Computing Diversion and Costs

To estimate the landfill diversion ("diversion", generally in tons of waste) associated with each of these programs, the author adopted a convention of examining the effects "per participant" and then scaled the results as needed. We used several sources for input data to the computations.

PAYT.
The author has published numerous studies inventorying the number of PAYT programs in the US, and quantifying the diversion impacts associated with PAYT programs in the US. These studies estimate that a total of approximately 17% of the waste generated by households is diverted when PAYT programs are implemented, with differing shares diverted to recycling, composting, and source reduction. Combined with data on generation rates[2] per household, we are able to compute the annual tonnage diverted per household, and the composition of the materials. We compute the following:

- per-household annual total of tons to "curbside recyclable mix" consisting of bottles, cans, newspapers, etc.,
- per-household annual total of tons of grass and other yard waste; and
- per-household annual tons to source reduction, and material that isn't discarded but re-used, etc.

Another key element of the analysis is the cost to deliver the program. The author conducted detailed regression analysis on a database of more than 500 communities with and without PAYT to estimate the incremental per-household cost for the program "controlling for" factors such as demographics, collection frequency, recycling program design, and myriad other factors affecting costs. The costs of the program were estimated using detailed, published data on the impacts of program changes on solid waste system costs.[3]

[2] We benchmarked the values we computed against secondary data from the California Integrated Waste Management Board, the EPA, and other sources.
[3] Skumatz, Lisa A., Ph.D. 1996. Skumatz 1999, updated by information from 2008 SERA survey of 760 programs around the US.

Residential Curbside Recycling.
To identify the landfill diversion associated with the introduction of a curbside recycling program, the author used several sources:

- The author assembled a database of solid waste programs, costs, tonnages, and other data from 760 communities across the US and Canada. Using this database, we computed the annual average pounds per household for curbside recycling programs around the US.
- We have conducted projects for clients across the US that involved interviews with two main groups: 1) “leading” communities, or 2) communities that were “similar” to the client community.
- We reviewed data from two other main sources – the California Integrated Waste Management Board, and EPA.

We used data from our database, but benchmarked the results using the other two sources to assure the data were reasonable. Again, cost is a key input into our analysis. The main source for the estimates was SERA’s community database. We used the subset of communities with curbside recycling to estimate the average per-household cost for curbside recycling programs in the US.

Residential Yard waste / Food Waste Composting.
To identify the landfill diversion associated with the introduction of a curbside yard waste / food waste (organics) program, the author used similar sources as the recycling data:

- The author’s database of solid waste programs around North America, which supported computation of average pounds diverted, costs, and similar data.
- Research projects conducted for clients across the US that involved interviews about yard waste programs.
- Web literature review, including data from the California Integrated Waste Management Board and EPA.

We used data from our database, but benchmarked the results using the other two sources to assure the data were reasonable.

Again, cost is a key input into our analysis. The main source for the estimates was SERA’s community database. We used the subset of communities with curbside organics programs to estimate the average per-household cost for curbside organics programs in the US.

Computation of Emissions Effects from the Recycling Strategies.
The next step was to calculate the greenhouse gas (GHG) impacts of the landfill reductions associated with the three programs. The EPA’s WAste Reduction Model (WARM) model[4] was used to estimate the GHG effects of each program. This required developing emissions estimates for both a baseline (no program) and alternative (including program) scenario, and computing the net change in emissions. In each case, for the program scenario we allocated tons from landfilling to the curbside recycling mix for the recycling scenarios, and for a combination of curbside recyclables, yard waste, and source reduction for the PAYT case. For the PAYT case, we assumed about 6% new tons would go to recycling, about 6% would go to composting, and about 2% would go to source reduction.[5]

[4] We recognize that this is an imperfect tool. It has particular biases in composting. However, the use of this tool only understates the impacts from solid waste programs, so the estimates provided in this paper are on the conservative side.
[5] This is a conservative assumption. A figure up to 6% for source reduction could be justified based on the literature. See Skumatz, Lisa A., Ph.D., 2000. A smaller figure (than 6% diversion) was used here because the WARM model restricts the categories of materials that may be modified through source reduction.

To provide an idea of the magnitude of the GHG savings associated with these initiatives nationally, we note that, based on the computations of tonnages affected and the WARM model runs, the PAYT programs currently in place in the US are leading to reductions of approximately 3 million metric tons of carbon equivalents annually, about 11 million metric tons of carbon dioxide equivalents annually, and about 80 million MBTU annually. The recycling and organics programs have the potential to divert even more materials, because the PAYT program delivers diverted tons as "increments" or higher performance from existing recycling and organics programs.

Note that the worth of these reduced emissions can be valued. Specifically, the dollar value of the reduced emissions in terms of carbon dioxide equivalents can be estimated using prices from the Chicago Climate Exchange (CCX). The CCX value for metric tons of CO_2 has been in the $4-$5 range for some time.[6] Given the estimated tons of emissions offset, the value of the reduced emissions due to PAYT is on the order of $30-$55 billion dollars annually. In earlier work, the author noted that using variations on these computations, the environmental "adder" from these types of effects may range as high as $11 per ton diverted from the landfill.[7] Landfill fees across the country average about $35 per ton, and in some areas, these fees can be less than $15 per ton, and this "environmental damage" figure exceeds the direct landfill fees in some areas.[8]

For the key purposes of this study, we used data on the annual per-household cost for each program, the annual tons diverted per household, and the computed emissions avoided for each program to estimate the cost per metric ton of carbon dioxide (MTCO2E) avoided for each of the three recycling (or waste diversion) programs.

Analyzing Emission Reductions from Energy Efficiency Programs

Using data from evaluation studies of energy efficiency (EE) programs conducted by the author combined with information from interviews with other evaluators around the nation, we compiled estimates of the costs and energy savings per participant for two types of energy efficiency programs, including residential weatherization program and commercial lighting retrofit programs. We gathered data on the costs and savings from typical photovoltaic and wind installations from published program data and from interviews with evaluation professionals around the nation, which provided typical ranges for costs per kilowatt-hour.
To compute the GHG effects, we used SERA's peer-reviewed "NEB-It "© model.[9] This model houses an extensive array of published secondary data on emissions per kilowatt-hour from various types of generation plants – including data based on fuel type and age of plant.[10]

There are three main approaches currently used to model the generation mix affected by programs – System Average, Margin Operations, and Hourly Dispatch.[11]

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[6] From www.chicagoclimatex.com. Other web sites like carbonfund.org suggest values of $5.50, for example.

[7] Skumatz, *Resource Recycling*, October 2008.

[8] Of course, the size of this damage factor may not be the same in all areas of the nation.

[9] This model and its non-energy benefits results have been presented in numerous conference proceedings including ACEEE, ECEEE, EEDAL and others since 2001.

[10] The model allows selection of factors from a number of published studies by Bertraw and Toman, EPA, EIA, eGRID, and EPA between 2000 to 2009. See Skumatz 2009.

[11] Skumatz 2009. System Average: Under this approach a system wide grid average is used for the local, regional, or national grid, and emissions per MWh are estimated. This may be the lowest cost approach, however it allows for the greatest level of uncertainty in emission impacts. It also masks potentially important differences between peak / off-peak programs. Margin Operations: Evaluators using this method look at the potentially displaced emissions for on-peak and off-peak hours, different seasons, and shoulder months (the State of Wisconsin's Focus on Energy "middle ground" is a good, and well documented, example of this approach). This method takes into account that the emissions for off and on peak hours may vary, and considers that EE impacts will most significantly affect the marginal energy producers, or

We used the middle approach.[12] We based our computations of GHG reductions on an assumption that the programs would be displacing baseload generation in the PG&E service territory[13]. The numbers would differ somewhat if we assumed the generation mix from another utility or if we used the generation mix for peak, but the programs we were using did not include specifically demand reduction, air conditioner or other peak-reduction programs. We used these assumptions to estimate the emissions of a variety of GHG components that are avoided due to the energy savings from specific programs.

Using the estimates for cost per participant, savings per participant, and emissions per kWh, we were able to compute the cost per metric ton of carbon dioxide equivalent from each of these four energy efficiency / renewables programs.

Results and Implications on the Relative Cost of Emission Reductions from Energy and Solid Waste Programs

For this analysis, we then normalized all figures by dividing by the results for the least expensive of the energy efficiency programs – the commercial lighting program. Thus, for simplicity, and to focus the discussion on the key point of the analysis, all the figures are presented as a ratio relative to the cost of the commercial energy efficiency program.

Figure 2 summarize the results of the computations. We choose to present the results "normalized" to highlight the *relative* costs – the point of our discussion. We normalize with respect to one of the most common energy efficiency programs, commercial lighting retrofit. The results show:

- For key program types, solid waste programs are a cheaper means of achieving GHG reductions than are typical energy efficiency programs.
- The results also demonstrate that the costs of achieving a reduction of a MTCO2E from renewables programs are many times higher than the same reduction achieved by the residential or commercial energy efficiency programs modeled.

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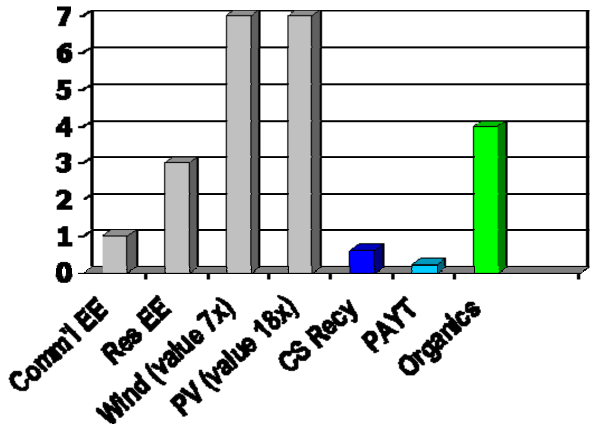
the plants that come on last to compensate for high demand periods. These plants may vary depending on the season. It is not much more expensive than the system average approach, and allows for tailoring based on basic differences in program targets. Hourly Dispatch: This approach has the potential to result in the most detailed and most certain results for GHG emission displaced. At the same time, it is the most expensive analysis to complete. In this method evaluators look at the individual plants and calculate emission for each plant for each hour. Determining the displaced emissions requires complex modeling of energy reduction over the entire grid and may include such calculations as the displaced emissions of building a new plant now, compared to in the future, when the plants may be more efficient.

[12] This is partly because the project was internally funded, so budget was a large concern, and partly because the programs were not targeted at particularly "impactful" times in the generation mix. All three methods are used in the current literature. A reviewer suggests that the emerging Greenhouse Gas Protocols from WRI suggests using the margin; however, that application was not the purpose of this particular paper, and examining a recent paper (Sumi et.al. 2009) seems to indicate a difference between hourly dispatch vs. marginal showing a difference of about 7-14% (and reversed for HVAC). It is an important difference for assigning carbon credits; it may be less important (and debatable) whether the extra effort and cost is needed for other program evaluation applications. This is a valid point for discussion..

[13] Selected as a typical utility mix, and these were data we had available from previous evaluation research. This project was not, however, conducted for PG&E, nor is it meant to reflect in any way on their programs or policies.

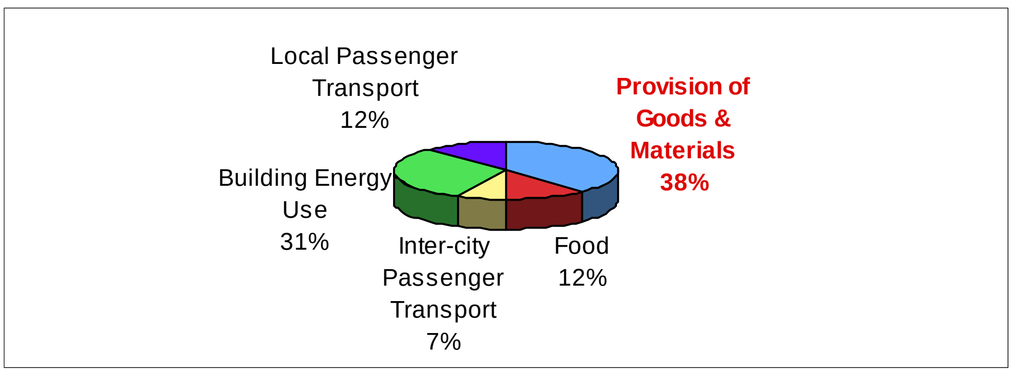
Figure 2: Relative Cost per MTCO2E Avoided for Selected Energy Efficiency (EE), Renewable, and Solid Waste Management Program Options, Compared to Normalized Cost for Commercial Energy Efficiency=1 (NOTE: Photovoltaics is about 18 times the cost per MTCO2E as Commercial EE; graph is truncated for improved visibilty)



These results illustrate that, although a review of the sources of emissions would lead to the conclusion that energy efficiency programs are the largest source of GHG, that fact is only part of the picture. Typical recycling programs – at least recycling and PAYT - may be the "low-hanging fruit", as they represent less expensive methods of achieving reductions in GHG.

Key to these computations is the fact that recycling achieves not only direct reductions from the landfills, but provides "upstream" production savings. Work by EPA shows avoidance of upstream impacts (production of virgin input materials and production of new goods) have many times the impacts of the direct landfill effects.[14] In fact, recent work by EPA shows an updated version of Figure 1. If the allocations of GHG to "sources" presented in Figure 1 are revised to "building energy use", "passenger transport", "food" and "provision of goods and materials" – this last being the production of materials that ultimately end up as solid waste – solid waste programs are among the most important contributors to GHG. The new results change the apparent hierarchy for GHG sources.

Figure 3: US Greenhouse Gas Emission Sources (Source: EPA, preliminary 2008)



[14] One important component illustrates the principle. Recycling aluminum not only reduces the mining, processing, and transportation of ore, but saves 95% of the energy required in producing new aluminum goods. The energy savings are many times more important than the landfill diversion impacts of recycling the aluminum.

Comparison of Other Features of Solid Waste vs. EE Programs

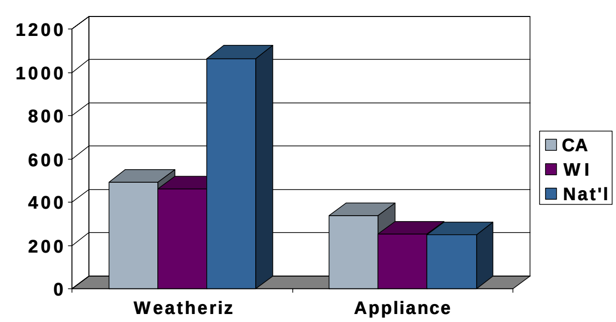
Three other considerations associated with these programs provide important policy implications:

- Job creation / economic development;
- Timing;
- Coverage; and
- Authority.

Job Creation / Economic Development.
Many energy efficiency programs have been demonstrated to be more labor intensive than electricity generation, so programs would tend to have job creation and economic development impacts for communities, states, or regions. Of course, the size of the impact depends very much on 1) the type of program (weatherization programs are more labor intensive than appliance rebate programs), and 2) the geographic region of concern (local job impacts will be smaller than job impacts that cover a larger geographic region where increasingly more and more of the materials will be manufactured. Figure 4 provides a comparison of the job impacts from two key types of programs over varied geographic regions. The authors used a widely available third party input-output modeling tool to estimate the economic effects of a $1 million investment in weatherization and appliance replacement programs, modeling programs that covered the State of California, the State of Wisconsin, and a nationwide program. The results indicate that a large share of the weatherization employment is local; on the appliance side, even if the whole US is considered the relevant impact area, few appliances are built in the US so the impacts are smaller (Imbierowicz and Skumatz, 2006, Gardner and Skumatz 2007). The net impact (illustrated in Figure 4) in jobs and economics from EE over generation is positive, and the sizes vary by program type and local industry mix.

So, too, more jobs are created in recycling than in landfilling. The authors used input-output models to estimate the job creation and economic development impacts from the energy efficiency and waste management programs.[15] We were careful to compare the program scenario case against the jobs and economic impacts from a base case that assumed the funds would otherwise have been spent on electricity generation in the EE case, and landfilling in the waste management cases.[16]

Figure 4: Net Economic Development Impacts from $1 million spent in two types of EE programs
(Source: Gardner and Skumatz, 2007)



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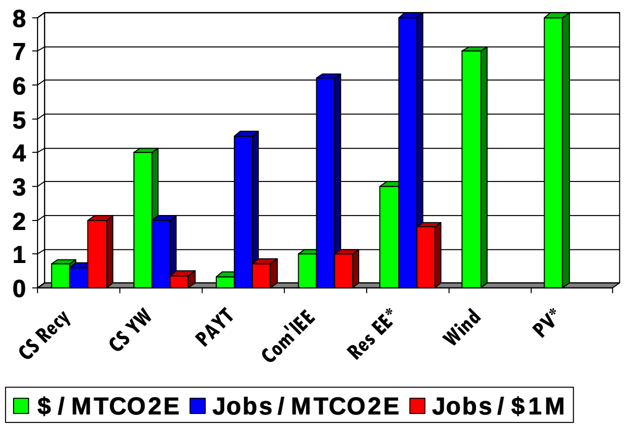
[15] The model is run selecting the relevant NAICS / industry code sources, and increasing expenditure in the appropriate business type / sectors, shifting from those that will see the decrease in economic activity.

[16] There are two widely used schools of thoughts on the baseline case, both widely used in the literature. For energy programs, some researchers compare the effects to the money otherwise being spent on electricity generation, and others use CPI market basket. In recycling, the alternatives or "base case" would tend to be, similarly, landfilling or CPI market basket. Credible cases for both have been made in the literature, and the literature is split (Skumatz 2009). We selected the former in each case.

The results of the direct and indirect impacts from the EE and recycling programs are summarized in Figure 5. The green bars replicate the findings from Figure 3 with cost relative to the cost for Commercial energy efficiency programs. The other two bars represent relative impacts on jobs, either in terms of jobs per MTCO2E reduced by the program, or in terms of jobs per million dollars invested in the program. The results show that job creation is generally larger in the energy programs, although jobs per million spent on the program are fairly strong for the waste management programs (especially for curbside recycling).[17]

Figure 5: Cost per MTCO2E and Job Impacts from Energy Efficiency and Waste Management Programs[18] (Source: Skumatz Economic Research Associates computations)



Timing.
Research on PAYT programs shows these programs can be implemented as quickly as 3-9 months. Research based on interviews with more than 1,000 communities with PAYT found programs implemented by cities or haulers that were implemented in this time frame (once the political decision was made).[19] Recycling programs are quite routinely implemented in a year or less.

Some energy efficiency programs can be implemented quickly (e.g. CFL exchanges); however, a great many programs are administered by large-scale utilities with RFP processes, equipment acquisition and similar (and in some cases, long-lead-time regulatory processes). The author conducted a review of the typical implementation schedule for weatherization programs. We found, for example, that the national Weatherization Assistance Program treated approximately 0.3% of eligible homes in a year, and a similar program in New Hampshire treated approximately 0.9% of eligible homes in a year. Certainly some utilities, NGOs, and jurisdictions can put programs in more quickly, but they are seldom as nimble as a PAYT program.[20] If these data are typical, it would take 100 years for a weatherization program to reach all eligible households; the typical recycling program or PAYT program is available to all homes in less than a year.[21] In communities in which trash service is provided by independent

[17] More work needs to be done to complete the estimates of job creation associated with renewables and wind.
[18] The programs are, from left to right, curbside recycling; curbside yard waste; PAYT, commercial energy efficiency program, residential energy efficiency program, wind, and photovoltaics.
[19] Skumatz 2006. Municipalities providing their own collection can implement directly; in other cases, ordinances or legislation requiring all haulers in a jurisdiction / county / state PAYT rate structures can be passed quickly, and it is not uncommon for implementation to be 6 months or 1 year.
[20] The author has developed and run programs on PAYT for a number of clients including states and EPA regions.
[21] And even if this is discounted by the fact that typical recycling programs achieve 75-90% "participation", recall that neither will weatherization programs achieve 100% penetration.

haulers, the implementation of recycling and/or PAYT can be particularly effortless for the community itself. Depending on the state-granted authority, communities or counties can often pass an ordinance with the speed of a stroke of a pen[22] that requires all haulers operating in a community (or county) to implement PAYT or universal recycling if it wishes to continue operations – and these ordinances typically require implementation within 6 months or a year.[23]

Coverage.
Most importantly, when a PAYT or curbside recycling program is put in place, it typically covers all single family households.[24] For an energy program, the program is advertised, participants sought, and the program (audits, retrofits, weatherization, equipment replacement, education, etc.) is delivered over time to a generally fairly limited share of households or business sector clients served by the utility or within the community.[25] As mentioned above, the program is not as immediately widespread as most types of (residential, at least) solid waste programs. The impact in solid waste is broader and more immediate.

Authority.
Communities often have some level of direct control over solid waste service – directly through municipal provision of service or through health and safety / police powers granted within state / home rule statutes. The bulk of energy efficiency programs are delivered through utilities. Those communities with municipal energy utilities have direct authority; many other communities are served by energy utilities over which they only have indirect influence. Table 1 summarizes the cost, job creation, and implementation timing results.

Table 1: Ranking of Cost Per Metric Ton of CO2 Equivalent from Program Alternatives (Relative to costs for Commercial EE program) (Source: Skumatz Economic Research Associates)

	Normalized Multiplier for Cost per MTCO2E	Job Creation / Economic Development Impacts	Speed to implement and full scale implementation coverage
Commercial Energy Efficiency (EE)	1.0 – baseline	Ten times the impact from curbside recycling per MTCO2E; twice the comparative impact per dollar spent.	1-3 years to cover a small fraction of customer base
Residential Energy Efficiency (EE)	3 times as expensive as commercial EE	Larger impact than commercial EE (25%) per MTCO2E; 70% higher impact per dollar spent on commercial EE. Generally similar in size of impact per dollar spent to curbside recycling, and per MTCO2E, similar to PAYT..	1-3 years to ramp up, each year covers perhaps 1% of customer households
Wind	7-8 times as expensive as commercial EE	Not estimated	Penetration low
Photovoltaic (PV)	18-25 times as expensive as commercial EE	Not estimated	Individual installations achieved quickly; penetration very low
Curbside Recycling	0.6-0.7 time the cost of commercial EE	Lowest of all programs per MTCO2E; highest impact in job creation per dollar spent.	6 months – 1 year; covers all households in area (typical participation 75%)

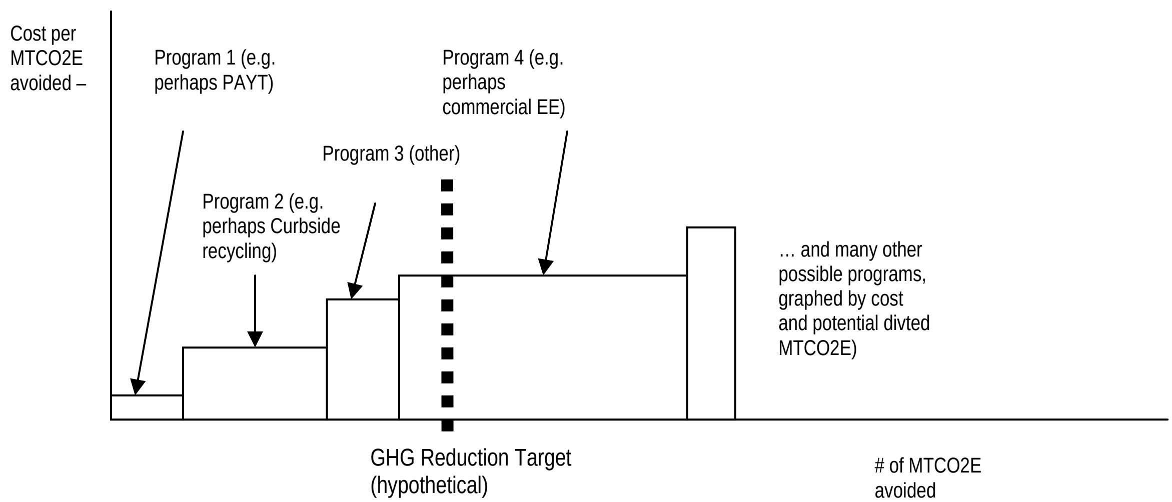
22 And of course, the political discussion required beforehand.
23 The author has reviewed legislation from around the nation and developed template ordinances of this type as part of projects designed to encourage PAYT in communities across the US.
24 And for recycling programs, in many cases, townhouses/ condos or small businesses are also covered. The author's research also finds some communities also require PAYT of businesses.
25 For example, National Public Radio stated that the stimulus package funds may lead to weatherization of 4,000-10,000 homes in Colorado. When PAYT or curbside recycling is introduced in a community, it covers all homes (at least all single family homes). In the State of Colorado, that would translate to about 2 million households ; in the average community in Colorado, that would translate to 4,000 homes.

	Normalized Multiplier for Cost per MTCO2E	Job Creation / Economic Development Impacts	Speed to implement and full scale implementation coverage
Pay As You Throw (PAYT)	0.2-0.3 times cost of commercial EE	High impacts per MTCO2E; impacts per dollar spent comparable to commercial EE programs.	3-9 months after political approval; covers all single family households in area
Organics / com-posting (yard waste & food)	4 times cost of commercial EE	Lower impact per MTCO2E than EE programs; higher than curbside recycling; Per program dollar spent, organics program is least effective.	Similar to recycling – 6 months to 1 year, covers all households in an area (lower participation than recycling)

Comparisons and "Supply Curve" Analysis / Implications

These types of results are very useful in creating cross-media 'supply curves' for strategies to reduce GHG. The horizontal axis represents MTCO2E, and the vertical axis represents cost per MTCO2E. Using the types of computations we have conducted in this paper, a community (or state or other government or company) can graph the MTCO2E available from each of a variety of programs (various energy efficiency options, various solid waste management options, transportation options, and others). The programs are put into the graph with the lowest cost per MTCO2E options on the left, and ramping up to progressively more expensive options. The step function can be used as the "supply curve". Given a demand curve, or more likely, a MTCO2E target (vertical line), then the programs to the left of the line represent the most cost-effective options for reaching the target. Of course, there are complexities with time and other parameters, but this is the basic approach in resource supply curve development in this area.[26]

Figure 6. Hypothetical "Supply Curve" for Avoided MTCO2E from Alternative Programs



Conclusions and Policy Implications

The results indicate that both energy efficiency and solid waste programs are feasible strategies for reducing GHGs and meeting climate change goals. However, they also show that recycling and waste management programs can have distinct advantages over EE programs in terms of

[26] These types of supply curves have been relatively common in the energy efficiency field, but are very uncommonly examined in the solid waste field.

cost per MTCO2E, have strong job creation benefits, and have timing, coverage, and control advantages. Rather than the immediate focus on energy efficiency as the "first tier" programs, our research indicates that the EPA pie chart showing waste management as responsible for only about 3% of GHG emissions provides a misleading indication of the importance of (at least some) solid waste strategies in achieving reductions in GHGs.

Our results on costs, coverage, and timing indicate that when governmental authorities – at the local, state, or federal level – are considering alternative strategies for reaching sustainability and climate change goals, solid waste programs should be included in the "first tier" of programs. Our research finds:

- Recycling and PAYT programs are cheaper per MTCO2E than the standard types of energy efficiency programs;
- These programs can be implemented relatively quickly,[27] and when implemented, they immediately cover ALL households, not just a fraction of the customer base as we find in most energy efficiency programs; and
- Solid waste programs are often more directly in the control of many communities and jurisdictions that may be responsible for meeting air quality or other "green" or sustainability goals.[28]
- Job creation is stronger in all these programs than the options of not conserving resources (e.g. generating electricity or landfilling rather than recovering materials).
- When considering the methane impacts of solid waste landfilling, the benefits of solid waste programs are even more dramatic, and are "front-loaded" in time with the largest impacts occurring in the first 20 years (not evenly spread at lower levels over 100 years). This enhances the case that solid waste programs should be among the early strategies implemented.
- The updated EPA figures on GHG sources (Figure 3) shows "provision of goods and materials" is the leading contributor to GHG emissions. This indicates the precursors to solid waste (efforts that can be avoided or reduced through recycling and reuse and other solid waste programs) are multiple times more important than the 3% share indicated in the traditional view presented in Figure 1.

In conclusion, GHG impacts from recycling and solid waste programs can be measured and valued. Most importantly, they can be compared to the cost of achieving similar emissions benefits from other programs. When compared, it becomes clear that rather than being secondary strategies, some specific waste diversion programs should be among the first tier of strategies implemented at the community, county, or state level.[29] Solid waste programs can represent a quick-hit part of the mix that provides GHG reductions as energy efficiency programs ramp up.

Although the purpose of this paper is not to minimize the importance of energy efficiency or renewables programs for reducing GHG, the results indicate that solid waste planners should be "in the room" when climate change strategies are being crafted to make sure that Plans include appropriate solid waste options in the mix. Based on this research, solid waste programs

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[27] More quickly than many standard energy efficiency programs, and much more quickly than many of the transportation strategies we have been examining as part of this on-going research.

[28] And note both EE and recycling programs have strong economic benefits over, respectively, power generation and landfilling. Computations of some of these effects are found in Skumatz and Gardner 2006. Work at the state level differs, depending on local industrial mix. See Skumatz And Freeman 2008.

[29] Obviously, as we assess other programs, there will be very high cost waste management strategies as well – ones that exceed the cost of the several EE programs included in this paper.

should potentially be included as cost-effective, big-bang, and “quick hit” set of strategies toward GHG reductions.

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