Working Papers

Program on Solid Waste Policy

Working Paper #1

DOES THE SOLID WASTE MANAGEMENT HIERARCHY MAKE SENSE?

A Technical, Economic and Environmental Justification for the Priority of Source Reduction and Recycling

by

John Schall

October 1992

School of Forestry and Environmental Studies

Yale University

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>
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Abstract

This paper examines the technical, economic and environmental justification for the solid waste management hierarchy. The hierarchy ranks waste management methods, prescribing that it is best to reduce the generation of waste at the source, then to recycle and compost what cannot be reduced, and finally to incinerate or landfill the remainder. While the hierarchy has received widespread support from environmentalists, industry groups and elected officials, over the past two years critics have attacked its extensive reliance on source reduction and recycling as misguided and expensive. This paper provides conceptual grounding and systematic empirical support for the priority of reduction and recycling and argues against several claims by the hierarchy's critics.

Managing waste has effects on both the solid waste system and the production system (i.e., industries that extract raw materials and manufacture products and packages). This paper identifies a series of solid waste and production system questions that must be addressed to determine the validity of the solid waste hierarchy. It uses several major research studies conducted by the Tellus Institute as well as industry data and reports to answer the questions posed. A key component of this research is the development and application of a methodology for estimating the monetary value of the environmental impacts of various types of pollution that occur in both production and waste management. By combining what would otherwise be "unpriced" environmental impacts with the conventional costs of collecting, processing and disposing of waste, a full cost comparison of options is made possible.

The paper argues that following the hierarchy is a technically feasible, cost-effective and environmentally desirable approach to managing solid waste. It shows that source reduction produces significant cost savings for the solid waste management system. Using data from the tri-state metropolitan New York City region, an area that includes 8% of the U.S. population and 10% of the U.S. municipal waste stream, the cost savings are shown to be approximately $100/ton of waste prevented, or 70% of the average cost of managing a ton of waste in the region's solid waste system. Further, the environmental impacts avoided by preventing the generation of waste through source reduction activities are almost twice as large as the conventional cost savings.

Recycling (and composting) up to 50% of the remaining waste is shown to be the next most beneficial waste management method. The findings show that, in the region studied, it is technically feasible to recover this quantity of waste in recycling and composting programs at a cost no greater than the cost to operate a disposal-only solid waste system. Further, the environmental impacts of the recycling-intensive approach are no greater (but no less) than the disposal-only approach when the solid waste management portion of the system is examined.

The greatest benefit from pursuing a reduction- and recycling-intensive waste management strategy, however, occurs in the production system. Using materials recovered from the waste stream instead of virgin resources as raw materials in manufacturing has significant environmental benefits. The utilization of 50% of the waste stream as raw materials is technically feasible and would reduce environmental impacts from materials production by nearly $1 billion per year in the study region. The paper also suggests, from as yet incomplete data, that the economic cost of increasing the utilization of recycled content in production processes is not prohibitive.

Thus, managing waste according to the hierarchy reduces costs and environmental impacts in the solid waste system. Further, it significantly reduces the environmental impacts arising from production. The paper concludes by examining the applicability of these results for the United States as a whole and argues for the need to address solid waste management as part of larger national resource policy in order to implement the hierarchy successfully.

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There were many organizations that helped to fund the research described in this report. These include the U.S. EPA, the U.S. Congressional Office of Technology Assessment, New Jersey Department of Environmental Protection, the Council of State Governments, the New York City Department of Sanitation, the Regional Plan Association of New York City, the Rockefeller Brothers Foundation, the New York State Energy Research and Development Authority and the California Integrated Waste Management Board. However, none of these organizations contributed directly to this working paper nor bears responsibility for its contents.

I would also like to thank Marian Chertow, Reid Lifset, and Jane Coppock of Yale University's Program on Solid Waste Policy for their interest and feedback. Hannah Holmes from *Garbage Magazine* provided major editorial assistance. Finally, many of the ideas, concepts and arguments presented in this paper were developed in discussions with Jeanne Wirka while she was at the Environmental Action Foundation. Her contribution to my thinking about solid waste management and materials policy has been invaluable.

Note to the reader: Minor differences exist between the September and October versions of this working paper because of typographical and editorial corrections made primarily to Tables 2, A.1 and A.2 and to figures in the text on page 42. These changes do not affect the meaning or argument of the paper.

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Introduction The Problem with Integrated Solid Waste Management

The prevailing paradigm for managing solid waste was born some twenty years ago when the environmental movement first developed a critique of the practice of disposal-based solid waste management. According to the disposal-based paradigm, garbage was viewed as one homogeneous mass that should be collected, compacted and buried or burned. The new paradigm argued that garbage was instead made up of several different components, and depending upon the physical, technical, and economic characteristics of each component, it should be handled by different types of solid waste management methods: some parts of the waste stream simply should not be generated; other parts have physical properties that make them technically and economically feasible to recycle; some parts can be composted; some can produce energy; and some parts of the waste stream can only be buried. The job of responsible solid waste management, what became known as "integrated solid waste management," is to develop the collection programs and processing facilities that appropriately address each of these waste stream components in the most cost-effective and environmentally beneficial way.[1]

In the last five years, the paradigm of integrated solid waste management has completely dominated the discourse of solid waste planners and practitioners. However, interpreting exactly what it means in practice produced two major competing viewpoints.

One interpretation of integrated solid waste management was that it was a "menu of options" for managing solid waste that included reduction, recycling, composting, incineration and land disposal. It was not a question of good or bad waste management options or technologies. Rather, each option was equally appropriate under the right set of conditions addressing the right set of waste stream components.

A second, and ultimately dominant position, said this is not just a menu of equal options, rather it is a "hierarchy" of options. According to this hierarchy we should *maximize* the amount of waste that is prevented at the source, and then *maximize* the amount we recycle or compost, and only burn or bury the remainder.[2] The implicit, underlying assumption behind this hierarchy was that it was most cost-effective and most environmentally sound to handle waste in this prescribed hierarchical order. However, this implicit assumption was never subjected to a technical, economic and environmental validation. Rather, it simply became the politically dominant position. The factors which produced this dominance are discussed in Section 1.

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[1]Some environmentalists of the late 1960s and early 1970s would have argued simply for less consumption and for total recycling, with no role whatsoever for incineration or land disposal. However, this position was not generally accompanied by an operational plan for actually addressing the problem of solid waste.

[2]Sometimes, as in the U.S. Environmental Protection Agency's *The Solid Waste Dilemma: An Agenda for Action* (EPA 1988a) recovering energy and land disposal are on the same level. Sometimes, as in New York State and Massachusetts State legislation, incineration with energy recovery is placed "higher" than land disposal. Some environmental organizations, e.g. most state Public Interest Research Groups, do not support incineration under any circumstances. Although the research on which this paper is based sheds much light on the incineration/landfill debate, this issue will not be addressed in this paper. Likewise, I have not distinguished between reduction and reuse. For the purposes of this paper, the term source reduction refers to both of these means of preventing the generation of waste.

The existence of this political dominance is, however, undeniable. It is most clearly demonstrated by the fact that almost every state in the U.S. has enacted legislation that endorses this solid waste hierarchy. This endorsement takes the form of percentage mandates or goals of up to 70% of the wastestream for both of the first two steps of the hierarchy -- reduce and recycle.[3] This is the reason that the questions required to address the technical, economic and environmental rationality of the solid waste hierarchy were never asked, much less answered. Over the last five years the hierarchy has made political sense, and that has been sufficient to win the day, at the local, state and federal levels.

However, in reviewing the practice of integrated solid waste management over this period, we can discover three intractable problems that have made implementing the solid waste hierarchy problematic at best. These are:

1) the inability of solid waste managers to implement source reduction programs that effectively reduce the production of materials that end up as waste;

2) the inability to develop adequate markets for the materials that are being generated as progress is made toward realizing state and national percentage recycling/composting goals; and

3) the difficulty of structuring the public/private sector relationship so that the legitimate public sector objectives of creating recycling and composting capacity, minimizing disposal capacity, and minimizing cost and environmental impacts can best be realized through combined public and private sector activities.

Solid waste managers have been unsuccessful at creating source reduction programs, because to insure that less waste is created, they must insure that less output (the ultimate source of garbage) is produced. But those who manage waste are not the same as those who manage production. Decisions about what to produce, what to make products from, and what to package them in have historically been made by product manufacturers who respond to market-based pressures. Only recently have solid waste managers tried to intervene actively in the workings of the market to help create source reduction outcomes. However, how to undertake this intervention is still not well understood, and largely ineffective.[4]

Solid waste managers have at the same time been equally unsuccessful in addressing real market development issues. Specifically, if the hierarchy is right, then "real market development" means market development that is consistent with source reduction. In other words, it must be

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[3]For a listing of state by state goals and legislation see Glenn (1992).

[4]Three of the more important attempts to promote source reduction have taken the form of legislation: the Coalition of Northeast Governors, Source Reduction Task Force, Model Legislation; a bill introduced by several of the state Public Interest Research Groups including the ones in Massachusetts, New York and Oregon (in Massachusetts it is H.B. 4003); and the Senate Resource Conservation and Recovery Act reauthorization bill S 976. For an analysis of these three pieces of legislation, see Tellus (1992a). Several hundred pieces of "source reduction" legislation have been introduced since 1987. For a list of these bills, contact the American Paper Institute in Washington.

market development that does not result in new "stuff" being made out of the increased supply of secondary materials,[5] but rather that insures products and packages formerly made of virgin resources are replaced with those made from the new supply of recyclable materials generated by the emerging municipal recycling programs. To accomplish this task, some markets must be developed (e.g. markets for recycled fiber) and some markets must be undeveloped (e.g. markets for virgin pulp made from trees). As with source reduction, insuring real market development means influencing the decisions made by product manufacturers, not solid waste managers.

Finally, if it is optimal from a public sector position to recycle and compost 50 or 60% of the waste stream, why is the private sector not reacting to this "opportunity" and creating this recycling and composting capacity?[6] How should public and private sector behavior be structured so that socially optimal outcomes are produced by the interaction of public and private sector activity? Attempts to resolve these three problems dominate the journals, conferences and meetings of the solid waste management field.[7]

In large measure because solutions to these problems have not been found, the "menu of options" school of integrated solid waste management has had a real revival in the last two years. This revival first appeared as an attack on "irrational," "uneconomic," and even "environmentally damaging" waste reduction and recycling programs.[8] In its place, the "menu of options" school argued that source reduction should be decided by the market-based outcomes of consumers expressing their preferences and producers pursuing profit and that recycling, good up to a point, is over-extended and largely uneconomical. The real solution, this theory says, is to site more comparatively inexpensive landfills and incinerators.[9]

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[5]"Secondary materials" is used throughout this paper to refer to both the materials that are recovered from the waste stream through solid waste recycling programs and to the materials when they are used as inputs in production processes. Likewise, "secondary production" refers to production facilities that utilize these recovered materials.

[6]As discussed in footnote #14, recycling rates have increased nationally from 10% to 17% in the last 2 years. However, they are nowhere near the 40-60% "targets" many states now have. Many argue it is because the targets are wrong. This is precisely the issue that is explored in this paper.

[7]Refer to any of the major solid waste industry publications such as *Resource Recycling*, *Biocycle*, *Waste Age* as well as any of the proceedings from recent industry conferences such as the EPA's "Second Annual Solid Waste Management Conference," in June 1992 or the National Recycling Coalition's "Eleventh National Recycling Congress and Exposition," September 1992.

[8]"The Similarity of Environmental Impacts from All Methods of Managing Solid Waste" (Visalli 1989) was one of the first explicit attacks on the validity of the solid waste hierarchy from an environmental perspective. Several stories in the Spring of 1992 have appeared in the national press, including the *New York Times*, *Washington Post*, and *Wall Street Journal* discussing the "irrationality" of recycling. A similar theme has also been the subject of two major network television programs in the spring of 1992. CBS news devoted a 7 minute segment of its national evening news program on Tuesday June 9, 1992 to "exposing" the "irrationality" of many municipal recycling programs, including Seattle's. A month earlier The MacNeil/Lehrer Report explored a similar theme.

[9]The level of recycling supported by the menu of options school is mostly that level which has always been occurring as a result of the activities of private sector scrap dealers together with some minimal amount of municipal recycling. Three of the more clearly articulated arguments for embracing the menu of options integrated waste management approach are "Waste Disposal: A Miracle of Immaculate Consumption?" (Starr 1991), "Integrated Waste

There are two fundamental mistakes made by the supporters of the "hierarchy" school of integrated solid waste management that have left them open to attack by the menu of options school, and more importantly, have prevented them from taking advantage of their original success. The first is that the political justification of the solid waste hierarchy has lasted far too long. Having nothing more than a political justification, the hierarchy supporters have been unable to defend themselves from economic hard times and a political backlash. By failing to understand the underlying technical, economic, and environmental justification for the solid waste hierarchy, its practitioners were largely defenseless when claims of "technical infeasibility" and "economic irrationality" were thrown their way.

The second, and in many ways more significant, problem facing the defenders of the solid waste hierarchy is that the paradigm of "integrated solid waste management" does not provide its practitioners with the tools needed to address the problems that have been produced by its attempted implementation. Demonstrating that the solid waste hierarchy makes technical, economic, and environmental sense is only the starting point. If the solid waste hierarchy is right, then its practitioners must overcome the problems that prevent real source reduction measures from being implemented. They must create real market development. And finally, they must insure that a solid waste infrastructure is developed that will facilitate levels of recycling/composting that are deemed technically feasible and cost-effective, whether they be 40% or 70%. However, to do this requires that solid waste managers think about this problem not as managing garbage, but rather as managing resources.

To do this, the problem of garbage must be approached from both a solid waste *and* production system perspective. If solid waste managers are going to maximize source reduction, they need to affect decisions made by the product manufacturers who decide what to produce, how much to produce, and what to use as raw materials. If they are going to recycle 50-60% of the waste generated, they need to insure 50-60% of the products and packaging manufactured use this same secondary material. Once again, currently these are resource management decisions made by production managers, not solid waste managers. If the objectives of the solid waste hierarchy are legitimate, materials, not garbage need to be managed in an "integrated" manner, both those recovered from wastes and those made from virgin resources. Implementing source reduction programs and creating real market development opportunities means addressing solid waste from both a solid waste and production system perspective, as part of an overall materials policy.

It will be the objective of this working paper to address the first of these two issues - is there a technical, economic and environmental justification for the solid waste hierarchy? I will do this using several industry and government sources, but will rely mainly on the results of $3 million worth of research conducted over the last four years by the Tellus Institute, a non-profit, public interest research organization in Boston, Massachusetts. During the period in which this research was conducted, I was Co-director and later Director of the Solid Waste Group at Tellus.

Management: Rethinking Solid Waste Problems and Policy Options," (Scarlett 1991) and "Major Issues Facing Solid Waste Management in the 1990's," (Zandi 1991). A less sophisticated version of this position can be found in the publications of the Citizens for the Environment, especially "How to Manage America's Trash: Private Solutions to a Public Problem," (Logomasini 1991).

Section 1 argues why the problems that produced the solid waste crisis (and with it the need for a new way of managing garbage), will not go away. Section 2 identifies the eight subsidiary questions that are required in order to answer the overall question, "Does the solid waste hierarchy make sense?" Section 3 describes the research that was undertaken to answer these eight questions. Section 4 answers the solid waste system questions. Section 5 answers the production system questions. Section 6 summarizes the major findings presented in this paper. Section 7 explores whether these findings can be generalized across the United States as a whole. Finally, Section 8 provides an overall conclusion and a discussion of the issues that must be resolved if source reduction and recycling are to succeed.

The problems described above that have confounded solid waste managers as they have attempted to implement the solid waste hierarchy must be addressed or the justification for the hierarchy provided in this paper will be moot. As the research described here will show, these problems have been intractable not because the solid waste hierarchy cannot be justified on economic and environmental grounds. Rather, these problems have not been solved because solid waste managers are trapped within the limitations fostered by the use of the integrated solid waste management paradigm and the solid waste system on which it focuses. To date, solid waste managers have neither developed nor used the tools required to bring about needed changes in our national resource policy -- changes that would not only make the solid waste hierarchy achievable, but would also incorporate solid waste issues into the larger issue of sustainable resource management. To do this, however, solid waste managers must better understand when the market place works and when it does not work with respect to solid waste management in particular and resource management in general.[10]

[10]These are issues which I will begin addressing in a forthcoming paper.

Section 1 The Crisis in Solid Waste Management and the Rise of the Integrated Solid Waste Management Paradigm

The new paradigm of "integrated solid waste management," given birth by the environmental movement of the late 1960s, was studied in great depth throughout the 1970s.[11] However, during this time it never caught on with the state and local solid waste managers whose job it was to collect and dispose of the 200 million tons of garbage generated each year in this country[12] because there was neither economic nor regulatory pressure to change.[13] These solid waste officials already knew how to collect, compact and either burn or bury their garbage in the still-available municipal incinerators and landfills.[14] Thus, from the early 1970s until the mid-1980s the new paradigm of integrated solid waste management lay dormant while the old disposal-based paradigm dominated the practice of solid waste management. Two types of recycling took place during this period, one driven by community-based non-profit organizations, the other driven by the already-existing scrap industry. The first effort was laudable but largely ineffective due to a lack of resources. The second handled material that had not traditionally been part of the municipal solid waste stream such as car hulks, printer waste, and industrial scrap metal.

However, in the mid-1980s the shift away from a disposal-based solid waste management system began to develop in hothouse fashion because of an emerging waste management crisis. The problem with the old way of *thinking* about solid waste was that it produced a three-fold crisis in the *practice* of solid waste management. This was a crisis of contamination, cost and capacity.

The reality of this three-fold crisis has been extensively documented in the last five years. With regard to contamination, landfills represent 22% (184 out of 850) of the sites on the Superfund list (OTA 1989, 271). Ground water supplies have been impacted by landfills throughout the country (OTA 1989, 285-286). The cost of disposal has risen dramatically, not only throughout the Northeast but in other areas of the country as well.[15] In addition, from the late 1980s until the current

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[11]Much of this research is summarized in several reports to Congress by the U.S. EPA, Office of Solid Waste Management Programs, issued throughout the 1970s (U.S. EPA 1974; 1975; 1977; 1979).

[12]The U.S. EPA, through work conducted by Franklin Associates, has estimated total municipal solid waste at 196 million tons in 1990 (U.S. EPA 1992).

[13]The federal solid waste regulations were contained in the Resource Conservation and Recovery Act of 1976 (RCRA), Subtitle D. The office that was created to develop and enforce these regulations shrank from a staff of 74 with a budget of $29 million in 1979 to a staff of 1 and a budget of $320,000 in 1981 (Blumberg and Gottlieb 1989). For a discussion of the original intent of RCRA on solid waste, see Kovacs and Klucsik (1977).

[14]In 1970, 93% of all waste was landfilled or incinerated, 1975 - 93%, 1980 - 91%, 1985 -90%. Thus, recycling grew from 7% to 10% during this 15 year period, an increase of 3%. From 1985 to 1990 recycling grew from 10% of the total U.S. waste stream to 17%, an increase of 7% of the total waste stream, but a 70% increase in recycling. The average annual increase during the 1985-90 period was 700% (or seven times) the average annual increase during the 1970-85 period (U.S. EPA 1990a; 1992).

[15]Annual surveys of 72 municipal landfills by the National Solid Waste Management Association show that between 1982 and 1988, the average cost to dump wastes throughout the country more than doubled - from $10.80 per ton to $26.93. Ten-fold increases are common in the Northeast and the upper Midwest.

recession, the cost of solid waste management was one of the most rapidly increasing items in many municipal budgets. Finally, the number of landfills, and more importantly, the capacity of those remaining to take the 750,000 tons of waste generated each and every day are rapidly diminishing.[16]

This is the set of historical circumstances that have produced the transition to a new way of thinking about and managing solid waste. Furthermore, it appears highly likely that the conditions which created this crisis will not soon disappear. It is possible that increased regulatory controls can minimize the impact of contamination created by burying and burning solid waste.[17] It is also possible that states could choose to control costs by regulating the pricing practices that have allowed unchecked rates of return to accrue to the private owners of what are often monopoly resources (i.e., landfills and incinerators) producing an acknowledged public good.[18]

The crisis of capacity, however, will be difficult to overcome. Solid waste disposal facilities, whether they be landfills or incinerators, will never be welcomed neighbors - they will always be unwanted though inevitable necessities that only get developed through long, arduous, public siting battles. The control that local public bodies (boards of health, city councils, etc.) have over siting decisions insures that siting outcomes will always be difficult and, consequently, disposal capacity will always be scarce. Thus, minimizing the amount of disposal capacity will always be an objective not only of solid waste managers and politicians, but of ordinary citizens as well.[19]

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[16]The EPA has estimated that 14,000 out of approximately 20,000 landfills have closed since 1978. More importantly, of the remaining 5,499 in 1988 with yearly capacity of 187 million tons, only 1,234 will still exist by 2008 with yearly capacity of only 35 million tons (U.S. EPA 1988b). The exact magnitude of the projected capacity shortfall in the United States is a subject of big debate and little data.

[17]As the data presented in Section 4.3 shows, when state-of-the-art environmental controls are used on both landfills and incinerators, the environmental impacts of burning and burying most materials are relatively small, especially compared to the impacts of manufacturing those same materials.

[18]Costs associated with solid waste management pose an interesting paradox. The costs of incineration and landfilling are underpriced because the costs associated with the environmental impacts of operating landfills and incinerators and the costs associated with landfill depletion are often excluded from the "price" of utilizing these facilities. On the other hand, when disposal facilities are privately owned, and when communities do not have adequate disposal options, tipping fees at these same facilities can be too high because of the monopoly prices accruing to the private owners of what are essentially regional monopolies. There are two solutions to this problem. One is to site more disposal facilities to ensure competition, while simultaneously applying regulatory controls that would force them to charge for "externalities." The second is to economically regulate these natural monopolies (as if they were public utilities) in order to insure only the absolute minimum are sited, the right mix is created, while simultaneously preventing monopoly prices. See Scarlett (1991) for an argument for taking the former course. I will argue in a subsequent paper, "Solid Waste, Materials Management and the Economics of Market Failure" for the latter solution.

[19]Many solid waste and materials manufacturing industry commentators in conference presentations like to point out the fallacy of the "capacity crisis" by putting on an overhead projector a map of the United States and pointing out a tiny dot (usually some place in Kansas or Oklahoma) that is in fact 20 miles long and 20 miles wide and 300 ft deep and could hold all of the waste generated in the United States for 100 years. It is commonly found in the standard recycling backlash article as well (Logomasini 1991 and Scarlett 1991). This type of comment completely misinterprets the nature of the "capacity" crisis by ignoring the political complexity of siting conflicts. Several recent books have described this complexity and argued that it is intractable. See, for example, Portney (1991).

Thus, resolving the problems that confront integrated solid waste management, the problems that have prevented it from realizing its source reduction and recycling promise of the last five years, is an undertaking of major importance. To summarize from the introduction, this involves two steps. The first is exploring whether a technical, economic and environmental justification of the solid waste hierarchy from both a solid waste and production system perspective can be satisfactorily provided. The second will be both to explore the solutions to the problems that have plagued the implementation of the solid waste hierarchy, and to develop the framework that is required to generate those solutions.

The remainder of this working paper will address the first issue, "Does the solid waste hierarchy make sense?"

Section 2 What Are the Questions Required to Test the Validity of the Solid Waste Hierarchy?

We can only answer the question "Does the solid waste hierarchy make sense?" by first identifying a series of subsidiary questions that will help us frame this issue in its non-political context. These questions, as the discussion above would lead us to believe, will include both solid waste system and production system components.

2.1 Source Reduction Questions

Determining whether source reduction belongs at the top of the hierarchy requires that we understand both the solid waste system *and* the production system impacts of realizing the source reduction goal or target. This requires addressing two questions.

1. When waste is prevented through source reduction activities, how much money does the solid waste system save in avoided collection, processing and disposal system costs?

2. What are the environmental benefits realized by the reduced collection, processing and disposal of waste and recyclables, *and* what are the environmental benefits obtained by avoiding production of these materials to begin with?[20]

2.2 Recycling Questions

To determine whether recycling belongs next in the hierarchy requires we ask three solid waste system questions and three production system questions. As a proxy for "maximizing" recycling and composting I have used a 50% goal, which is now simply a mid-range recycling target, currently part of proposed RCRA reauthorization legislation, and found in several states, including California. Some states, such as New Jersey (60%) and Rhode Island (70%), have higher targets. I am not here addressing the question, what is the highest feasible recycling rate. Rather, I am exploring whether or not at least a 50% rate is technically, economically, and environmentally feasible.[21]

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[20] There is a third type of cost savings associated with source reduction practices that I am not discussing here. That is the cost to consumers of purchasing excessively packaged products, and products with short life spans. Work by Ligon (1991) has shown that excessive packaging increases the price of consumer products by anywhere from 9% to 1531% per unit of product delivered. The Minnesota Office of Waste Management in St. Paul has also done interesting work measuring this potential financial benefit to consumers from implementing source reduction practices. These results are published in a series of brochures about their S.M.A.R.T. (Saving Money and Reducing Trash) Shopping Campaign.

[21] For a critique of existing literature attempting to estimate "maximum" feasible recycling rates see Section 4.1 below.

2.2.1 Questions Concerning Recycling's Impact on the Solid Waste System

The solid waste system questions that need to be answered to determine whether realizing this goal makes sense are:

3. Is a 50% recycling level technically feasible? Are there enough materials in the waste stream with the physical properties that allow them to be reused as raw materials in production processes? Do the participation programs exist to get them out of the waste stream and at the curb or drop-off center? Do the collection systems exist to collect them? And finally do the processing facilities exist that can turn them back into raw materials available for use in secondary production processes?

4. Is a 50% recycling level economically rational? Is it cost effective to implement the public participation programs, collection systems, and processing facilities described above rather than leaving these materials in the "garbage," picking them up in garbage trucks and hauling them off to the incinerator or landfill?

5. Is a 50% recycling level environmentally sound? What are the differential environmental impacts of implementing the 50% recycling/composting system versus implementing the disposal-only alternative?

2.2.2 Questions Concerning Recycling's Impact on the Production System

Addressing these three questions, however, is not sufficient. If 50% of the waste stream is diverted from disposal, it also means that these same materials must be incorporated into some production process, or else this solid waste system will produce the irrational result of burying or burning processed recyclables.[22] Thus, we must also ask these same three questions from a production system perspective.

6. Is it technically feasible to incorporate the materials that make up this 50% of the waste stream in secondary production processes across the country and the world?

7. Is it environmentally beneficial to utilize 50% secondary content instead of its virgin material alternative, in each of the various production processes that would be the consumers of this secondary material?

8. Finally, does it make economic sense for production facilities to utilize, on average, 50% secondary content, once again, compared to its virgin material counterpart?

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[22]A common component of the argument used by the menu of options school of integrated waste management (Scarlett 1991, Zandi 1991, and Logomasini 1991) is to cite isolated cases of cities or towns having to give away or even dispose of their collected recyclables because markets were not available to absorb them as an example of the irrationality of recycling. The "disposing of recyclables" might, instead, be an example of the failure of the market to create what could be a more socially optimal outcome. In the first case recycling is the problem, in the second market failure is the problem. The evidence presented in this paper provides support for the market failure position.

This is the set of eight questions that must be addressed in order to answer, "does the solid waste hierarchy make sense?", not from a political perspective, but rather from a technical, economic and environmental perspective. Only with answers to this set of questions and only if those answers are in the affirmative, can we go on to analyze the problems that must be overcome in order to implement the solid waste hierarchy. To implement effective source reduction programs, create "real" market development strategies, and insure the institutional arrangements are developed that will create the public/private partnership that will make recycling and composting solid waste programs work requires first determining whether the solid waste hierarchy makes-sense.

Section 3 The Research Conducted to Address The Solid Waste and Production System Questions

There are three major interrelated research projects conducted by the Tellus Institute from 1988 through 1992 that bear directly on addressing this set of questions. These include: the development of a solid waste system planning computer model called *WastePlan*; a comprehensive lifecycle assessment study of 13 different packaging materials; and an analysis of the economic and environmental impacts of several different 20-year solid waste management scenarios for the 20-million-person Metropolitan New York City area. I will present in this paper as much of the methodologies and results from these studies as is required in order to address each of the above eight questions.

3.1 The Development of WastePlan

The first research project undertaken in the process of addressing these issues was the development of a computer software model. This model made possible an analysis of the physical and economic characteristics of alternative systems for managing a given solid waste stream as it grows over a specified planning period. Originally developed for the Congressional Office of Technology Assessment for their study *Facing America's Trash*, the model has since been enhanced and adopted by several states and New York City as their "official" solid waste management planning tool.

To answer a question like, "Is it cheaper to recycle than to burn garbage?" one cannot simply compare the per-ton costs of recycling relative to the per-ton costs of burning. Rather, one needs to understand the impact on the cost of the overall system when recycling programs are either added or expanded compared to the costs when simply collecting and burning and/or burying that same material. One needs to understand the marginal system cost when the tonnage handled by one part of the system is increased and the tonnage handled by another part is decreased. And one needs to understand these effects over the long run.

For example, if a recycling program is added to a disposal-only solid waste system several effects occur. Recycling collection costs increase as recycling trucks are purchased and operated, garbage collection costs decrease as garbage trucks make more stops before filling up and therefore make fewer trips to the disposal site. (Thus, each truck can make more stops and fewer trucks will be needed to collect the same routes.) Furthermore, a recycling processing cost will be incurred with a capital, operating, and revenue component. However, less disposal capacity will also now be required. All of these interactions will depend on many variables, including the different collection program efficiencies of the recycling program compared to the garbage program, the different miles to each respective facility, etc. This system of interactions needs to be captured and accounted for over the entire solid waste planning period in order to evaluate the full cost of changing or adding to any one part of the solid waste system.

WastePlan allows for this analysis of overall system cost when different components of the waste stream are handled by alternative waste management options. This was the basic analytical tool that was used in addressing the solid waste system questions asked above and answered in the work that follows.[23]

3.2 The Tellus Institute Packaging Study

In the Tellus Packaging Study[24] the environmental impacts of producing different types of materials from both virgin and secondary resources and the environmental impacts of processing/disposing of each type of material through each type of waste management option were quantified in monetary terms. This made it possible to answer both the solid waste system and production system environmental questions posed above.

The overall purpose of the study was to measure, value and compare the "life cycle" impacts from the production and disposal of 13 different packaging materials.[25] Broadly understood, there are four sets of costs involved in making any given package.[26] There is one set of costs measured by the marketplace that include all of the "conventional costs" of the land, labor, capital and raw materials that go into producing a package. These are the costs that packaging producers actually incur and pass on to packaging consumers. However, there are three sets of costs packaging and product producers do not pay.

One is the conventional cost of land, labor and capital incurred in managing each of the packaging materials through each stage of the waste management system after its original use is over.

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[23]A more complete description of WastePlan is included as Appendix A.

[24]The Tellus Packaging Study's formal title is *Assessing the Impacts of the Production and Disposal of Packaging and of Public Policy Measures to Alter Its Mix*, Volume 1 and Volume II (Tellus 1992b). This study was conducted over a three year period and was funded by several sources including two offices at EPA, the New Jersey Department of Environmental Protection, and the Council of State Governments. The Council of State Governments provided funds that were given to them explicitly for the study by the states of Rhode Island, New York, Illinois and Minnesota and by the following companies and industry organizations: Dow Chemical, Proctor and Gamble, Sonoco, TetraPak and the Aseptic Packaging Council, the Aluminum Association, the American Paper Institute, and the Council for Solid Waste Solutions. The findings and conclusions expressed in this study are those of Tellus Institute alone, none of the sponsors are responsible for the findings and conclusions expressed in this study, nor do they necessarily agree with them.

[25]The materials studied in the packaging study include high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terepthalate (PETE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC), bleached kraft paperboard, unbleached coated folding boxboard, corrugated cardboard (both linerboard and corrugated medium), unbleached kraft paper, glass, aluminum, and tin-coated steel (Tellus 1992b). "Life cycle assessment" is a methodology that first inventories all pollutant releases from all stages of the production and disposal of a given product, process or material. It also measures the costs of managing the product or material or the residues from the given process through each stage of the waste management system. A life cycle assessment is then supposed to analyze the impact from each of the pollutants inventoried in stage one. The final stage is to suggest ways to remediate the impacts reported in stage two (SETAC 1991).

[26]The structure of the argument that I am about to make is based on the solid waste system and production system impacts of different materials, not of individual packages. Everything I say in this paper about packaging materials, however, could also be said for materials used in making newspapers, office paper, and other consumer products.

These costs will vary depending upon how much of each material is recycled, composted, buried or burned. The total cost for handling each packaging material will be the weighted average of each respective waste management option cost.

There are also two types of environmental cost not paid by the packaging producer. The first is the environmental cost of operating the aforementioned solid waste management system. The second is the environmental cost incurred at each stage of the packaging production process. These last three sets of costs (the convention cost of waste management, the environmental cost of waste management, and the environmental cost of production) are "external" to the cost (and price) of the package. The Tellus Packaging Study measured these three sets of costs for each of 13 packaging materials, including, when possible, the impacts of using virgin resources versus secondary materials in the production process. Following is a brief description of how each of these three "external" costs were measured and the results.

3.2.1 Conventional Solid Waste System Cost

The first external cost, (i.e. cost not paid by either the individual producer or consumer) measured in the Packaging Study was the cost of managing each of the 13 materials through a solid waste management system, based on the percentage of each material that was actually handled by the recycling, incineration and landfill system. The 1990 New Jersey solid waste system was selected as the model to use in this analysis.[27] The result of this stage of the analysis was to identify the increased cost of collecting, processing and disposing of additional quantities of each of the 13 different materials. Table 1 below describes the methodology and its results for the case of glass.[28]

Thus, according to Table 1, 41% of New Jersey's glass was recycled in 1990, 31% was burned and 28% was buried. The marginal cost was $27/ton to collect and process in the recycling program (including a weighted average revenue for green, amber and flint less shipping costs), $107/ton to collect and incinerate,[29] and $93/ton to collect and bury an additional ton of glass. Weighting each respective cost/ton by the percent handled by each respective waste management

[27] The New Jersey solid waste system was selected as the model system for several reasons. Most importantly, the state had the most advanced "integrated" waste management system in the country. In addition, New Jersey was the largest and first funder of the Packaging Study. Since this portion of the Packaging Study was completed, New Jersey has significantly revised its overall state solid waste plan. It is this revised plan which was modelled in the Regional Plan Association study (Tellus 1992c, 1992d) and that is used in this working paper (Section 4.2) to determine the conventional cost of alternative waste management systems.

[28] The additional or "marginal" cost of managing each material was used in the Packaging Study rather than the average cost because the purpose of this study was to determine whether altering the mix of packaging in the waste stream was sound public policy. To do this first required determining whether the use of some packaging materials were superior -- using the three cost criteria described above -- to others. Tellus then determined how the cost of the New Jersey solid waste system would change if some types of packaging increased and other types decreased. This required understanding marginal costs and not average costs.

[29] The incineration facility cost incorporates the revenue obtained from energy sales (for this case zero because glass is noncombustible) and the costs of handling the amount of each ton of material that ends up as ash.

option produces the overall $70/ton "conventional cost" to the solid waste system of managing an additional ton of glass.[30]

Table 1
The Cost of Managing Glass in the New Jersey Solid Waste System

Waste Management Option	Cost/Ton	Percent Handled By Option	Contribution to Waste Management System Total
Recycling System			
Collection	$19/ton		
Recycling Facility	$ 8/ton		
Total Recycling System	$27/ton	41%	$11.07
Incineration System			
Garbage Collection	$13/ton		
Incinerator (w/ashfill and w/energy revenue credit)	$94/ton		
Total Incineration System	$107/ton	31%	$33.17
Landfill System			
Garbage Collection	$13/ton		
Landfill	$80/ton		
Total Landfill System	$93/ton	28%	$26.15
TOTAL COST OF MANAGING GLASS IN SWM SYSTEM		100%	$70.39

3.2.2 Environmental Solid Waste System Cost

The second nonmarket-valued cost or externality created by each packaging material is the environmental impact of handling that material through each respective waste management option. There are air impacts (e.g. carbon monoxide and oxides of nitrogen) that occur from collecting each type of recyclable material. A portion of the truck's impacts each day were allocated to each of the recyclable materials collected based solely on the density of the material. Likewise, there are impacts

[30]The results of this analysis for the other packaging materials are reported in Tellus (1992b), Volume 1, Report 3. As explained below (p.33), since these exact values are not going to be used in the task at hand, I have not included them in this paper.

from collecting solid waste in garbage trucks, and impacts that vary by material for handling waste in each type of solid waste facility. For example, each type of material produces one set of impacts (both air and water) at recycling processing facilities known as MRFs (Material Recovery Facilities) while it produces another set of impacts at landfills or incinerators. Sometimes impacts are a function of volume (e.g. landfills) and sometimes they are a function of weight (recycling facilities and incinerators). Sometimes (in landfills and incinerators) impacts are a function of the chemical composition of the material. Each of the pollutants produced by each material in each collection program and at each waste management facility was estimated in this phase of the Packaging Study.[31]

3.2.3 Environmental Production System Cost

The final externality measured by the packaging study was the environmental impact that occurs from *producing* each of the packaging materials studied in this project. Production stage emissions to the air and water were measured starting with raw material extraction and proceeding through packaging material manufacturing. Impacts were measured from the extraction and production of any raw material used in producing each packaging material so long as it was at least 5% by weight of the raw material mix. Impacts from all energy sources used at each stage of the raw material extraction and packaging material manufacturing process were also included.[32] Next production impacts were measured for each of the 13 packaging materials made from virgin resources. Finally, these production impacts were measured for 6 of the 7 non-plastic materials that utilized secondary or recycled materials.[33]

The end result of this production modelling stage of the study was to identify the amount of each pollutant that was emitted into the air and water from each virgin extraction and production process, and, where available, each secondary production process.[34] At this stage for each packaging material there existed a dollar value for the conventional solid waste management externality and the pounds of each different pollutant emitted by producing each ton of material and by managing each

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[31]The pollutants produced by each waste management facility and each waste collection process, by material, are reported in Tellus (1992b), Volume I, Report 4, Chapter 2.

[32]Due to budget limitations, several components to a full lifecycle assessment were not included in this study. These include: impacts from industrial solid waste, packaging forming, product loading, and impacts from all transportation stages. Many types of environmental impacts were also not measured. These include habitat loss, biodiversity impacts, and worker health and safety impacts. Thus, the absolute magnitude of the full environmental impacts is significantly larger then the results reported here. It was the (untested) hypothesis of this study that the major environmental impacts from the packaging production process occur in the raw material extraction and material manufacturing stages, not in packaging forming or product loading. Whether including these impacts would also change the relative ranking of packaging materials and the ranking of waste management options is an important subject for further research.

[33]Tellus did not have any publicly available data documenting the emissions coming from facilities that produce plastic resins from secondary plastics for any of the six plastic resins studied in this project. Tellus also did not have secondary production impacts data for kraft paper, either bleached or unbleached.

[34]The pollutants produced by each material's production process using both virgin resources and when possible, secondary materials is reported in Tellus (1992b), Volume I, Report 4, Chapter 3.

ton of material through each waste management option. At this point in all previous lifecycle analyses (e.g. Franklin 1989 and A.D. Little 1990) a discussion ensued about the difficulty of comparing different pollutants emitted to different mediums. Rather than trying to address this difficulty, previous researchers claimed to avoid it not by developing relative weighting systems for each pollutant but instead simply added up all of the pounds of each pollutant to create a "total pounds of pollutants."

Of course, this does not eliminate the "incomparability" difficulty - by adding pounds of all different pollutants together, it resolves it by in effect weighting the impact of a pound of each pollutant exactly the same as a pound of any other. This means that one pound of a very toxic pollutant, for example, dioxin would be treated as having the same impact as a much less toxic pollutant such as methane.

The Tellus Packaging Study rejected this approach and developed a pollutant valuation methodology that assigned monetary values to the release of each pollutant based on a combination of or interaction of two different valuation approaches: one based on the marginal cost of pollutant control; the other on the relative health impacts of one "hazardous substance" (see section 3.2.4.3) compared to another.

3.2.4 The Packaging Study Valuation Methodology[35]

Three methods are currently employed to calculate the monetary value of environmental impacts. The first approach attempts to estimate the physical damage associated with the degradation of the environment. This implies tracing the physical environmental impacts and valuing the physical damage. The second approach focusses on consumer preferences and efforts to elicit them. The third approach uses pollution abatement and remediation costs to indicate the value that society places on avoiding environmental damage. This last approach, labelled the control cost approach, was adopted, in a modified form, for the packaging study.[36]

The control cost approach is based on the notion that the additional or marginal cost of each additional unit of pollution abatement rises with the amount of pollution abated.[37] The value that

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[35]Sections 3.2.4 and 3.2.5 have been mostly excerpted from the Tellus Packaging Study. The Tellus staff who worked on developing this methodology include Steven Bernow, Donald Marron, Bruce Beiwald, Karen Shapiro, Frank Ackerman and Irene Peters. Those readers not concerned with understanding the exact details of this valuation methodology can go directly to section 3.2.6 for the results without losing any of the solid waste hierarchy argument being made in this working paper.

[36]See Tellus (1992b), Volume I, Report 4, Appendix 1A for a detailed discussion of each method and the reasons which were used for selecting the pollution abatement and remediation costs method. Several state utility regulatory agencies, including the Massachusetts Department of Public Utilities and the California Energy Commission use the control cost approach in determining the prices to charge for environmental externalities.

[37]Marginal control costs usually increase with the amount of pollution controlled. For example, if a pollution source tries to reduce its emissions with a control device that removes 80% of the pollution, 20% is still emitted. The source could purchase a second device that is the same as the first to further reduce these emissions. The second device would control 80% of the remaining 20%, or 16% of the uncontrolled emissions. Thus, the first device

society places on residual emissions is a point on this rising marginal cost curve. The *highest* amount that is required, or actually observed to be spent on the abatement of a specific pollutant, can be taken as the minimum value that society places on removing this pollutant from the environment (Bernow and Marron 1990). In other words, if society placed a higher value on the pollutants that were actually released than the costs of meeting the current standards, it would increase the standards and require even stricter and more costly pollution control devises. Thus the highest actual expenditure which is associated with the removal of the pollutant is the cost that is ascribed to the presence of that pollutant in the environment.

When society or a community, through its regulations and policies, establishes pollution limits – either through ambient concentrations, air basin aggregates, facility-specific emission caps, technology specifications, or outright bans on certain materials or facilities – it is implicitly establishing its monetary value for the avoided pollution at the margin. Of course, this process of revealing the values and their monetary expression is an evolving one, which depends upon science, public discourse, and policy. Thus, the values may change over time.

The task then is to identify regulations and policies that address the pollutants associated both with waste management and industrial processes, and to determine the costs of complying with these regulations. The pollutants that are typical for waste management and products typically found in the solid waste stream include a host of hazardous substances, criteria air pollutants and greenhouse gases. Each pollutant group and its valuation is discussed below.

3.2.4.1 Criteria Air Pollutants

One class of pollutants encountered in solid waste management and materials production is the criteria air pollutants defined by EPA's Clean Air Act regulations. These include particulates, sulfur dioxide (SO_2), carbon monoxide (CO), ozone, oxides of nitrogen (NO_x), and lead. They impair human health, are ozone precursors, and precursors of acid precipitation. Under the Clean Air Act, the U.S. Environmental Protection Agency has been mandated to develop National Ambient Air Quality Standards (NAAQS) that establish permissible ambient concentrations for these pollutants. Regulatory limits for volatile organic compounds (VOCs) were also established, but only as a reference in regard to the ozone standards. The stated goal of these standards is to protect the public health.

Several studies have been conducted to estimate the costs of meeting these standards. Perhaps the most extensive study has been conducted by the Southern California South Coast Air Quality Management District. The costs established in this study of meeting the standards for criteria air pollutants have been adopted by the California Energy Commission (CEC) in their efforts to include the external, environmental costs of energy production in the price of electricity. Tellus used this work to establish prices for criteria air pollutants (C.E.C. 1990). However, lead has been evaluated below in the hazardous substances category.

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would reduce emissions by 80%, while the second device, which cost the same as the first, would only reduce emissions by 16%. Therefore, for the second device each unit of emission reduction costs more (5 times more) than for the first device.

3.2.4.2 Greenhouse Gases

Another group of pollutants are the greenhouse gases. These are carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), oxides of nitrogen (NO_x), and chlorofluorocarbons (CFCs).[38] The most important greenhouse gas is CO_2. While other gases have a higher warming potential per unit, CO_2 dominates in absolute magnitude all other gases and thus its contribution to climate change impacts.

No regulation exists to date that addresses greenhouse gases. However, the ongoing debate about the greenhouse effect and the apparent willingness of nations to subject themselves to protocols does reflect a concern about the issue of global climate change.

In the absence of regulations and reference doses, one measure that can be used to value greenhouse gases is reforestation, as a means to offset CO_2 production. Trees are a "carbon sink"; they absorb CO_2 and produce oxygen. One can calculate the cost of planting the number of trees required to absorb a certain amount of CO_2 and thus obtain a value for controlling this gas. There are no unique values for the cost of reforestation. Much depends on where the trees will be planted. Reforestation in less developed countries with low wage levels will cost less than reforestation in the United States. The costs also depend on the terrain that the trees are planted in, and other conditions. Clearly reforestation costs can only be interpreted as a placeholder for a more substantive valuation of CO_2. However, the California Energy Commission has developed a value for CO_2 based on reforestation which was adopted for this study (C.E.C. 1990).

Other greenhouse gases can be valued on the basis of the estimate for CO_2. These gases have different impacts in the atmosphere; specifically, they differ in their potentials to produce global warming. While the equivalences of the global warming potentials are not exactly known, there are some estimates as to how these gases relate to each other. The global warming potential of methane, for example, has been estimated to be ten times that of CO_2 (Bernow and Marron 1990). The environmental costs of the greenhouse gases other than CO_2 are calculated as the product of the value of CO_2 and the global warming potential equivalent of the specific gas.

3.2.4.3 Hazardous Substances

The largest group of pollutants falls into the group termed in this study "hazardous substances." These pollutants are neither criteria air pollutants (except for lead) nor greenhouse gases. As many of these pollutants are not regulated in the environment, the cost method used for criteria pollutants and greenhouse gases cannot be applied to this class of pollutants. Therefore, a different approach is needed to evaluate these pollutants. This is where the methodology used in the Packaging Study differs from standard applications of control cost and incorporates a "damage cost" component.

Several complications arise in developing prices for hazardous substances. First, what is the appropriate control cost to determine society's willingness to pay for the control of pollution? In order to fully assess the highest price society is willing to pay, a wide range of regulations impacting

[38]For NO_x and CO which are both criteria air pollutants and greenhouse gases, the criteria air pollutant control costs were used.

hazardous substances must be examined including the cost of controlling hazardous emissions from industrial sources and from the solid waste management system.

Second, when one control device or control measure deals with a group of very different pollutants, the question of how to attribute the joint cost of pollution abatement to individual pollutants becomes an important issue.[39] One potential solution is to find different regulations for different pollutants, and to attribute the cost of a control device to only that pollutant that the device was intended to abate. However, this is quite difficult. Moreover, it is possible that the device was intended to control the full mix of pollutants.

Evaluating the entire body of regulations in place to mitigate emissions of hazardous substances was not possible within the budget constraint of the packaging study. Instead, Tellus investigated control measures impacting lead. As lead is a regulated pollutant, control costs for lead can be determined. Assuming pollutant control costs are proportional to the damage associated with a pollutant, the control cost for lead can then be applied to other hazardous pollutants based upon the relative damage they cause as compared to lead. (The derivation of prices is discussed below in section 3.2.5) This valuation approach therefore combined the control cost approach with a *health effects ranking system*, a system which ranks pollutants according to the relative damage they cause. Specifically, this ranking system establishes equivalencies between individual pollutants, such that the health impacts caused by any pollutant are expressed in proportion to the impacts of any other. In other words, the system establishes a numerical ranking to reflect the relative toxicity of various pollutants.

Construction of such a health-effects ranking system is an extremely complex undertaking. There is no unique catalogue of criteria to be employed. No such system can take account of all environmental impacts of all pollutants. Ultimately, the relative impact of various pollutants depends upon many variables such as their transport in the environment, the exposure of sensitive populations, and the exposure-response relationships of those populations. This type of analysis, which is part of a standard risk assessment, was beyond the scope of the packaging study. Nevertheless, applying such a hazard ranking system is an improvement over the simple averaging of control costs across pollutants with very different potentials for causing environmental damage. Averaging control costs across different pollutants implicitly assumes for example, that one pound of sulfur dioxide has the same impact as one pound of benzene, two pollutants that have very different health effects.

Numerous hazard ranking systems have been developed in the past decade to help establish priorities for those chemicals requiring regulations and further environmental/health effects studies. These studies typically look at a wide range of factors for each chemical including indicators of human health, ecological impacts, yearly production quantities, and release into the environment. Each of these factors is then scored independently, yielding a scoring matrix. Interpreting the matrix can be difficult as it requires judgement, or valuation, of the importance of each factor.

Due to the drawbacks of using risk assessment methods and hazard matrices, a simplified ranking system was developed instead. This ranking system is based upon human health effects only

[39] See also Tellus (1992b), Volume I, Report 4, Chapter 1, Appendix IA for a discussion of this problem (p. 1A-I-8).

(as extrapolated from animal testing); environmental impacts such as habitat loss, biodiversity, and global warming are not considered.

The first step in developing the health effects ranking system was to classify the list of pollutants associated with materials production and disposal into carcinogens (cancer causing pollutants) and noncarcinogens (pollutants that cause toxic health effects other than cancer). The health impacts of these two classes are measured differently, thereby requiring a separate ranking in each class. Pollutants were assigned to these two classes based upon the U.S. Environmental Protection Agency's classification system (U.S. EPA 1990b).

Carcinogenic compounds were ranked based upon each pollutant's cancer potency factor, measured as milligrams of pollutant/kilogram bodyweight/day (see Appendix 2 and U.S. EPA 1990b). This factor is indicative of the relative cancer-causing potential of a pollutant. Isophorone has one of the lowest potency factors of the carcinogenic pollutants associated with materials production and disposal; its potency factor was used as the baseline of comparison for carcinogens. The potency factors of other carcinogens were then compared to isophorone to derive "isophorone equivalents." Thus, for example, the isophorone equivalent for benzene is seven, meaning that benzene is seven times more potent in causing cancer than isophorone.

Noncarcinogenic compounds were ranked based upon each pollutant's oral reference dose (see Appendix 2 and U.S. EPA 1990b). The reference dose, measured as milligrams of pollutant/kilogram of bodyweight/day, is an estimate of the maximum daily level of exposure which will not cause harm.[40] Less toxic chemicals have a higher reference dose since a higher dose is required to elicit an effect. The inverse of the reference dose (i.e., 1/reference dose) was used as the ranking factor so that a smaller number would be indicative of lower toxicity. As xylene has one of the smallest values based upon this scale, it was used as the baseline of comparison. The inverse of the reference dose of all other noncarcinogenic pollutants were then compared to xylene to derive "xylene equivalents.". Based upon this equivalency, lead is 1429 times more toxic than xylene for example.

While the ranking scheme described above allows a long list of pollutants to be compared, the problem remaining is that there are still two disparate groups of pollutants - carcinogenic and noncarcinogenic pollutants. These two groups do not lend themselves easily to comparison. For example, an exposure to even a small dose of a carcinogen still carries a positive, albeit small, cancer risk while theoretically, there is a "safe" dose for noncarcinogenic pollutants. Thus, it is difficult to compare the two groups.

One method that can be used to infer a relationship between the two groups of pollutants is to compare the regulated levels of isophorone and xylene. The only regulations for these two chemicals is in the workplace environment. The Occupational Safety and Health Administration (OSHA) sets permissible exposure levels (PELs) that specify the amount of a pollutant to which a worker can be exposed, averaged over the course of an eight hour workday. The PEL represents the concentration

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[40]While reference doses, or RfDs, may be determined for two routes of exposure - oral and inhalation - in this study noncarcinogens were ranked solely based upon oral RfDs due to the fact that for many pollutants oral RfDs are available in the literature but inhalation RfDs are not. The difficulty in performing inhalation toxicity studies may explain the absence of inhalation RfDs for many pollutants.

of a pollutant to which daily exposure will not incur an adverse health effect in exposed workers. OSHA has set a PEL of 100 parts of xylene per million parts of air (ppm) and a PEL of 25 ppm for isophorone.

The unitless exposure limits expressed in ppm can be converted to milligrams of pollutant per cubic meter of air. For xylene, a PEL of 100 ppm corresponds to 433 mg/m^3 and for isophorone, a PEL of 25 ppm corresponds to 141 mg/m^3. This implies that a "safe" dose of xylene is three times the "safe" dose of isophorone. On the occupational health standards basis, isophorone has a xylene equivalent of three. A carcinogen such as benzene, with its isophorone equivalent of seven (as cited above), then has a xylene equivalent of 21. Tellus used this approach to express all carcinogens in terms of xylene equivalents, producing a unified ranking for both types of hazardous substances. In addition, a factor of three has been used to weight the isophorone equivalents to reflect the fact that a given dose of a carcinogen is not equivalent to the same dose of a noncarcinogen. Table 2 displays the aggregate ranking system. It is important to note that this aggregate system presents *relative* values - that is, it allows relative comparisons between pollutants. Some pollutants in this table can cause both carcinogenic and noncarcinogenic health effects. To determine the combined ranking for these pollutants, the xylene equivalents and the weighted isophorone equivalents for the pollutant were averaged. Thus, from Table 2 we can conclude that cadmium, which has a combined ranking score of 4,350 is 3 times worse than lead which has a combined ranking score of 1429.

Problems arise when using PELs to compare chemicals. Since they are developed for use in the workplace, and workers are typically relatively healthy adults, PELs may not reflect the effect of hazardous substances on more sensitive members of the population such as children, the elderly, or those with compromised health.

Other methods were also explored for ranking and comparing carcinogens and noncarcinogens. For example, in addition to PELS, other indices are used in evaluating pollutants in the workplace. The American Conference of Governmental Industrial Hygienists (ACGIH), a non-governmental independent organization, issues Threshold Limit Values (TLVs), similar to PELs, which specify the amount of a pollutant to which a worker can be exposed, averaged over an eight hour workday. As TLVs are *recommended* rather than regulated concentrations, this index was not used. Other worker-related indices such as short term exposure limits (STELs) and immediately dangerous to life and health (IDLHs) are only established for a small number of chemicals and are thus not useful for evaluating the wide array of chemicals emitted from the production and disposal of materials.

Other regulations affecting pollutants were also explored. For example, the Safe Drinking Water Act sets maximum concentration levels (MCLs) for pollutants in community water systems. To date, MCLs have only been set for a handful of pollutants. Likewise, the Clean Air Act regulates toxic air pollutants; but again, only a small number of these pollutants has been regulated to date.

Table 2
Hazard Ranking System

Pollutant	Carcinogens Isophorone Equivalents	Noncarcinogens Xylene Equivalents	Combined Ranking [1]
Acenapthene		33	33
Acenapthylene	[2]		
Acetone		20	20
Acetophenone		20	20
Acrylonitrile	138		415
Aluminum			
Ammonia		2	2
Anthracene		7	7
Antimony		5000	5,000
Arsenic	12821	2000	20,231
Barium		40	40
Benzene	7		22
Benzo(a)anthracene			
Benzo(a)pyrene			
3,4-Benzoflouranthene			
Benzo(k)flouranthene			
Benzo(ghi)perylene			
Benzoic Acid		0.5	0.5
Beryllium	1103	400	1,854
Biphenyl		40	40
Bis(2-ethylhexyl)phthalate	4	100	55
1,3-Butadiene	462		1,385
2-Butanone			
Butyl benzyl phthalate		10	10
Cadmium	1564	4000	4,346
Carbon disulfide		20	20
Carbon tetrachloride	33	2857	1,479
Chlorine			
Chlorobenzene		100	100
Cloroethane			
Cloroform	2	200	102
p-Chloro-m-cresol		1	1
2-Chlorophenol		400	400
Chloroprene		100	100
Chromium		2	2
Chrysene			
Copper		54	54
Coke oven emissions			
p-Cresol		40	40
Cyanide		100	100
2,4-D		200	200
4,4-DDT	2.49E-03	4000	2,000

Table 2
Hazard Ranking System
(continued)

Pollutant	Carcinogens Isophorone Equivalents	Noncarcinogens Xylene Equivalents	Combined Ranking [1]
Dibenzo(a,h)anthracene			
1,4-Dichlorobenzene	6	3	11
Dichlorobromomethane			
1,1-Dichloroethane		20	20
1,2-Dichloroethane	23		70
1,1-Dichloroethylene	154	222	342
1,2-trans-dichloroethylene		100	100
2,4-Dichlorophenol		667	667
1,2-Dicloropropane	17		52
1,3-Dicloropropene	46	6667	3,403
Diethyl phthalate		3	3
2,4-Dimethylphenol		100	100
Dimethyl phthalate		2	2
Di-n-butyl phthalate			
4,6-Dinitro-o-cresol			
2,4-Dinitrotoluene	174		523
2,6-Dinitrotoluene	174		523
1,2-Diphenylhydrazine	205		615
Endosulfane sulfate			
Ethylbenzene		20	20
Ethylchloride			
Ethylene oxide	90		269
Fluoranthene		50	50
Fluorene		50	50
Fluoride		33	33
Hexachlorobenzene	410	2500	1,865
2-Hexanone			
Hydrogen chloride			
Hydrogen fluoride			
Hydrogen sulfide		667	667
Indeno(1,2,3-cd)pyrene			
Iron			
Isophorone	1	10	7
Lindane		6667	6,667
Lead		1429	1,429
Magnesium			
Manganese		10	10
Mercury		6667	6,667
Methane			
Methylene chloride	2	33	20
4-Methyl-2-pentanone			
Napthalene		500	500

Table 2
Hazard Ranking System
(continued)

Pollutant	Carcinogens Isophorone Equivalents	Noncarcinogens Xylene Equivalents	Combined Ranking [1]
Nickel	215	100	373
Nitrobenzene		4000	4,000
PAHs	2949		8,846
Parachloronitrocresol			
Pentachlorophenol		67	67
Phenanthrene			
Phenol		3	3
Propylene	62		185
Pyrene		67	67
Selenium		667	667
Silver		667	667
Sodium hydroxide			
Styrene	8	10	17
Sulfides			
2,3,7,8-TCDD	38461538		115,384,615
2,3,7,8-TCDF			
Tetrachloroethylene	13	200	120
Thallium		28571	28,571
Thiocyanates			
Tin		3	3
Toluene		7	7
1,1,1-Trichloroethane	15	22	33
Trichloroethylene	3		8
Trichlorofluoromethane		7	7
2,4,6-Trichlorophenol	3		8
1,2,3-Trichloropropane		333	333
Triethanol			
Vanadium		286	286
Vinyl chloride	590		1,769
Xylenes		1	1
Zinc		10	10

Notes:
[1] The Combined Ranking assumes that 1 Isophorone Equivalent = 3 * Xylene Equivalent.
[2] Pollutants listed in this table without rankings lacked either toxicity data or the EPA database used to produce the ranking classified the data as inadequate.

Another alternative considered was comparing the dose of a carcinogen associated with a one-in-a-million risk of cancer to the reference dose (RfD) for non-carcinogens. The problem with this methodology is that the RfD is considered a "safe" dose while the dose of a carcinogen associated with a one-in-a-million risk of cancer still poses a health risk, albeit a small one. Thus, these two benchmarks are not equivalent.

Thus, given the available options, Tellus selected the comparison between the permissible exposure limits for xylene and isophorone to equilibrate noncarcinogens with carcinogens and thereby weighted health effects from carcinogens more heavily. While it is not possible to ascertain exactly how much greater society values the damage caused by carcinogens as opposed to noncarcinogens, clearly the health risk posed by carcinogens is perceived to be greater than the risk posed by noncarcinogens. This fact has been the subject of numerous articles and books (Efron 1984).

Several pollutants listed in Table 2 do not have a ranking attributed to them as no toxicity data were available for them, or the EPA database classified the data as "inadequate." As discussed in the following section, where possible, Tellus inferred a price for these pollutants so that their environmental costs were accounted for. However, many of the pollutants without health effects data were unable to be included in the environmental costs of production and disposal. As a result, the environmental costs reported in this study are underestimated. In addition, some pollutants in this table can cause both carcinogenic and noncarcinogenic health effects. However, since each pollutant can only receive one price, as previously discussed, a combined ranking score using the xylene equivalents and the weighted isophorone equivalents was determined.

3.2.5 Developing Prices for Pollutants

At this point the valuation methodology used in this study has produced a relative scale by which one can compare pollutants. The next step is to determine the "price" for each pollutant, a dollar amount per pound of residual pollutant emission. This price is a valuation of the damage that this pound of specific pollutant imposes on society. If the price of one pollutant were fixed, prices could be generated for the other pollutants using the scale developed in the health effects ranking system. As lead is one of the few regulated hazardous pollutants, the marginal control cost of lead can be determined and used as a reference point for comparison.

The Massachusetts Department of Public Utilities has been investigating environmental externality values to be used in energy resources planning. In conjunction with this activity, marginal control costs for lead have recently been determined (Chernick and Caverhill 1991). Various sources of lead, arsenic, and chromium in the environment were examined and the marginal control costs for controlling each of these three pollutants were determined. Using each of these control costs as the reference point by which values for all hazardous substances were determined gave rise to three different valuations for the environmental impact of lead (Bernow and Shapiro 1991). One was based on the actual control cost of lead. The other two were derived using the control costs for arsenic and chromium and calculating a new estimate for lead, based on the relative toxicity of these two hazardous substances to lead. Averaging the three lead values produced by this approach produced a cost for lead of $1,600 per pound. This price was used as the basis for determining the environmental costs for all other hazardous substances.

To determine the prices for the remaining hazardous pollutants, the combined ranking score for each pollutant was compared to the lead score. For example, as shown in Table 2 cadmium has a combined ranking score of 4,346 while lead has a combined ranking score of 1,429. Thus, cadmium is approximately three times as hazardous as lead. Therefore, cadmium is assigned a price approximately three times the per-pound control cost of lead, or $4,868 (see Table 3).

For criteria air pollutants and greenhouse gases, this study used the numbers adopted by the California Energy Commission (C.E.C 1990). The price for methane was obtained as explained above, i.e. by applying the price of carbon dioxide to the global warming potential of methane, measured in CO_2 equivalents.

As discussed in the preceding section, there were several pollutants that Tellus was initially unable to price since they lacked toxicity information for them, as required by the health effects ranking system. Where possible, costs were inferred for these pollutants as described below. Hydrogen chloride was not initially assigned a price due to lack of a reference dose. Tellus assigned the pollution abatement-based sulfur dioxide price to hydrogen chloride since both pollutants are controlled with similar control devices. Initially coke oven emissions were not assigned a price as it is actually a class of pollutants rather than a single pollutant. As benzene is a major component of coke oven emissions, the benzene price was assigned to the entire coke oven emissions pollutant class.

3.2.6 Summary of Pollutant Valuation Results

Table 3 describes the list of prices that were assigned to each of the pollutants that came from either handling a given material through a given waste management option or from producing a material from either virgin or secondary materials. The valuation methodology described above (and more fully in the Tellus references) and developed to produce these pollutant prices, is both very complex and, in many ways, not near complex enough. Many simplifying steps were taken in the development of these pollutant prices. However, the results reported in Table 3 are very powerful in substantiating our underlying premise for undertaking the pollutant valuation task in the first place. The range of pollutant prices varies across 9 orders of magnitude. Dioxin (2,3,7,8-TCDD) causes 3 billion times more of a health impact *per pound of pollutant* than methane. This is a tremendous range and strongly supports our initial contention thata pound of a given pollutant should not necessarily be valued as the same as a pound of any other pollutant. Even if we leave dioxin out of the list the prices still vary over 6 orders of magnitude, e.g. thallium is approximately 1 million times more harmful per pound than methane.

Table 3
Pollutant Prices

POLLUTANT	Pollutant Price ($/pound)
CO	$0.42
NOx	$3.63
Particulates	$5.85
SOx	$5.87
VOCs	$2.50
Acenapthene	$37
Acenapthylene	
Acetone	$22
Acetophenone	$22
Acrylonitrile	$465
Aluminum	
Ammonia	$2
Anthracene	$7
Antimony	$5,600
Arsenic	$22,658
Barium	$45
Benzene	$25
Benzo(a)anthracene	
Benzo(a)pyrene	
3,4-Benzoflouranthene	
Benzo(k)flouranthene	
Benzo(ghi)perylene	
Benzoic Acid	$1
Beryllium	$2,076
Biphenyl	$45
Bis(2-ethylhexyl)phthalate	$62
1,3-Butadiene	$1,551
2-Butanone	
Butyl benzyl phthalate	$11
Cadmium	$4,868
Carbon disulfide	$22
Carbon tetrachloride	$1,656
Chlorine	$6
Chlorobenzene	$112
Cloroethane	
Cloroform	$115
p-Chloro-m-cresol	$1
2-Chlorophenol	$448
Chloroprene	$112
Chromium	$2
Chrysene	
Copper	$60
Coke oven emissions	$25
p-Cresol	$45
Cyanide	$112
2,4-D	$224

Table 3
Pollutant Prices
(continued)

POLLUTANT	Pollutant Price ($/pound)
4,4-DDT	$2,240
Dibenzo(a,h)anthracene	
1,4-Dichlorobenzene	$12
Dichlorobromomethane	
1,1-Dichloroethane	$22
1,2-Dichloroethane	$78
1,1-Dichloroethylene	$383
1,2-trans-dichloroethylene	$112
2,4-Dichlorophenol	$747
1,2-Dicloropropane	$59
1,3-Dicloropropene	$3,811
Diethyl phthalate	$3
2,4-Dimethylphenol	$112
Dimethyl phthalate	$2
Di-n-butyl phthalate	
4,6-Dinitro-o-cresol	
2,4-Dinitrotoluene	$586
2,6-Dinitrotoluene	$586
1,2-Diphenylhydrazine	$689
Endosulfane sulfate	
Ethylbenzene	$22
Ethylchloride	
Ethylene oxide	$302
Fluoranthene	$56
Fluorene	$56
Fluoride	$37
Hexachlorobenzene	$2,089
2-Hexanone	
Hydrogen chloride	$6
Hydrogen fluoride	
Hydrogen sulfide	$35
Indeno(1,2,3-cd)pyrene	
Iron	
Isophorone	$7
Lindane	$7,467
Lead	$1,600
Magnesium	
Manganese	$11
Mercury	$7467
Methane	$0.04
Methylene chloride	$22
4-Methyl-2-pentanone	
Napthalene	$560

Table 3
Pollutant Prices
(continued)

POLLUTANT	Pollutant Price ($/pound)
Nickel	$418
Nitrobenzene	$4,480
PAHs	$9,908
Parachloronitrocresol	
Pentachlorophenol	$75
Phenanthrene	
Phenol	$4
Propylene	$207
Pyrene	$75
Selenium	$747
Silver	$747
Sodium hydroxide	
Styrene	$19
Sulfides	$35
2,3,7,8-TCDD	$129,230,769
2,3,7,8-TCDF	
Tetrachloroethylene	$134
Thallium	$32,000
Thiocyanates	
Tin	$4
Toluene	$7
1,1,1-Trichloroethane	$37
Trichloroethylene	$9
Trichlorofluoromethane	$7
2,4,6-Trichlorophenol	$9
1,2,3-Trichloropropane	$373
Triethanol	
Vanadium	$320
Vinyl chloride	$1,982
Xylenes	$1
Zinc	$11

Table 3
Pollutant Prices
(continued)

POLLUTANT	Pollutant Price ($/pound)
Nickel	$418
Nitrobenzene	$4,480
PAHs	$9,908
Parachloronitrocresol	
Pentachlorophenol	$75
Phenanthrene	
Phenol	$4
Propylene	$207
Pyrene	$75
Selenium	$747
Silver	$747
Sodium hydroxide	
Styrene	$19
Sulfides	$35
2,3,7,8-TCDD	$129,230,769
2,3,7,8-TCDF	
Tetrachloroethylene	$134
Thallium	$32,000
Thiocyanates	
Tin	$4
Toluene	$7
1,1,1-Trichloroethane	$37
Trichloroethylene	$9
Trichlorofluoromethane	$7
2,4,6-Trichlorophenol	$9
1,2,3-Trichloropropane	$373
Triethanol	
Vanadium	$320
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1,2-trans-dichloroethylene	$112
2,4-Dichlorophenol	$747
1,2-Dicloropropane	$59
1,3-Dicloropropene	$3,811
Diethyl phthalate	$3
2,4-Dimethylphenol	$112
Dimethyl phthalate	$2
Di-n-butyl phthalate	
4,6-Dinitro-o-cresol	
2,4-Dinitrotoluene	$586
2,6-Dinitrotoluene	$586
1,2-Diphenylhydrazine	$689
Endosulfane sulfate	
Ethylbenzene	$22
Ethylchloride	
Ethylene oxide	$302
Fluoranthene	$56
Fluorene	$56
Fluoride	$37
Hexachlorobenzene	$2,089
2-Hexanone	
Hydrogen chloride	$6
Hydrogen fluoride	
Hydrogen sulfide	$35
Indeno(1,2,3-cd)pyrene	
Iron	
Isophorone	$7
Lindane	$7,467
Lead	$1,600
Magnesium	
Manganese	$11
Mercury	$7467
Methane	$0.04
Methylene chloride	$22
4-Methyl-2-pentanone	
Napthalene	$560

The final step in our environmental valuation methodology was to combine the results of the pollutant loadings from the production and disposal of each material with the pollutant prices in Table 3. Thus, the pounds of each pollutant emitted from managing each material through each waste management option was multiplied by the appropriate pollutant price and then summed to produce an overall dollar value for the environmental impacts from the solid waste system based on the percentage of each packaging material recycled, buried and burned in the New Jersey solid waste system. Likewise, the pounds of each pollutant emitted from producing each packaging material were multiplied by their respective pollutant price and then summed to produce the total environmental impact of producing each ton of packaging material. This was done for production using both virgin resources and secondary materials, when possible.[41] Table 4 below summarizes each of the three externalities on a per-ton basis for each of the packaging materials used in the packaging study for which data were available.

The packaging study then went on to show how these per ton impacts translated into per package impacts over several different packaging case studies. It was only at this stage that comparisons as to the relative benefit of one package over another, in terms of delivering the *same quantity of product* could be compared. This was the point at which "good" and "bad" packages could be determined.[42] However, for our purposes (determining the impacts to both the solid waste system and to the production system of reducing and recycling different amounts of waste) impacts on a per-ton basis of material will be all that is needed.

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[41] The pollutants produced by each waste management facility and each waste collection process, by material, are reported in Tellus (1992b), Volume I, Report 4, Chapter 2. The pollutants produced by each material's production process is reported in Volume I, Report 4, Chapter 3.

[42] For a listing of the full monetary costs of individual packages see Tellus (1992b), Volume 1, Report 4, Chapter 4.

Table 4
Full Cost of Packaging Material Production and Disposal Externalities from the Tellus Packaging Study

Materials	Conventional Disposal ($/ton)	Environmental Impact of Disposal ($/ton)	Environmental Impact of Production ($/ton)	FULL COST ($/ton of material)
PLASTIC				
HDPE	$242	$4	$292	$537*
LDPE	$232	$4	$344	$580
PET	$250	$5	$854	$1,108
PP	$232	$4	$367	$602
PS	$232	$4	$385	$620
PVC	$232	$4	$5,053	$5,288
PAPER				
Bleached Kraft Paperboard	$110	$2	$330	$443
Unbleached Coated Folding Boxboard	$110	$2	$269	$382
Corrugated Cardboard[43]	$118	$2	$214	$334
Unbleached Kraft Paper	$110	$2	$277	$390
Recycled (100%) Folding Boxboard	$110	$2	$135	$247
Recycled (100%) Corrugated Cardboard	$118	$2	$150	$270
GLASS				
Virgin Glass	$71	$1	$85	$157
Recycled (100%) Glass	$71	$1	$55	$127
ALUMINUM				
Virgin Aluminum	$24	$5	$1,933	$1,963
Recycled (92%) Aluminum	$24	$5	$313	$342
STEEL				
Virgin Steel Containers	$134	$2	$230	$366
Recycled (12%) Steel Containers	$134	$2	$222	$358

* Totals may be slightly off due to rounding errors.

[43] Corrugated cardboard is made up of 69% linerboard and 31% corrugated medium. Each of these paper processes was modelled separately in the Packaging Study. The values reported here for both virgin and recycled corrugated cardboard are the weighted average of the two grades used in making corrugated cardboard.

Still, there are two problems which result from trying to use the data in Table 4 to evaluate the validity of the solid waste hierarchy. As Table 4 shows, in the Packaging Study the marginal conventional costs for managing each ton of material through the New Jersey solid waste system of 1990 were calculated based on the weighted average of the cost/ton to recycle, incinerate, and bury each type of material. However, these costs are not generic; rather, they were based on actual costs of New Jersey collection programs, processing facilities, incinerators, landfills and export from New Jersey at that point in time. Furthermore, the baseline system was not compared with another alternative system that either prevented more or less, or recycled and composted more or less. Thus, the conventional solid waste system costs of the Packaging Study could not be used to address either the technical or the economic questions concerning the solid waste hierarchy. This step -- determining whether a 50% recycling/composting level is technically feasible and what its cost impact on the solid waste management system would be -- was conducted as part of a study done for the Regional Plan Association of New York City and will be described in the next section.

The second problem in using the numbers in Table 4 is with the solid waste system environmental costs. Two issues are present here. First, only packaging materials are described in Table 4, and these account for only approximately 30 percent of the waste stream. The second is that, although the emissions from handling each material through each different waste management option are generic, the weighted system cost/ton in Table 4 is based on the percentage of each material that is recycled, buried and burned in the New Jersey solid waste system. The issue of expanding the list of materials to include all materials, not just packaging materials, was resolved in a study conducted by Tellus for the California Integrated Waste Management Board (Tellus 1991). In this study Tellus determined the full conventional and environmental cost of managing *every* non-food and non-yardwaste material in the California waste stream through the California waste management system. In the process, emissions data for managing all waste stream components through each waste management process were developed.[44] These results will be presented and used in Section 4.

The issue of being overly dependent on one state's data was resolved in the RPA Study, described in the next section. This study analyzed not only a 1990 baseline system for roughly 8% of the U.S. population, handling roughly 10% of the U.S. waste stream, but it also analyzed various future scenarios that reduced, recycled, and composted different levels of waste. Based on this scenario analysis, we are able to address the technical, economic and environmental feasibility of alternative waste management systems from a solid waste perspective.

Thus, the only costs that are completely generic and will be used intact from the Packaging Study are the environmental costs of producing each packaging material. This data will be used in addressing the questions raised in Section 5 on the environmental soundness of the solid waste hierarchy from a production system perspective.

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[44]The second phase of the RPA study (Tellus 1992d) discussed below, updated some of the results of the California study. Specifically, it added to the recycling facilities, incinerators, and landfills included in the California study both mixed waste composting and mixed waste processing data. These updated results are discussed below in section 4.3 and are reported in Table 14.

3.3 The Discarded Materials Management Plan for the RPA Tri-State, New York, New Jersey and Connecticut Metropolitan New York City Region

In August 1992 Tellus Institute completed an in-depth analysis of several alternative solid waste management "futures" for one major region of the country. The study, *A Discarded Materials Management Plan for RPA Region*, hereafter referred to as the RPA study, was conducted for the Regional Plan Association in New York City. The first phase of this study examined the conventional solid waste system costs of these alternative scenarios (Tellus 1992c). The second phase examined the environmental impacts on both the solid waste system and the production system of each of these same alternative waste management scenarios (Tellus 1992d).

The RPA region is the 31-county, 20 million-person region comprising western Connecticut, Long Island, New York City, southeastern New York, and the northern half of New Jersey. The region is demographically diverse: large sections of western Connecticut, the mid-Hudson valley, and northwest New Jersey are semi-rural areas, while many other areas are suburban. The region also contains several core urban centers, including New York City. The study first modelled the existing (1990) solid waste management systems throughout the region, including the waste generation rates and compositions, collection programs, and processing and disposal facilities. Three alternative scenarios for the region's solid waste management future were then developed and compared to both each other and the baseline. For the baseline and the three alternative scenarios, both physical requirements and costs were analyzed. For each alternative scenario, forecasts were developed for the anticipated growth in waste generation rates and changes in composition based in part on forecasts of population growth, employment and industry-specific production levels for each of the materials manufacturing sectors.

Scenario 1 in the RPA analysis modelled the implementation of the integrated waste management plans developed by each of the counties in this tri-state region through the year 2015. This scenario assumed that all the counties realized their state mandated solid waste management goals which are listed in Table 5.

In Scenario 2, the source reduction programs were eliminated and instead this previously prevented waste was collected, processed and disposed of at the same rates for each material as was the case in Scenario 1. This allowed the cost to be determined of the additional collection trucks, recycling facilities, incinerators and landfills that would be needed if source reduction did not occur (but still assuming that state recycling goals were met).

In Scenario 3, we eliminated the recycling and composting programs and modelled the solid waste management system as an incineration- and landfill-only system. All waste was collected together as mixed garbage and either burned or buried.

Table 5
Legislatively-Mandated Source Reduction and Recycling Goals in the Tri-State Region By Weight

State	Source Reduction[45]	Recycling/Composting
New York	10%	40%
New Jersey	26%	60%[46]
Connecticut	22%	25%

Thus, with the 1990 baseline scenario and the three alternative "future" scenarios, the RPA analysis was able to answer the following three questions:

1) Are recycling rates of up to 50% technically feasible?

2) How would the costs change if the proposed source reduction programs were not implemented (Scenario 2). In other words, is reducing waste from a solid waste management system cost effective?

3) And finally, what would the future costs of the region's solid waste management systems be if the proposed recycling and composting programs were not developed (Scenario 3)? In other words, comparing the intensive recycling Scenario 2 (but with no

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[45]For New Jersey and Connecticut, the source reduction goals were expressed as "no net increase" in waste generation; the percentages shown are Tellus' estimates of the implied reduction required to achieve these goals, based on projected waste stream growth resulting from population and employment growth and per-capita and per-employee waste generation growth rates. States have not developed consistent ways of measuring both reduction and recycling rates. A reduction rate cannot use the waste stream actually generated as its base (i.e., as the denominator). Rather, it must use the waste stream that would have been generated if the source reduction programs were not implemented. This requires having a forecast of waste stream growth. The reduction rate is then the difference between the projected waste stream minus the actual waste divided by the projected waste stream. Recycling rates, however, are not usually measured against this same projected waste stream. They are instead measured against the waste that was actually generated. Thus, reduction rates and recycling rates have different baseline waste streams against which their rates are measured. That is why in Table 5, the New Jersey percentages appear so high. In fact, the 60% recycling rate measured against the waste actually generated would equal only 44% of the waste that would have been generated without the reduction program. In order for the reduction rates to be comparable (and additive to) the rates for other waste management options, the RPA study used the projected waste stream without source reduction as the baseline. The rates for all waste management options are then measured against this projected waste stream.

[46]As discussed in numerous articles, New Jersey's definition of solid waste incorporates scrap autos, industrial scrap steel, construction and demolition and other materials that are not generally included in standard definitions of municipal solid waste. Since all of these waste stream components have very high recycling rates, when they are eliminated both from the definition of MSW and from the recycling rate, the New Jersey rate drops to between 45-50%. Since the standard definition of MSW was used in the RPA study, this revised, lower recycling/composting goal was also used. For a discussion of the New Jersey recycling rates and its definition of "solid waste" compared to "municipal solid waste" see *Recycling Times* (1992).

reduction) against the disposal-only Scenario 3 we can answer the question, "is recycling cost effective?"

Combined, answering these three questions will allow us to address the technical feasibility and economic rationality of the solid waste hierarchy from a solid waste perspective, at least for the RPA region. This will be done in the first two parts of the following Section 4. I will explore at the end of this paper (Section 7) whether or not these results can be generalized across different regions of the country.

Applying the material- and facility-specific emission factors developed in the Packaging Study and the California Disposal Fee Study to the alternative solid waste management scenarios from the RPA study allow us to answer the environmental soundness question from the solid waste perspective. This will be done in the third part of Section 4. Section 5 will then explore the technical feasibility, environmental soundness and economic rationality of the solid waste hierarchy from the production system perspective. These combined solid waste and production system results will then be summarized in Section 6.

Section 4 Results of the RPA Study - Does the Solid Waste Hierarchy Make Sense from a Solid Waste System Perspective?

4.1 Is the Solid Waste Hierarchy Technically Feasible?

In 1990, the Tri-State, RPA region was comprised of some 20 million residents with a labor force of over 11 million employees. These residents and employees generated 20.3 million tons of waste in their homes and work places. Overall in 1990, 9% of this waste was recycled, 2% was composted, 21% was incinerated and 68% was buried in landfills either inside or outside of the region. The total cost for collecting, processing and disposing of this waste was $2.8 billion, an average of $138/ton.

The first column of Table 6 describes these 1990 baseline conditions. The second and third columns in Table 6 describe the results of implementing waste management plans based on state mandated goals in each of the three states, for the years 2000 and 2015 (i.e., Scenario 1). The inputs to each of these model runs were based on the plans already developed by each of the 31 counties in this region.

The physical components (i.e. number of trucks, size of processing and/or disposal facility, quantity and composition of waste stream) for each county program were based on county-specific characteristics. For example, collection vehicles and collection program characteristics (vehicles, stops/hour, miles to disposal or processing site, etc.) were dependent upon demographic and geographic characteristics of each county. The capital and operating costs for existing and future facilities were based on location-specific costs, when they had been determined, and costs of similar facilities when they had not been determined. Commercial collection programs were modelled based on costs determined for each RPA subregion, through surveys of commercial haulers. Recycling and composting program design, and corresponding participation and capture rates, were based on data from existing and planned programs.[47]

Thus, the overall recycling and composting rate in the region goes from 11% in 1990 to 40% (44% of the non-prevented waste stream) by the year 2000 just by expanding the population covered by the recycling and composting programs and by increasing the number of materials targeted in all programs to those targeted by the most effective ones already existing in the region. In addition, a relatively small amount of material is captured by proposed mixed-waste processing systems in the region. Revenues (less shipping costs) generated from the sale of recyclables were based on the historically low prices being received by almost all materials in the spring of 1991 as reported by *Recycling Times*, May 7, 1991 and presented in Table 7. Thus, demonstrated technical feasibility governed all assumptions made in arriving at the recycling and composting levels identified in Scenarios 1 and 2.

[47]A full description of the methodology employed in modelling the generation, collection and facilities for the RPA region can be found in Chapter 1 and the accompanying appendices of Tellus (1992c).

Table 6
RPA Regional Solid Waste System Summary (Scenario 1)

TONS COLLECTED	1990	2000	2015
Source Reduction Programs	0	2,007,858	3,794,425
Source Separation Programs	2,687,632	8,938,627	9,978,432
Final Collection Programs*	17,711,776	11,510,342	12,203,934
SYSTEM DISTRIBUTION			
Tons Source Reduced	0	2,007,858	3,794,425
Tons Recycled	1,881,688	6,645,647	7,657,001
Tons Composted	391,544	2,211,085	2,144,341
Tons Incinerated	4,282,791	8,345,065	8,522,478
Tons Exported	3,871,209	1,268,740	1,341,796
Tons Landfilled (excluding ash)	9,931,426	1,879,266	2,414,495
Total System Tons	20,358,458	22,357,661	25,874,536
Tons Incinerator Ash	1,202,396	1,584,399	1,543,681
% BY MANAGEMENT OPTION			
Percent Source Reduced	0%	9%	15%
Percent Recycled	9%	30%	30%
Percent Composted	2%	10%	8%
Percent Incinerated	21%	37%	33%
Percent Landfilled (excluding ash)	49%	8%	9%
Percent Exported	19%	6%	5%
Percent Ash	6%	7%	6%
TOTAL SYSTEM COSTS			
Source Reduction Programs	$0	$17,702,897	$19,038,676
Source Separation Collection Programs	$193,683,046	$720,673,534	$832,377,962
Final Collection Programs	$1,231,653,923	$830,575,205	$920,678,119
Recycling Facilities	$89,378,196	$326,138,709	$328,037,877
Compost Facilities	$6,398,405	$88,053,250	$73,140,383
Incinerators (including ash fills)	$275,013,550	$651,640,119	$543,108,339
Landfills (excluding ash fills)	$731,422,760	$191,219,640	$245,697,564
Export	$276,116,323	$119,968,203	$124,351,531
Total System Cost	$2,803,917,383	$2,945,971,557	$3,080,624,611
TOTAL SYSTEM COST/TON			
Source Reduction Programs	$0	$9	$5
Source Separation Collection Programs	$72	$81	$83
Final Collection Programs	$70	$72	$75
Recycling Facilities	$47	$49	$43
Compost Facilities	$16	$40	$34
Incinerators (including ash fills)	$64	$78	$64
Landfills (excluding ash fills)	$74	$102	$102
Export	$71	$95	$93
Total Collection Cost Per Ton	$70	$70	$68
Total Facility Cost Per Ton	$64	$58	$48
Total System Cost Per Ton	$138	$132	$119

*Final collection denotes the collection of all wastes that were not source reduced or collected in a source separation recycling or organics (composting) program. It is generally referred to as garbage collection.

Table 7
Revenues Used for Recycled and Composted Materials in the RPA Study ($/ton)

Materials	Revenue/Ton	Materials	Revenue/Ton
Corrugated	$15	Glass (Flint/Clear)	$48
Newsprint	$2.50	Glass (Green)	$16
Office/Computer	$150	Glass (Brown)	$39
Magazines/Glossy	$0	Misc. Glass	$0
Books/Phonebooks	$0	Aluminum food container/foil	$240
Non-corrugated cardboard	$0	Aluminum cans	$600
Mixed paper	($12)	Misc. aluminum	$450
HDPE	$200	Steel food cans	$50
LDPE	$0	Misc. ferrous	$50
Films and bags	$0	Bimetal cans	$0
PET	$120	Non-bulk ceramics	$0
PVC	$0	Misc. inorganics	$0
Polypropylene	$200	Household Haz. Waste	$0
Misc. plastics	$0	Textiles	$0
Grass	$0	Rubber	$0
Leaves	$0	Fines	$0
Diapers	$0	Brush/stumps	$0
Foodwaste	$0	Lumber	$10
Misc. organics	$0	Bulk	$5

Using these modelling parameters, by the year 2000 the implemented RPA region plans would result in 9% of the waste stream being reduced, 30% being recycled, 10% composted, 37% incinerated, and only 16% buried. If the source reduction tons are excluded, then this translates into an overall 44% recycling and composting rate. By 2015, the recovery rate for these materials becomes 47% (36% recycling and 11% composting). Furthermore, if we just measure the recycling rate as a percentage of the waste stream excluding foodwaste and yardwaste, by 2000 the RPA region is recycling approximately 45%. Thus, although the region does not, on average, reach the goal of 50%, it still comes quite close.[48]

Thus, the RPA study demonstrates that simply meeting the statewide goals of the RPA region, using program parameters well within the range of already existing programs, produces a near 45% recycling rate of the non-food and -yardwaste waste stream. Furthermore, the overall recycling and composting rate is 47% of the entire non-prevented waste stream. Thus, targeting an overall recycling and composting rate of 50% appears to be well within the range of technical feasibility.

This finding challenges recent estimates that have placed maximum attainable recycling rates at 15% (Alter 1991). However, since the EPA has announced that in 1990 the U.S. had already achieved an overall 17.1% recycling rate, and rates have only increased dramatically since then, the Alter numbers must be, at a minimum, revised.[49] Franklin Associates (EPA 1990a) has argued that the maximum attainable recycling rate (not including composting of any organics) is currently 28% but could be higher with appropriate market development incentives. The Franklin findings are somewhat lower, though largely consistent with the findings from the RPA study.

4.2 Is the Solid Waste Hierarchy Economically Rational?

From Table 6 we can see that implementing the state-mandated reduction and recycling programs in the RPA region result in a *decrease* in the costs of solid waste management. Under Scenario 1, total system cost per ton (in 1990 dollars) declines from $138 per ton in 1990 to $132 in 2000 and to $119 in 2015. A number of factors cause this decline in overall waste management costs as the reduction, recycling and composting programs are phased in, as can be seen from the cost-per-ton results at the bottom of Table 6.

First, 9% of the waste stream in 2000 would be handled by the relatively inexpensive source reduction program. The costs for this program were modelled simply as public education

[48]If the relatively low recycling rate of 25% mandated by Connecticut was increased to 40%, certainly a technically feasible goal as demonstrated by the New York and New Jersey regions, the region as a whole would have a recycling/composting rate of over 50% of the non-prevented waste stream.

[49]Alter (1991), whose work is sponsored by the U.S. Chamber of Commerce, is the standard source used to argue for a greatly reduced role for recycling and source reduction by analysts from the Reason Foundation (e.g., Scarlett 1991) and the Citizens for the Environment (e.g., Logomasini 1991) who are spearheading the rejuvenation of the "menu of options" school of integrated waste management.

programs required to promote source reduction activities. But the economic benefits of meeting the state-mandated goals are not limited to source reduction.

Capital and operating costs of actual collection programs rise as more material is collected in recycling and composting programs. Source separated (recycling and composting) collection costs rise from $72 to $82 per ton as more difficult areas of the region with lower collection efficiencies are brought on line. Garbage collection programs decrease in total costs as less waste is collected in garbage collection programs but costs-per-ton also rise slightly from $70 to $72 per ton as less waste is collected at each stop, while the time to collect each stop does not decrease proportionately.

However, the opposite occurs in processing and disposal facilities. As more of the waste is diverted into the relatively less expensive recycling and composting facilities, and fewer tons go to the more expensive landfills and incinerators, average facility costs per ton decline.[50] The net result is that total waste management system costs decline over time as the reduction, recycling and composting programs are implemented.

Because it includes the effect of the source reduction program, Scenario 1 does not reflect the cost impacts of the recycling and composting programs alone. In order to examine this effect, Scenarios 2 and 3 are needed. Scenario 2, summarized in Table 8, eliminates the source reduction program and expands all other waste management options (recycling, composting, incineration, and landfilling) proportionally to handle the additional wastes. This scenario therefore includes the additional costs required to buy and operate additional trucks and facilities to handle the waste that would have otherwise been reduced in Scenario 1. In other words, the cost difference between Table 8 and Table 6 (i.e. between Scenario 2 and Scenario 1) is the "value" to the solid waste management system of the source reduction program. The cumulative benefit of the reduction of 43 million tons over the 15 year period from 2000 to 2015 is approximately $4.25 billion.[51] Overall, the average system cost per ton rises in the no source reduction Scenario 2 from $138 in 1990 to $140 in 2000 and then falls to $134 per ton in 2015. Thus the reduction program produces a total systems savings of $8 per ton in 2000 and $15 per ton in 2015 for every ton of waste generated in the RPA region.[52]

The final scenario not only excludes the impacts of the source reduction program, but also eliminates the costs of the recycling and composting programs used in the prior scenarios. In Scenario 3 (Table 9) all waste is collected in a single garbage collection program and either incinerated or buried (either in or out of the region). In this case, the cost of the zero recycling,

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[50] For a description of the methodology used in developing costs for each type of solid waste facility, see Tellus (1992c), Chapter 1 - Methodology.

[51] The public education costs of the source reduction program were modelled at $2 per household. This produces an overall source reduction program cost/ton of $9/ton. This $4.25 billion ($100/ton) can also be thought of as the amount of money the region could spend on source reduction initiatives and still have them be cost-effective.

[52] This is just Scenario 2 Total Cost/Ton minus Scenario 1 Total Cost/Ton.

(i.e., incineration- and landfill-only) system is $131 per ton in the year 2015, compared to the $134 per ton in Scenario 2. Recall that Scenario 2 recycles 35% of the waste stream and composts an additional 9%. In other words, the conventional costs of the integrated system with almost 44% recycling/composting (Scenario 2) is only $3 per ton, (2%) more expensive than the zero recycling, incineration- and landfill-only alternative.

This is a trivial cost difference, within the margin of error for such long-term projections. The calculated cost difference between scenarios 2 and 3 reveals that the cost of recovering over 9 million tons of materials annually is less than $3 per person, or less than $6 per household per year, for the 20 million-person RPA region. For all practical purposes, the Tellus RPA study demonstrates that recycling- and composting-intensive solid waste management systems are no more costly than incineration- and landfill-only systems in the Connecticut, New York and New Jersey region.

Table 8
RPA Regional Solid Waste System Summary: No Source Reduction (Scenario 2)

TONS COLLECTED	1990	2000	2015
Source Reduction Programs	0	0	0
Source Separation Programs	2,687,632	9,186,809	11,109,400
Final Collection Programs	17,712,849	13,271,721	14,870,098
SYSTEM DISTRIBUTION			
Tons Source Reduced	0	0	0
Tons Recycled	1,881,785	7,382,712	9,137,514
Tons Composted	391,344	2,292,003	2,269,300
Tons Incinerated	4,282,791	9,122,298	10,070,420
Tons Exported	3,871,209	1,315,735	1,471,075
Tons Landfilled (excluding ash)	9,932,505	2,231,635	2,869,755
Totals System Tons	20,359,634	22,344,383	25,818,064
Tons Incinerator Ash	1,201,987	1,735,350	1,832,405
% BY MANAGEMENT OPTION			
Percent Source Reduced	0%	0%	0%
Percent Recycled	9%	33%	35%
Percent Composted	2%	10%	9%
Percent Incinerated	21%	41%	39%
Percent Landfilled (excluding ash)	49%	10%	11%
Percent Exported	19%	6%	6%
Percent Ash	6%	8%	7%
TOTAL SYSTEM COSTS			
Source Reduction Programs	$0	$0	$0
Source Separation Collection Programs	$193,702,485	$786,457,311	$956,048,132
Final Collection Programs	$1,231,858,823	$875,309,348	$1,000,808,272
Recycling Facilities	$89,386,827	$362,010,295	$386,380,338
Compost Facilities	$6,398,405	$88,661,386	$74,480,800
Incinerators (including ash fills)	$274,969,380	$675,740,165	$617,927,093
Landfills (excluding ash fills)	$731,485,140	$224,769,029	$287,976,538
Export	$276,116,323	$122,787,918	$132,108,319
Total System Cost	$2,803,917,383	$3,135,735,452	$3,455,729,494
TOTAL SYSTEM COST/TON			
Source Reduction Programs	$0	$9	$0
Source Separation Collection Programs	$72	$86	$86
Final Collection Programs	$70	$66	$67
Recycling Facilities	$48	$49	$42
Compost Facilities	$16	$39	$33
Incinerators (including ash fills)	$64	$74	$61
Landfills (excluding ash fills)	$74	$101	$100
Export	$71	$93	$90
Total Collection Cost Per Ton	$70	$74	$75
Total Facility Cost Per Ton	$64	$61	$54
Total System Cost Per Ton	[illegible]	$140	$134

Table 9 -
RPA Regional Solid Waste System Summary: Incineration- and Landfill-Only (Scenario 3)

TONS COLLECTED	Export/Landfill	Incineration/Landfill
Source Reduction Programs	0	0
Source Separation Programs	0	0
Final Collection Programs	25,748,797	25,748,797
SYSTEM DISTRIBUTION		
Tons Source Reduced	0	0
Tons Recycled	0	0
Tons Composted	0	0
Tons Incinerated	8,522,478	13,901,758
Tons Exported	14,811,824	486,733
Tons Landfilled (excluding ash)	2,414,495	11,360,306
Totals System Tons	25,748,797	25,748,797
Tons Incinerator Ash	1,543,681	2,851,928
% BY MANAGEMENT OPTION		
Percent Source Reduced	0%	0%
Percent Recycled	0%	0%
Percent Composted	0%	0%
Percent Incinerated	33%	54%
Percent Landfilled (excluding ash)	9%	44%
Percent Exported	58%	2%
Percent Incinerator Ash	6%	11%
TOTAL SYSTEM COSTS		
Source Reduction Programs	$0	$0
Source Separation Collection Programs	$0	$0
Final Collection Programs	$1,516,669,766	$1,601,796,363
Recycling Facilities	$0	$0
Compost Facilities	$0	$0
Incinerators (including ash fills)	$596,573,460	$669,244,744
Landfills (excluding ash fills)	$245,697,564	$1,104,787,738
Export	$1,072,724,114	$24,003,529
Total System Cost	$3,431,664,904	$3,399,832,404
TOTAL SYSTEM COST/TON		
Prevention Programs	$0	$0
Source Separation Collection Programs	$0	$0
Final Collection Programs	$58	$62
Recycling Facilities	$0	$0
Compost Facilities	$0	$0
Incinerators (including ash fills)	$70	$48
Landfills (excluding ash fills)	$102	$97
Export	$71	$49
Total Collection Cost Per Ton	$58	$62
Total Facility Cost Per Ton	$74	$69
Total System Cost Per Ton	[illegible]	[illegible]

Two additional points should be made. First, the RPA study makes no allowances for rising disposal costs due to depletion of existing landfills. This is a very conservative assumption, understating the cost effectiveness of recycling over alternative disposal options. Second, source reduction programs are significantly less expensive, compared to either recycling or disposal options. Vigorous recycling and composting programs are likely to be complementary to source reduction efforts, since public education about one environmentally motivated alternative for waste management may carry over into support for other alternatives. In the RPA study, the lowest overall costs were achieved in the scenario including source reduction. Promotion of recycling may indirectly help achieve source reduction results, thus helping to achieve lower costs.

This finding is also at odds with much of the anecdotal data that is presented by analysts skeptical of the current emphasis on recycling as a solid waste management practice. The evidentiary method used by this school of scholarship to support their claims often relies on selection of a particularly inefficiently run recycling program to show how the cost/ton for recycling is higher than the cost/ton for disposal (Scarlett 1991, 25; Logomasini 1991, 12). New York City is a common example used by these scholars attempting to expose the economic irrationality of recycling. It is true that many recycling programs currently are inefficiently run, for many reasons. The two most important are first, the private/public sector partnership required to make programs run rationally is not properly structured; and second, programs are run at too small of a scale. What may be expensive on a per-ton basis when run on a small scale, can be very cost-effective when operated at a large scale. For example, 1990 recycling collection costs in New York City were over $300/ton. Projected costs of the new program, recently approved by the New York City Council that is both more efficiently designed and targeting a much larger number of materials, is $130/ton. This compares to garbage collection costs of approximately $100/ton for the City. Because the recycling facilities operate more than $30/ton below the City's costs for using incinerators or landfills, the projected New York City recycling program, capturing over 40% of the waste stream, is a cost-effective part of New York City's solid waste future. Scholarship that points to isolated, individual examples and then generalizes from those to broad principles should always be viewed with a critical eye.

4.3 Is the Solid Waste Hierarchy Environmentally Sound?

In each of the baseline and three alternative RPA scenarios, the materials generated by the production and consumption activities of the households and businesses in the RPA region are handled in different quantities by different waste management systems. Tables 6, 8 and 9 (p. 38, 43, 44) describe what the costs of those alternative systems are. Table 10 identifies how the tons of each material are distributed among each waste management option in the RPA 1990 baseline. Likewise, Tables 11, 12, and 13 report this same finding for each of the three alternative waste management futures for the year 2015.[53]

[53]Total tons from Tables 10 - 13 will vary from those in Tables 6, 8 and 9 by very small amounts due to rounding errors.

Table 11 reports how much of each material generated in the year 2015 is handled by each waste management method if the RPA region's integrated prevention, recycling, composting and incineration/disposal plans are implemented. Table 12 reports how many tons will be handled in 2015 if no source reduction is accomplished, but the recycling and composting goals are met. Table 13 reports how many tons will be handled in 2015 if no source reduction and no recycling or composting occur.

Table 10
Material Distribution By Waste Management Option for RPA's
1990 Baseline

MATERIALS	MRFs	COMPOST	INCINERATOR	LANDFILL & EXPORT	PREVENTED
Corrugated	283,796	0	517,429	1,620,881	0
Newsprint	537,506	0	252,629	960,169	0
Office/Computer	93,906	0	179,481	682,328	0
Magazines/Glossy	26,831	0	114,188	368,421	0
Book/Phonebooks	1,475	0	63,291	177,252	0
Non-Corrug Crdbrd	3,642	0	122,488	311,197	0
Mixed	58,695	0	565,037	2,093,940	0
HDPE	3,035	0	49,136	177,714	0
LDPE	419	0	7,004	21,563	0
Films & Bags	3,756	0	179,445	525,829	0
PET	1,379	0	22,653	76,516	0
PVC	774	0	18,481	43,771	0
Polypropylene	586	0	9,3258	28,532	0
Polystyrene	1,564	0	30,956	93,912	0
Misc. Plastics	3,022	0	77,252	316,938	0
Grass	0	168,235	147,011	344,742	0
Leaves	0	167,993	146,744	344,398	0
Diapers	0	0	44,753	172,167	0
Foodwaste	28,761	0	425,591	1,378,311	0
Misc. Organics	0	0	133,552	742,478	0
Glass Clear Container	75,039	0	110,784	254,926	0
Glass Green Container	26,361	0	35,574	86,643	0
Glass Brown Container	20,698	0	25,449	64,777	0
Misc. Glass	22,335	0	48,254	232,314	0
Food Contnr./Foil	13,213	0	22,206	49,014	0
Beverage Cans	17,568	0	13,852	34,158	0
Misc. Aluminum	6,477	0	21,074	54,381	0
Food Container	54,131	0	38,574	118,922	0
Misc. Ferrous	95,201	0	113,358	301,150	0
Bimetal Cans	5,950	0	27,013	41,743	0
Misc. Inorganics	1,674	0	145,163	272,748	0
HHW	0	0	18,813	47,226	0
Textiles	5,227	0	107,834	525,477	0
Rubber	0	0	46,666	127,449	0
Fines	0	0	87,413	346,298	0
Brush/Stumps	0	55,118	91,179	281,910	0
Lumber	0	0	194,742	345,389	0
Bulk	488,103	0	29,406	136,750	0
TOTAL	1,881,121	391,346	4,282,797	13,802,336	0

Table 11
Material Distribution By Waste Management Option for RPA's 2015 Integrated Waste Management Plan (Scenario 1)

MATERIALS	MRFs	COMPOST	INCINERATOR	LANDFILL & EXPORT	PREVENTED
Corrugated	2,226,440	117,368	964,738	605,009	824,731
Newsprint	1,124,198	38,864	268,558	138,795	239,849
Office/Computer	554,110	31,939	358,319	178,771	162,544
Magazines/Glossy	379,607	12,352	439,600	211,896	189,205
Book/Phonebooks	61,817	3,955	176,204	51,958	55,877
Non-Corrug Crdbd	93,547	23,278	238,983	80,742	84,682
Mixed	679,025	235,094	1,145,260	493,713	507,268
HDPE	270,011	11,323	169,276	81,918	94,755
LDPE	56,090	1,650	18,554	7,590	21,681
Films & Bags	197,497	46,725	672,397	167,367	167,053
PET	70,142	2,713	57,825	28,653	27,471
PVC	87,553	3,770	74,373	19,474	34,288
Polypropylene	59,350	1,744	20,366	8,770	21,450
Polystyrene	95,421	6,047	67,324	21,810	41,000
Misc. Plastics	35,209	4,146	66,923	19,665	19,957
Grass	0	250,792	181,256	98,778	116,878
Leaves	0	250,356	180,819	98,652	116,766
Diapers	0	43,973	83,069	29,501	34,880
Foodwaste	29,590	489,084	902,076	341,877	193,950
Misc. Organics	0	294,218	544,920	175,477	93,538
Glass Clear Container	205,740	5,609	57,759	28,091	68,601
Glass Green Container	68,332	2,826	23,066	10,435	25,159
Glass Brown Container	56,183	2,092	17,923	8,005	20,612
Misc. Glass	143,196	4,514	84,396	28,280	32,503
Food Contnr./Foil	47,704	1,931	23,104	13,957	15,537
Beverage Cans	101,280	4,627	56,057	31,291	38,095
Misc. Aluminum	45,395	3,418	27,363	13,773	11,537
Food Container	105,371	1,790	35,3111	15,892	27,607
Misc. Ferrous	441,712	5,472	101,154	38,214	90,659
Bimetal Cans	57,151	335	7,853	9,414	12,493
Misc. Inorganics	41,052	25,944	187,947	103,038	46,806
HHW	1,593	1,768	42,802	12,124	7,330
Textiles	101,942	10,247	323,291	118,300	85,145
Rubber	0	3,229	125,702	43,671	27,810
Fines	0	53,206	137,969	133,930	52,524
Brush/Stumps	0	129,596	163,006	79,194	50,146
Lumber	14,171	15,448	338,753	143,136	77,529
Bulk	206,366	2,900	138,176	66,010	47,162
TOTAL	7,656,795	2,144,341	8,522,471	3,757,171	3,794,719

Table 12
Material Distribution By Waste Management Option for RPA's 2015 No Source Reduction Plan (Scenario 2)

MATERIALS	MRFs	COMPOST	INCINERATOR	LANDFILL & EXPORT	PREVENTED
Corrugated	2,746,493	120,049	1,121,094	728,481	0
Newsprint	1,289,883	38,856	322,064	152,585	0
Office/Computer	641,941	31,970	406,828	202,580	0
Magazines/Glossy	431,761	12,345	559,457	228,276	0
Book/Phonebooks	75,692	3,958	216,577	53,208	0
Non-Corrug Crdbrd	114,141	23,777	295,592	87,236	0
Mixed	853,196	247,157	1,415,459	557,301	0
HDPE	317,072	11,329	199,405	97,185	0
LDPE	70,385	1,650	24,608	8,147	0
Films & Bags	229,358	46,744	775,046	197,464	0
PET	82,203	2,713	66,705	34,689	0
PVC	106,523	3,770	88,231	20,078	0
Polypropylene	73,184	1,744	26,469	9,516	0
Polystyrene	115,917	6,051	84,609	24,016	0
Misc. Plastics	40,912	4,145	77,059	23,396	0
Grass	0	309,465	219,673	117,993	0
Leaves	0	308,984	219,179	117,862	0
Diapers	0	48,904	108,027	33,972	0
Foodwaste	44,970	475,086	1,024,832	406,694	0
Misc. Organics	0	285,039	614,257	204,961	0
Glass Clear Container	255,113	5,594	69,996	32,994	0
Glass Green Container	85,861	2,825	27,896	12,517	0
Glass Brown Container	70,676	2,087	21,831	9,591	0
Misc. Glass	158,149	4,507	88,026	40,393	0
Food Contnr./Foil	56,085	1,941	27,263	16,314	0
Beverage Cans	120,840	4,650	70,227	34,959	0
Misc. Aluminum	49,851	3,425	30,585	17,419	0
Food Container	121,576	1,789	44,940	16,860	0
Misc. Ferrous	502,108	5,468	116,150	50,772	0
Bimetal Cans	66,493	331	8,345	11,576	0
Misc. inorganics	45,375	25,930	226,938	113,657	0
HHW	1,636	1,769	47,898	14,311	0
Textiles	112,861	10,212	372,710	141,337	0
Rubber	0	3,227	146,334	50,777	0
Fines	0	52,416	181,692	138,286	0
Brush/Stumps	0	141,247	182,348	97,349	0
Lumber	21,536	15,240	380,311	169,434	0
Bulk	254,095	2,903	161,739	66,645	0
TOTAL	9,137,886	2,269,299	10,070,402	4,340,830	0

Table 13
Material Distribution By Waste Management Option for RPA's 2015 Incineration- and Landfill-Only Plan (Scenario 3)

MATERIALS	MRFs	COMPOST	INCINERATOR	LANDFILL & EXPORT
Corrugated	0	0	2,282,539	2,488,125
Newsprint	0	0	1,027,437	795,188
Office/Computer	0	0	607,631	686,117
Magazines/Glossy	0	0	731,578	503,585
Book/Phonebooks	0	0	235,513	115,156
Non-Corrug Crdbrd	0	0	330,220	192,478
Mixed	0	0	1,779,300	1,188,293
HDPE	0	0	341,185	291,749
LDPE	0	0	72,162	35,645
Films & Bags	0	0	809,380	445,498
PET	0	0	93,219	94,447
PVC	0	0	148,284	74,063
Polypropylene	0	0	74,073	39,778
Polystyrene	0	0	159,973	74,650
Misc. Plastics	0	0	94,026	52,533
Grass	0	0	402,790	244,900
Leaves	0	0	402,113	244,469
Diapers	0	0	141,279	49,930
Foodwaste	0	0	1,295,254	663,203
Misc. Organics	0	0	782,865	324,857
Glass Clear Container	0	0	203,681	165,770
Glass Green Container	0	0	72,627	58,522
Glass Brown Container	0	0	58,558	47,313
Misc. Glass	0	0	109,837	184,659
Food Contnr./Foil	0	0	50,684	51,960
Beverage Cans	0	0	130,858	102,840
Misc. Aluminum	0	0	43,984	57,830
Food Container	0	0	96,788	90,582
Misc. Ferrous	0	0	312,835	367,605
Bimetal Cans	0	0	28,581	58,868
Misc. Inorganics	0	0	218,534	196,064
HHW	0	0	39,411	26,222
Textiles	0	0	399,453	238,755
Rubber	0	0	123,310	77,047
Fines	0	0	156,716	220,888
Brush/Stumps	0	0	251,199	170,446
Lumber	0	0	311,215	276,681
Bulk	0	0	151,429	309,220
TOTAL	0	0	14,570,531	11,305,936

Table 14 below summarizes the environmental impact value of handling a ton of each waste stream component through each waste management collection program and processing/disposal facility as developed by the California Disposal Fee Study (Tellus 1991), the Packaging Study (Tellus 1992b) and supplemented by the RPA study (Tellus 1992d).[54] Negative numbers denote materials and processes with environmental costs. Positive numbers (under the Production Benefit column) denote environmental benefits credited to the MRF/Process system of using secondary materials instead of virgin resources in production processes. Under the prevention column the positive numbers denote the environmental benefit of not producing the materials in the first place.

The collection values, reported on the first page of Table 14 are based on the emissions from recycling and garbage collection trucks, compaction ratios for each type of program and material, and the density of each material. The emission factors for recycling facilities and compost facilities (on the second page of Table 14) could not be tied to individual waste components, thus, the total facility emissions were allocated on an equal basis to all materials processed by those facilities. Emissions from landfills and incinerators were first derived for generic facilities and then assigned to waste stream components based on the chemical and physical properties of the components.

We can now apply these environmental impact values for recycling, composting, burning or burying each ton of waste (including both collection and processing impacts) to each ton of waste reported in Tables 10 - 13 to determine the environmental impacts of the baseline and the three alternative RPA waste management systems.

[54]A more detailed description of the generation and meaning of the material and waste management specific environmental emission factors is represented in (Tellus 1992d), Section 2 and below p. 56.

Table 14
Value of Environmental Impact for Each Material for Each Waste Management Option - Collection Impacts[55]

MATERIALS	Recyclables	Processibles	Compostables	Garbage
Corrugated	-$3.07	-$1.21	-$1.21	-$1.21
Newsprint	-$1.54	-$0.69	-$0.69	-$0.69
Office/Computer	-$1.73	-$0.94	-$0.94	-$0.94
Magazines/Glossy	-$6.92	-$1.10	-$1.10	-$1.10
Book/Phonebooks	-$6.92	-$1.10	-$1.10	-$1.10
Non-Corrug Crdbrd	-$3.07	-$1.21	-$1.21	-$1.21
Mixed	-$4.61	-$1.01	-$1.01	-$1.01
HDPE	-$19.77	-$2.56	-$2.56	-$2.56
LDPE	-$19.77	-$2.85	-$2.85	-$2.85
Films & Bags	-$27.68	-$1.49	-$1.49	-$1.49
PET	-$23.06	-$2.61	-$2.61	-$2.61
PVC	-$19.77	-$2.85	-$2.85	-$2.85
Polypropylene	-$19.77	-$2.85	-$2.85	-$2.85
Polystyrene	-$19.77	-$2.85	-$2.85	-$2.85
Misc. Plastics	-$19.77	-$2.85	-$2.85	-$2.85
Grass		-$0.58	-$0.58	-$0.58
Leaves		-$0.58	-$0.58	-$0.58
Diapers		-$1.35	-$1.35	-$1.35
Foodwaste		-$0.41	-$0.41	-$0.41
Misc. Organics		-$0.82	-$0.82	-$0.82
Glass Clear Container	-$1.15	-$0.27	-$0.27	-$0.27
Glass Green Container	-$1.15	-$0.27	-$0.27	-$0.27
Glass Brown Container	-$1.15	-$0.27	-$0.27	-$0.27
Misc. Glass	-$1.15	-$0.27	-$0.27	-$0.27
Food Contnr./Foil	-$11.53	-$3.04	-$3.04	-$3.04
Beverage Cans	-$11.53	-$3.04	-$3.04	-$3.04
Misc. Aluminum	-$11.53	-$3.04	-$3.04	-$3.04
Food Container	-$3.46	-$1.20	-$1.20	-$1.20
Misc. Ferrous	-$3.46	-$1.20	-$1.20	-$1.20
Bimetal Cans	-$3.46	-$1.20	-$1.20	-$1.20
Misc. Inorganics	-$0.15	-$0.75	-$0.75	-$0.75
HHW		-$0.75	-$0.75	-$0.75
Textiles		-$1.66	-$1.66	-$1.66
Rubber		-$1.16	-$1.16	-$1.16
Fines		-$0.32	-$0.32	-$0.32
Brush/Stumps		-$0.88	-$0.88	-$0.88
Lumber		-$0.88	-$0.88	-$0.88
Bulk		-$0.94	-$0.94	-$0.94

[55] Processibles refers to material collected in garbage trucks, and thus compacted, but was processed (and recovered) at mixed waste processing facilities. Garbage refers to unsorted waste similarly collected but sent directly to incinerators or landfills.

Table 14 (continued)
Value of Environmental Impact for Each Material for Each Waste Management Option - Facility Impacts

MATERIALS	Facility Costs						Production Benefit[illegible]	
	MRF	IN-VESSEL PROCESS	LEAF/YD COMPOST	COMPOST	INCIN	LANDFILL	MRF/PROCESS	PREV[illegible]
Corrugated	-$0.13	-$0.13	-$2.85		-$1.63	-$0.38	$99	$19
Newsprint	-$0.13	-$0.13	-$2.85		-$1.63	-$0.38	$99	$19
Office/Computer	-$0.13	-$0.13	-$2.85		-$1.63	-$0.38	$99	$19
Magazines/Glossy	-$0.13	-$0.13	-$2.85		-$1.63	-$0.38	$134	$19
Book/Phonebooks	-$0.13	-$0.13	-$2.85		-$1.63	-$0.38	$134	$19
Non-Corrug Cdbrd	-$0.13	-$0.13	-$2.85		-$1.63	-$0.38	$134	$20
Mixed	-$0.13	-$0.13	-$2.85		-$1.63	-$0.38	$134	$18
HDPE	-$0.13	-$0.13	-$2.85		-$1.44	-$0.07		$29
LDPE	-$0.13	-$0.13	-$2.85		-$1.44	-$0.07		$34
Films & Bags	-$0.13	-$0.13	-$2.85		-$1.44	-$0.07		$34
PET	-$0.13	-$0.13	-$2.85		-$1.44	-$0.07		$86
PVC	-$0.13	-$0.13	-$2.85		-$1.52	-$0.07		$5,05
Polypropylene	-$0.13	-$0.13	-$2.85		-$1.44	-$0.07		$36
Polystyrene	-$0.13	-$0.13	-$2.85		-$1.44	-$0.07		$38
Misc. Plastics	-$0.13	-$0.13	-$2.85		-$1.52	-$0.07		$1,09
Grass		-$0.13	-$2.85	-$3.97	-$0.37	-$1.15		
Leaves		-$0.13	-$2.85	-$3.97	-$0.37	-$1.15		
Diapers		-$0.13	-$2.85		-$1.54	-$0.23		$26
Foodwaste	-$0.13	-$0.13	-$2.85		-$0.37	-$1.15		
Misc. Organics		-$0.13	-$2.85		-$4.82			
Glass Clear Contnr.	-$0.13	-$0.13	-$2.85		-$1.04		$30	$[illegible]
Glass Green Contnr.	-$0.13	-$0.13	-$2.85		-$1.04		$30	$[illegible]
Glass Brown Contnr.	-$0.13	-$0.13	-$2.85		-$1.04		$30	$[illegible]
Misc. Glass	$0.13	-$0.13	-$2.85		-$1.04		$30	$[illegible]
Food Contnr./Foil	-$0.13	-$0.13	-$2.85		-$0.90		$1620	$1,1
Beverage Cans	-$0.13	-$0.13	-$2.85		-$0.90		$1620	$1,1
Misc. Aluminum	-$0.13	-$0.13	-$2.85		-$0.90		$1620	$1,1
Food Container	-$0.13	-$0.13	-$2.85		-$0.90		$8.00	$2
Misc. Ferrous	-$0.13	-$0.13	-$2.85		-$0.90		$8.00	$2
Bimetal Cans	-$0.13	-$0.13	-$2.85		-$0.90		$8.00	$2
Misc. Inorganics	-$0.13	-$0.13	-$2.85		-$1.60			
HHW	-$0.13	-$0.13	-$2.85		-$12.66	-$448.56		
Textiles	-$0.13	-$0.13	-$2.85		-$1.31	-$0.14		
Rubber		-$0.13	-$2.85		-$1.13	-$0.16		
Fines		-$0.13	-$2.85	-$3.97	-$0.00			
Brush/Stumps		-$0.13	-$2.85		-$0.67	-$1.15		
Lumber	-$0.13	-$0.13	-$2.85		-$0.67	-$0.11		
Bulk	-$0.13	-$0.13	-$2.85		-$0.90			

Table 15 below summarizes the environmental impact of the 1990 baseline and of each of the three RPA solid waste management scenarios analyzed in this paper. The table is produced by multiplying the cost factors from Table 14 by the tons from Tables 10 - 13.

Table 15
Environmental Impacts of Alternative Waste Management Scenarios

	1990 Baseline	2015 - Implemented Integrated Waste Management Plans (Scenario 1)	2015 - No Source Reduction (Scenario 2)	2015 - Incineration- and Landfill-Only (Scenario 3)
Tons Prevented	0	3,794,719	0	0
Tons Recycled	1,881,121	7,656,795	9,137,886	0
Tons Composted	392,346	2,144,341	2,269,299	0
Tons Incinerated	4,282,797	8,525,471	10,070,402	14,570,531
Tons Landfilled	13,802,336	3,757,171	4,340,830	11,305,936
Total Tons	20,358,600	25,875,497	25,818,417	25,876,467
ENVIRONMENTAL (COSTS)/BENEFITS				
Prevention	$0	$840,360,557	$0	$0
Recycling	($5,026,439)	($48,363,059)	($56,862,390)	$0
Composting	($1,753,714)	($10,143,078)	($10,739,488)	$0
Incineration	($10,220,546)	($21,665,951)	($24,365,664)	($37,893,565)
Landfill	($[illegible],158)	($10,700,851)	($11,972,855)	($28,163,778)
Total Environmental (Cost)/Benefit	($57,641,857)	$749,487,618	($103,940,397)	($66,057,343)
Total Environ. (Cost)Benefit/Ton	($2.83)	$28.97	($4.03)	($2.55)

Before proceeding with the results of this analysis we need to address how the environmental impacts of implementing the source reduction programs were measured. Two environmental benefits and one potential environmental cost occur as a result of implementing a source reduction option. The environmental benefits are derived from eliminating the solid waste system truck and facility impacts for collecting and processing this waste. These collection impacts by material by collection type are reported on the first page of Table 14. The facility impacts that are prevented for each ton of waste that is source reduced are reported under the first six columns of the second page of Table 14.

Second, there will be no production facility impacts from producing this waste. These per ton environmental benefits from not producing materials are reported in the last column of the second page of Table 14.[56] Both of these impacts are captured in the results presented in Table 15.

Conceivably, reducing the amount of *materials* used would result in increased water or air impacts. For example, by not using disposable cups, impacts are produced by using hot water to wash the alternative ceramic cups. These additional impacts have not been measured in our work to date. A series of source reduction options should be evaluated against their more material-intensive alternatives in order to improve the quality of this overall assessment. However, because several source reduction processes (double-sided copying, buying goods minimally packaged) simply use fewer resources without increasing any other impacts, the results presented below are a good first approximation of the environmental benefits of many source reduction options.[57]

There are several important results found in Table 15. Comparing the 1990 baseline with the 2015 Scenario 1 we observe that as the integrated waste plans across the RPA region are implemented, the environmental costs produced by the solid waste management system decline. In fact, they become positive because of the dramatic effect that not producing waste has on the overall environmental impacts. Each ton of waste prevented results in an average environmental benefit of $221/ton.[58] This compares to an overall average environmental *cost* of $4/ton to manage a ton of waste through a waste management system with no reduction. Thus, not only is source reduction the economically preferable option, it is also the vastly preferable environmental option, and thus clearly belongs at the top of the hierarchy.

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[56]These values are the weighted average of production processes using virgin and secondary resources and will be described more fully in Section 5.

[57]For an excellent discussion of several source reduction programs with these non-impacting characteristics that are being implemented in both businesses and communities see Fishbein and Gelb (1992).

[58]$221/ton is calculated by dividing the total environmental benefit obtained by not producing all of the materials for which we had production system data for by the total tons of prevented waste. Since we have production data for only approximately 76% of the prevented waste stream, this result understates the environmental benefit of the prevention program. When we compare the overall *system* benefit by assigning the difference between the Total Environmental (Cost)/Benefit line from the reduction system (Column 3 of Table 15) and the no reduction program (Column 4) to the prevented tons, the benefit/ton is $225. This includes both the benefits from not producing this material and the benefits of not handling it in the waste management system.

Two additional points are of note here. One is that the environmental costs of producing materials are significantly larger (up to 100 times) than the environmental costs of managing them in a solid waste system, regardless of the option chosen. Second, if we compare the environmental cost of Scenario 2 (the no source reduction, but intensive recycling/composting system) with Scenario 3 (the disposal-only system - column 4 with column 5) we find that the environmental impacts of the recycling-intensive scenario are slightly larger than the disposal-only system ($38 million or $1.50/ton). In other words, systems that recycle large quantities of waste have slightly larger combined air and water impacts than systems that only burn and bury waste.

This is an interesting result that certainly challenges conventional wisdom. What produces this unusual result? Two general factors are at work here. As shown in Table 14 examining the unit costs of managing each material through each waste management method more closely reveals the source of this result.

First, the environmental costs of recycling collection programs are approximately five times higher per ton of material (this varies across materials) than the environmental costs of garbage collection. There are two sources of this impact. One is because material is not (generally) compacted in recycling collection programs. Thus, for example, a 25 cubic yard garbage packer truck collects 3 to 5 times more weight than a 25 cubic yard non-compacting recycling truck. In addition, in general, there are more tons of garbage collected per hour than recyclables.[59] Truck emissions are largely dependent upon how long the truck is actually running and since it runs approximately 3 to 5 times as long to collect a ton of recyclables as it does to collect a ton of garbage, emission factors scale in a similar way.[60]

Off-setting this negative effect of the recycling program is the positive effect of utilizing recycling facilities over incinerators and landfills. However, this facility offset does not outweigh the collection impacts, and thus, overall, the system with the intensive recycling programs has slightly higher solid waste system environmental impacts. One could argue again that since effective recycling programs are probably prerequisite for effective source reduction programs, the recycling program might be "credited" with some of the significant environmental benefits of the source reduction program. But, apart from that source-reduction credit, it appears that

[59]In New York City, pounds of garbage collected per hour range from 3,295 to 4,089, depending upon the population density of the neighborhood. Pounds of recyclables collected per hour range from 663 to 1,484 depending upon both type of recyclable and density of the neighborhood, "Baseline Solid Waste and Recycling Collection Program Evaluation", p. 17, Appendix 4-O in Appendix Volume 4.2 (NYC DOS 1992).

[60]This is only true when recycling programs target small amounts of material compared to disposal programs. If, at each stop, the same amount of material was placed out in the recycling container as in the disposal container, the time to collect a ton of recyclables would be roughly equal to the time to collect a ton of garbage.

recycling could at best be called "comparable" with disposal from a solid waste environmental perspective.[61]

Therefore, since recycling is not superior to but only competitive with disposal on a cost and environmental basis, is the solid waste hierarchy wrong? Is the menu-of-options school of integrated waste management right? We cannot answer these questions before we examine the technical, economic and environmental impacts of utilizing secondary as compared to virgin materials from the production system perspective. As the above analysis shows, production impacts are dramatically larger than solid waste system impacts across all materials. Thus, until the production perspective is added, we have an incomplete picture.

To summarize, so far we have addressed five of the eight questions we originally posed at the beginning of this paper. Source reduction belongs at the top of the hierarchy due to its reduction of environmental impacts in the solid waste system and in the production system and because of the economic savings in the operation of the solid waste system.[62] Furthermore, recycling (and composting) up to 50% of the remaining waste stream is technically feasible and is at least economically and environmentally competitive with a disposal-only system from a solid waste system perspective.

We now need to address the remaining three questions: Is utilizing up to 50% of the materials generated by recycling intensive solid waste systems in secondary production processes technically feasible, environmentally sound, and economically rational?

[61]Very conservative assumptions were used in this study, that were biased against the recycling programs. For example, many recyclables are, in fact, compacted, including many plastics and the majority of corrugated cardboard. However, in this study, all of the recyclables were assigned uncompacted truck impacts. In New York City, the proposed plan would have dual chamber, compacting trucks pick up textiles and paper in one half of the truck and compact them at roughly 4/1 ratio. Glass, metal and plastics would be placed in the second chamber and "squeezed" without destroying the quality of the material at a 2/1 to 3/1 ratio. Thus, in New York City, the recycling collection impacts would probably not offset the disposal facility impacts and the recycling intensive scenario would have *lower* environmental impacts than the disposal intensive system.

[62]A second economic question can be asked about source reduction and production system impacts: Does not increased output (i.e. making more things) create jobs, thus, if we make less output, do we not lower our overall standard of living? This position was argued by Kovacs (1992) at a conference in New Brunswick, NJ. In response to the material presented in the present paper Kovacs argued that its logical extension is that we would be better off not making anything. In fact, there is not a necessary relationship between "standard of living," even measured by its most crass indicator, per capita income, and per capita waste generation. Many countries produce much less waste per unit of income then does the United States. Norway produces $22 of income per pound of waste, while the United States ranks 13th with $9.44 of per capita income per pound of waste (Denison and Ruston 1990). Disputing the claim that Americans waste resources is a common theme found in the "menu of options" school of waste management (Scarlett 1991 and Logomasini 1991).

Section 5 Does the Solid Waste Hierarchy Make Sense from a Production System Perspective?

5.1 Is It Technically Feasible to Utilize 50% Secondary Content in Production Processes?

Column 2 of Table 16 describes the amount of secondary content that is currently technically feasible to include in the production of several types of packaging and non-durable goods. Column 3 identifies the existing level of secondary content utilization across each major material. These findings are based on several sources from solid waste and industry publications.[63]

Table 16
Technically Feasible Levels of Secondary Content and Existing Secondary Content Levels - (1990)

Material	Technical Feasibility Level	Existing Secondary Content
Corrugated Cardboard	100%	19%
Boxboard*	100%	47%
Bags and Sacks	25%	7%
Glass Containers	100%	30%
Steel Packaging Structural Steel	40% 100%	12%
Aluminum Containers	93%	55%
Plastics (All Resins)	0-100%	0-1%
Newspapers	100%	23%
Writing Paper	100%	6%
Towel and Tissue	100%	58%

* Boxboard is the material used to make containers such as cereal boxes, shoe boxes, etc.

Technical feasibility is not the limiting factor in the utilization of 50% secondary content in essentially all industries except plastics. At present, the plastics industry is relying heavily on

[63] Corrugated Cardboard (Apotheker 1992b); Boxboard and Bags and Sacks (Apotheker 1991a); Glass (Apotheker 1991b); Steel Cans (Apotheker 1992a and Tellus 1992b, Vol. II, Chapter 5, p. 10); Aluminum (Creel 1991 and Apotheker 1991c); Plastic Resins (Glenn 1991 and Powell 1991a, 1991b); Newspaper, Printing and Writing Paper, and Tissue (American Paper Institute 1991).

non-packaging uses to absorb the packaging recovered from the waste stream. However, even in the plastics field, the trend to utilize materials in its own packaging is proceeding across several different resin categories (Glenn 1991; Powell 1991a, 1991b). If, apart from some plastic resins, technical feasibility is not a limiting factor, then what about the relative environmental impacts of utilizing secondary materials as opposed to virgin resources?

5.2 Is It Environmentally Sound to Utilize 50% Secondary Content in Production Processes?

To answer this question, we need to compare the production impacts that occur from the production of materials using virgin with the impacts that occur from the production of materials using already existing, (i.e. secondary) materials. This is precisely what the Packaging Study did for five different packaging materials that comprise roughly 25% of the total MSW waste stream and 33% waste stream excluding food and yardwaste (corrugated cardboard, boxboard, glass, steel and aluminum). However, the production benefits of using secondary compared to virgin resources for these five materials were applicable to over 83% of the materials targeted for recycling in the RPA integrated waste management scenario. For example, although we did not model the virgin and secondary production processes for newspaper, because recovered newspaper can be used in making corrugated cardboard or boxboard, it could be assigned a value derived from the boxboard and corrugated values (Tellus 1992d). Table 17 below, taken from the larger Table 4, describes the environmental impacts from the production of each of the five packaging materials for which the Tellus Packaging Study generated estimates of both virgin and secondary production impacts.

Table 17
Environmental Impacts from the Production of Materials Using Virgin Resources and Recycled Materials

Material	Environ'l Cost Impact of Use of Virgin Material ($/Ton)	Environ'l Cost Impact of Use of Secondary Material ($/Ton)	Difference between Virgin and Secondary Materials Use ($/Ton)	Virgin as a Percent of Secondary
Corrugated Cardboard	$214	$150	$64	143%
Boxboard	$269	$135	$134	200%
Glass	$85	$55	$30	154%
Steel Containers	$230	$222	$8	104%
Aluminum	$1,933	$313	$1,620	618%

Thus, in every case the impacts from virgin production are significantly (43% to 518%) greater than the impacts from secondary production, except in steel packaging. The relatively smaller difference for steel is the result of utilizing only 12% non-prompt scrap secondary content in the recycled steel package.[64] Thus, the real benefit of utilizing 100% secondary steel in an electric arc furnace relative to utilizing 100% virgin content is greatly underestimated by using the recycled steel can packaging process as an estimate for steel recycling.

The last step in comparing the *environmental production* impacts of a recycling-intensive solid waste management scenario and a disposal-intensive system is to assign the materials recycled in the recycling-intensive system with their appropriate secondary material production credit (column 4 in Table 17 - this is also reported in the second to last column of the second page of Table 14). Those materials for which production data were not available, but could be used in one of the processes for which data were available, were assigned the substitute production process credit. (For example, since newspaper can be used to make boxboard and corrugated cardboard it was assigned the average of the corrugated and boxboard secondary benefit.) Where no information was available on a secondary process, such as for all of the

[64] Steel can production uses the basic oxygen furnace which can only use at most 40% secondary content. Roughly 28% of the raw material input to all basic oxygen furnaces is prompt scrap, scrap material generated in-house as part of the normal production process. Thus, the maximum possible difference between "virgin" steel cans and "recycled" steel cans is 12% post-consumer secondary material. If the $8 reduction in environmental impacts was equal to every 12% increase in use, then a process that used 100% secondary steel would produce a $67 reduction in environmental impacts per ton of steel. This would make virgin steel 37% more burdensome than secondary steel.

plastic resins, an environmental production credit was not assigned to the recycled materials. Table 18 below repeats the environmental results of the baseline and three RPA alternative management scenarios reported in Table 15, except it now assigns (where possible) the recycled-content production credit identified in Table 17 (and 14) to each of the tons of material recycled in each scenario.

Table 18
Environmental Impacts of Alternative Waste Management Scenarios Including Production System Benefit from Recycled Materials

	1990 Baseline	2015 - Implemented Integrated Waste Management Plans (Scenario 1)	2015 - No Source Reduction (Scenario 2)	2015 - Incineration-and Landfill-Only (Scenario 3)
Tons Prevented	0	3,794,719	0	0
Tons Recycled	1,881,121	7,656,795	9,137,886	0
Tons Composted	392,346	2,144,341	2,269,299	0
Tons Incinerated	4,282,797	8,525,471	10,070,402	14,570,531
Tons Landfilled	13,802,336	3,757,171	4,340,830	11,305,936
Total Tons	20,358,600	25,875,497	25,818,417	25,876,467
ENVIRONMENTAL (COSTS)/BENEFITS				
Prevention	$0	$840,360,557	$0	$0
Recycling	$163,739,060	$835,043,360	$991,791,442	$0
Composting	($1,753,714)	($10,143,078)	($10,739,488)	$0
Incineration	($10,220,546)	($21,665,951)	($24,365,664)	($37,893,565)
Landfill	($40,641,158)	($10,700,851)	($11,972,855)	($28,163,778)
Total Environmental Cost	$111,123,643	$1,632,894,037	$944,713,435	($66,057,343)
Total Environ. (Cost)Benefit/Ton	$5.46	$63.10	$36.59	($2.55)

Now, rather than being roughly analogous to the disposal-only system, the recycling-intensive system produces an environmental benefit over the disposal-only system of $1.0 billion in the year 2015. Between 2000 and 2015 this benefit is $13.3 billion for the 107 million tons of material recycled during this period. This is a benefit of, on average, $120/ton for every ton of material recycled.[65] Since only 83% of all recycled materials receive this production credit, as more secondary production processes are modelled and evaluated, especially plastics, it is likely based on the current findings that this environmental benefit of recycling-intensive systems will only grow.[66]

This overall environmental benefit has been derived in a very detailed manner, based on the differential disposal and production system impacts of different materials described previously. But it can also be understood in more simple terms.

One of the major differences between the use of virgin and secondary materials is the amount of energy needed to produce the given material. The energy difference between producing materials from virgin resources and producing them from secondary materials was determined as part of a comprehensive study conducted for the New York State Energy Research and Development Authority (NYSERDA) (Tellus 1992e). The results of this analysis are presented in Table 19. In the 1970s the energy balances between virgin and secondary materials were studied in great depth due to the energy crisis. However, using less energy also means emitting fewer pollutants since energy production is a significant source of the total environmental impacts in materials production. For some materials, such as virgin glass, the impacts from energy production are 97% of the total environmental impacts. For aluminum they are 78% of the total. For various paper grades, they range between 70% and 90%. For steel and various plastics, they range from 30% to 60%, except for PVC which is only 4%.[67] Thus, given that it takes less energy to make packages and products from secondary materials than from virgin resources, it follows that this reduced energy requirement not only saves energy, it prevents a significant percentage of the environmental impacts associated with material production.

Table 19 presents the energy impacts from production processes using virgin and secondary resources to make several materials that were not investigated in the Packaging Study. Early in this section, I argued that since only 83% of all recycled materials received a secondary production system benefit, we were likely undercounting the benefit of the recycling system.

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[65]The total in the year 2015 is the difference between the Total Environmental Cost of Scenario 2 (No Source Reduction) minus the Total Environmental Cost of Scenario 3 (Incineration- and Landfill-Only). The total for the 15 year period is derived by taking the total difference for the year 2000, adding the total difference for the year 2015, dividing by 2 to get an average year's difference and then multiplying by the 15 year period. This assumes, as the modelling methodology warrents, that the changes in the system from year to year are linear. The per ton benefit is derived by dividing the total benefit by the total tons recycled during this period.

[66]This analysis has also not credited compost production with replacing either chemical fertilizers, soil amendments or any other materials that compost may replace.

[67]See Tellus (1992b) Volume 1, Report 4, Chapter 3, Table 3.1 for the exact percentage for each material.

Plastic resins were the major missing gap. The plastics data reported in the last three rows of Table 19 lends support to this claim. The ratio of secondary to virgin energy requirements is lower than for any other material except aluminum. Since energy production has a significant impact on total environmental impacts, especially for energy-intensive materials like plastic resins, it is likely the overall environmental impacts of making plastic from secondary resins are significantly lower than making them from petrochemicals.

Table 19
Energy Requirements from Production Processes Using Virgin Resources Compared to Secondary Materials[68]

Material	Energy Requirements of Virgin Production (MM Btu/ton)	Energy Requirements from Secondary Production (MM Btu/ton)[69]	Difference Between Virgin and Secondary Production (MM Btu/ton)	Ratio of Secondary Material Energy Use to Virgin
Linerboard	31.19	24.81	6.38	80%
Boxboard	29.92	24.04	5.88	80%
Newsprint	28.81	17.66	11.15	61%
Writing Paper	37.57	17.29	20.28	46%
Glass	7.38	4.65	2.73	63%
Aluminum	166.91	9.39	157.52	6%
Steel	20.93	8.31	12.62	40%
LDPE	63.59	16.38	47.21	26%
HDPE	49.78	11.13	38.65	22%
PET fiber	46.28	11.13	35.15	24%

[68] This table is constructed from Table 3.3 in Tellus (1992e).

[69] This value includes the energy consumed in collecting and processing the recyclables and transporting the recycling residues to disposal sites. However, as the Tellus NYSERDA study (1992e) demonstrates, the energy saved from production processes that use the secondary material produced by solid waste systems that recycle 30% of their waste saves 10 to 100 times (depending largely upon the amount of waste-to-energy capacity used) more energy than the entire solid waste system uses.

5.3 Is It Economically Rational to Utilize 50% Secondary Content in Production Processes?

This is the final question we need to resolve in order to answer the question "Does the Solid Waste Hierarchy Make Sense?" I know of no research to date that compares all of the "conventional" production costs of making each material from virgin resources to the costs of using secondary materials. Table 16 indicates, however, a significant amount of production capacity is already producing every material (with the exception of plastics) from secondary material. Thus, we could conclude that it must be cost competitive under some circumstances to make all packaging materials (except plastics), newspaper, towel and tissue and writing paper from secondary content. This is certainly the case in well-established secondary content utilizing industries such as aluminum, steel, glass, newsprint, boxboard, and corrugated cardboard. It is significant to note that this 1990 level of secondary content utilization had not yet been influenced by the several state secondary content laws passed in the 1990-92 period. It is simply the result of market forces responding to an increased supply of material. This level of production has also not yet accounted for the impact that would occur if the secondary processes were credited with the difference in environmental externalities between virgin and secondary production. Indeed, the best defense of the economic viability of secondary production facilities comes from a paper industry representative at the 1992 EPA Solid Waste Management Conference who claimed the firms using secondary content had profit margins in 1991 4-5 times greater than those companies using virgin resources (Horton 1992).[70]

However, to determine whether we can *increase* the existing secondary content utilization from current levels to those that would insure that at least 50% of the major material production capacity was using secondary content, another cost component must be assessed. This is the transition cost in moving from existing virgin and secondary production levels to 1) reduced utilization of virgin resources and 2) increased utilization of secondary materials.

No research to date has systematically explored the costs involved in undertaking and sustaining this transition. I have elsewhere described the research agenda that would need to be addressed to answer this question (Schall and Lifset 1992, 2,14).[71] Once again, empirically, the fact that so many individual businesses are switching to increased use of recycled content suggests there are cost effective ways to accomplish it. Between 1988 and 1990 all packaging materials incorporated increased amounts of secondary content, some significantly (Schall and Lifset 1992, 13).[72] According to industry sources (Iannazzi and Strauss 1992), the paper

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[70] This statement is interesting at another level as well. It supports the obvious, though often ignored, fact that what communities (or paper dealers) experience as a "paper glut" translates into increased profitability for secondary paper manufacturers.

[71] Research examining such transition costs will be conducted by Tellus for the Regional Plan Association of NYC beginning November 1992.

[72] Glass grew from 12% to 30%, aluminum from 41% to 55%, corrugated cardboard from 16% to 19%, and boxboard from 45% to 47%.

industry is projected to increase consumption of secondary fiber by on average 50% across all major paper grades between 1992 and 1995. This is in some measure a result of the increased profitability of secondary paper manufacturers described above. It is also, no doubt, a response to the passage of secondary content legislation in several states and the projected passage of many more.

Finally, we can think of the environmental benefit realized by the utilization of secondary content as a potential offset to cost increases that may be incurred achieving this increased secondary content system. Thus, even if there were a cost to move from the current 19% utilization rate for corrugated cardboard, for example, to the 50% or higher rate, the $64/ton environmental benefit could be considered as a potential offset to the cost of the transition. As we just demonstrated, for the RPA region, this environmental benefit between the years 2000 (when the RPA region's plans will be fully implemented) and 2015, is $13.3 *billion* or roughly $120/ton for every ton of material recycled.

Section 6 Summary of Major Findings

From the results of the research conducted by the Tellus Institute in addition to industry data, it appears that the solid waste hierarchy is on firm technical, economic and environmental footing. Below, I repeat the eight questions posed in Section 2 and summarize the answers generated by the research described in this paper.

1. When waste is prevented through source reduction activities, how much money does the solid waste system save in avoided collection, processing and disposal system costs?

In the RPA study, we found that if the source reduction goals of New York, New Jersey and Connecticut are realized in the 31 county metropolitan New York City region, the solid waste system will prevent 43 million tons of waste at a conventional solid waste system cost reduction of $4.25 billion between 2000 and 2015. This is roughly $100/ton of waste prevented.

2. What are the environmental benefits realized by the reduced collection, processing and disposal of waste and recyclables, *and* what are the environmental benefits obtained by avoiding production of these materials in the first place?

Preventing this 43 million tons of waste during this time period for the RPA region produces $7.6 billion in reduced environmental impacts to the air and water. This is approximately $170 per ton of waste prevented. Approximately $4/ton is the reduced solid waste system impacts and $166/ton is from the production system impacts.

3. Is a 50% recycling level technically feasible? Are there enough materials in the waste stream with the physical properties that allow them to be reused as raw materials in production processes? Do the participation programs exist to get them out of the waste stream and at the curb or drop-off center? Do the collection systems exist to collect them? And finally do the processing facilities exist that can turn them back into raw materials available for use in secondary production processes?

The RPA region can achieve a 44% recycling and composting rate by the year 2000 by implementing collection programs targeting materials already being collected in curbside and dropoff recycling and composting programs across the country. The region does this based on participation and capture rates only in the mid range of rates already being achieved. By 2015, the recycling/composting rate will increase to 47%. Thus, technical limitations, either based on materials in the waste stream or on the participation programs, collection systems, or processing facilities, are not a limiting factor in realizing a 50% recycling and composting rate.

4. Is a 50% recycling level economically rational? Is it cost-effective to implement the public participation programs, collection systems, and processing facilities described above rather than leaving these materials in the "garbage," picking them up in garbage trucks and hauling them off to the incinerator or landfill?

Implementing the integrated solid waste management plans in the New York, New Jersey, and Connecticut RPA region results in overall system costs declining on a per/ton basis from the 1990 baseline. Per/ton costs go from $138/ton in 1990 to $132/ton in 2000 to $119/ton in 2015. However, the major source of this cost decline results from the source reduction program already accounted for in Question 1 above. When two region-wide systems were compared, one with no source reduction but realizing the state mandated recycling/composting goals and another that simply collected all waste as garbage and buried or burned it, the disposal-only system was 2% less expensive ($3/ton). This meant, essentially, that recycling and composting 47% of the region's waste stream was no more expensive (but also no less so) than burying or burning this same material.

5. Is a 50% recycling level environmentally sound? What are the differential environmental impacts of implementing the 50% recycling/composting system versus implementing the disposal-only alternative?

This research found that the recycling-intensive solid waste system was no more environmentally advantageous than the disposal-intensive system. Although recycling facilities had lower environmental impacts than incinerators and landfills, recycling collection programs produced greater environmental impacts than the garbage collection programs. This latter effect offset the former and the net difference between the recycling and disposal-intensive systems was roughly comparable. Because some recyclables were collected in compacting vehicles and because all landfills and incinerators were modelled with state-of-the-art pollution control equipment, this part of the study was strongly biased towards the disposal-only system.

6. Is it technically feasible to incorporate the materials that make up this 50% of the waste stream in secondary production processes across the country and the world?

Across all material categories, it was found that technical feasibility for utilizing up to and over 50% secondary content was not a limiting factor for any material targeted by the intensive recycling systems except plastics. However, even in the case of plastics, it appears from recent developments that the technical limitations to incorporating secondary plastics in both packaging and non-packaging applications will be overcome and use of secondary plastics will be feasible.

7. Is it environmentally beneficial to utilize 50% secondary content instead of its virgin material alternative, in each of the various production processes that would be the consumers of this secondary material?

Employing secondary content in production processes dramatically reduced environmental impacts. Virgin resource impacts range from 43% to 518% greater than their secondary-material counterparts. These reduced environmental impacts would result in a net environmental benefit from the implementation of the recycling-intensive RPA region waste management plans of $13.3 billion for the 107 million tons of material recycled during the period 2000 to 2015. This production system benefit averaged $120/ton. Because the differential environmental impact (comparing production using virgin resources to production using secondary material) only included 83% of the recycled material, the total and per-ton environmental benefits are likely to be understated. The fact that recycled plastics (the major material making up the 17% of material with unknown differential virgin/secondary impacts) use dramatically less energy supports the premise that the overall environmental benefit of using secondary materials is greater than reported in these findings.

8. Finally, does it make economic sense for production facilities to utilize, on average, 50% secondary content, compared to its virgin material counterpart?

There is no definitive data available on this issue to date. However, circumstantial evidence suggests that for the vast majority of materials, production processes utilizing secondary content compete effectively with processes utilizing virgin resources. In addition, the growth of secondary content in the last five years suggests that the transition to even greater levels of secondary content can be cost-effectively accomplished. However, determining the precise cost characteristics of this transition -- to an industrial structure that uses up to 50% secondary content, on average, across all material industries -- is an important topic requiring further research.

Implementing the integrated waste management plans for the 21 million person RPA New York, New Jersey, and Connecticut region will result in dramatic economic and environmental benefits to the solid waste and production systems. The cost reduction during the period from 2000 to 2015 for this region would be $25.15 billion. This is $1.68 billion per year. Of this total, $4.25 billion is attributable to the effect on the conventional solid waste system costs of preventing 43 million tons of waste. $7.6 billion is the avoided environmental impacts gained by not building and operating the solid waste collection trucks and facilities to handle this waste, as well as from the avoided environmental impacts created by not producing this 43 million tons of material. Combined, the prevention program savings are $11.85 billion or $270/ton. Finally, $13.3 billion is attributable to the reduction in environmental impacts that will occur by replacing in the production processes 107 million tons of virgin resources with recyclables generated during this 15 year period. This produces a net environmental benefit of $120/ton of recycled material.

Section 7 Can the Results of This Research Be Generalized to the United States as a Whole?

Before drawing final conclusions about what this body of research tells us about the solid waste hierarchy, I need to address the important question: "What parts of this research can be used to generalize across the United States (and beyond) and what parts cannot?" For each of the eight issues addressed in this paper, the answer will vary.

Certainly, the economic and environmental benefits of source reduction are generalizable across all parts of the country. The magnitude of the economic benefits will depend upon both the amount of reduction that occurs and the costs of the solid waste system, and those costs vary widely. An 8%-12% source reduction program will reduce overall system cost by approximately 70% of the average system cost for every ton of waste reduced.[73] However, the environmental costs described in this working paper were developed for generic processing and disposal facilities and for generic production facilities. Thus, the $170/ton environmental benefit of source reduction can be applied to the prevention of waste in the U.S. as a whole. In other words, if 10% of the 200 million tons of waste generated in 1990 had been prevented, a net environmental benefit of $3.4 billion could have been realized. If we assume that the average cost of managing waste in the U.S. is $100/ton for collection, processing, transportation and disposal (compared to the RPA region's $138/ton) the conventional cost savings of a 10% reduction program would be $1.4 billion/year in reduced solid waste management costs. Thus, if this 10% source reduction program were implemented by the year 2000, between 2000 and 2015 the U.S. would realize a $72 billion benefit in reduced solid waste system costs and reduced environmental impacts.

The technical feasibility of implementing a 50% recycling and composting program is also readily generalizable across the U.S. There is nothing unique about the materials, collection programs, or processing facilities used in the RPA region.

Ideally, determining the conventional solid waste management costs of achieving a 50% recycling and composting rate nationwide would involve modelling the existing solid waste management systems for each region of the country. For each region, alternative scenarios should be constructed around region-specific variables. There are, of course, significant regional differences in the cost of disposal, a key factor in determining the cost-effectiveness of recycling programs. However, there are a number of regions, including areas of the Southeast, Midwest and West Coast that have adopted more stringent landfill pollution control requirements and where disposal costs are approaching those levels seen in the Northeast (and used in the RPA study).

In addition, because the RPA study makes no allowances for rising disposal costs due to the depletion of existing landfills, it understates the cost-effectiveness of achieving a 50%

[73]For a discussion of the impact of more- or less-effective source reduction programs on overall solid waste management system costs see the New York City Comprehensive Waste Management Plan, Appendix Volume 7.1, Section 7-A.5, Prevention memo #3.

recycling level. It is widely assumed that landfill costs will continue to rise (apart from temporary, recession-influenced disturbances) because of the continuing decline in landfill capacity, the promulgation of new federal landfill regulations, and the expected passage of federal legislation allowing states to limit the interstate transport of wastes. These factors will all increase landfill scarcity, increase the costs of waste disposal, and thus make recycling even more economical.

If landfill costs continue to rise around the country, then costs in the RPA region will exceed those used in this research, while costs in many other areas will reach the levels used here. Thus, it appears to be prudent public policy to assume that by 2000, disposal costs in other parts of the country will be more like Northeast costs today than like existing costs in other regions today. Therefore, the finding that recycling is *at least* cost competitive with disposal is a realistic first approximation, and is likely to be an understatement.

Likewise, the environmental comparability between recycling- and disposal-intensive programs would, if anything, be more favorable to the recycling systems if the environmental impacts of actual disposal facilities were used, rather than the impacts of projected facilities in the year 2000 using state-of-the-art pollution control technologies. More importantly, the strong finding that utilizing up to 50% of the waste stream in new production processes is technically feasible is not region-specific, but applies to the country as a whole.

Finally, the most striking result of this research is the environmental superiority of utilizing secondary materials over virgin resources in every production process studied. This finding is completely generalizable across the country as a whole. In addition very strong partial evidence supports the claim of the environmental superiority of secondary material for those items such as newspaper and plastics for which only energy data were available. If the benefit in the RPA region (roughly 8% of the population with roughly 10% of the garbage) is representative of the benefit realized by managing the other 90% in the same way, the total environmental benefit from recycling and composting 50% of our waste stream, and utilizing this same material in production processes, would produce an environmental benefit of over $130 billion during the period 2000 to 2015.

Thus, the total measurable benefit of implementing the solid waste hierarchy across the United States during the period 2000 to 2015 would be $202 billion. $72 billion would come from the source reduction program and $130 billion would come from the recycling program.

Thus, even if the final issue, namely the economic cost to industry of engaging in this transition to secondary materials does have a positive cost, this $202 billion can be thought of as the amount up to which society could invest in this transition and still produce a net social benefit.

Section 8 Conclusion

The overwhelming conclusion of this research is that the solid waste hierarchy is on a firm technical, economic and environmental foundation. However, for this foundation to be fully understood the impacts of preventing waste and recycling waste must be understood from both a solid waste system and production system perspective. To do this, we must think about solid waste within a framework that includes production level issues -- decisions about what to produce, how much to produce, and what to use in terms of raw material inputs into those production processes. If solid waste managers think about what they do as managing garbage, even in an "integrated" manner, they will not be able to implement the solid waste hierarchy, even though it makes technical, economic and environmental sense. It is not the solid waste hierarchy that is wrong. Rather, it is the framework of integrated solid waste management that is wrong. To implement the solid waste hierarchy, solid waste managers must participate in the larger endeavor of managing all of society's resources.

This working paper began by discussing three intractable problems that have stopped the initial success of "integrated solid waste management" cold in its tracks. These three problems are:

1) the inability of solid waste managers to implement source reduction programs that effectively reduce the production of materials that end up as waste;

2) the inability to develop adequate markets for the materials that are being generated as progress is made toward realizing state and national percentage recycling/composting goals; and

3) the difficulty of structuring the public/private sector relationship so that the legitimate public sector objectives of creating recycling and composting capacity, minimizing disposal capacity, and minimizing cost and environmental impacts can best be realized through combined public and private sector activities.

Solving these three problems requires solid waste managers to first develop and then employ a new materials management framework for addressing issues of both solid waste and resource use. It will also require that we explore the workings of the marketplace as they apply to solid waste and resource allocation. The market is the institution that is supposed to insure that none of this becomes a problem in the first place. With respect to implementing the solid waste hierarchy, however, it has failed badly. Thus, developing a materials management framework and exploring why the market fails to develop the optimal mix of waste management options is the agenda that must be pursued if we are to maximize the amount of waste we reduce and then maximize the recovery of what remains. More importantly, it is the agenda we must pursue if we are to manage resources in a sustainable and equitable manner.

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Appendix 1[74]

Description of WastePlan

Overview

WastePlan, Tellus Institute's solid waste planning model, is a microcomputer-based model for use in integrated solid waste planning. Developed for the Office of Technology Assessment, it has been enhanced and applied in the states of Michigan, Illinois, Ohio, Tennessee, New York and is now being used in Maine, Indiana, Delaware, California, and New York City.

There are four major interactive programs in WastePlan: Waste-Stream Definitions, Waste-Stream Generation, Collection, and Facilities.

Waste-Stream Definitions

The first program defines the individual waste components that make up each of the waste streams (including residential, institutional, commercial and industrial) It then defines the physical characteristics of each of these components, including their density (lbs/cu.yd), the heating content (btu.s/lb), ash content (%), ultimate analysis (% oxygen, hydrogen, carbon, nitrogen, chlorine, etc) and metal content (parts per million). This program also allows the identification of each waste stream component to be handled by a particular waste-prevention program, recycling program, composting program, resource recovery program, or landfilling program.

Waste-Stream Generation

The second program then generates each of the waste streams defined in the Definitions Program. It does this by identifying the demographic and/or economic activities that are responsible for producing each of the waste streams. Once the activity unit or waste-stream "driver" is identified, the amount of waste that each of these units currently generates is specified. The total waste quantity is then calculated by multiplying the activity units by the waste-generating factor. The composition of this quantity of waste is then calculated using generator specific waste-composition information.

Within each waste stream, several substreams can be produced. For example, the residential waste stream can be comprised of the waste streams produced by different housing and density strata, for example single versus. multi-family. The commercial waste stream can be produced by several different commercial sectors (e.g. retail, foodstore, eating and drinking establishments, motel and hotel, wholesale, etc.) For

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each substream, the waste-generating unit (e.g. people), the waste-generating factor (e.g. lbs/person/day), and the composition of waste produced by that strata are identified, and then the total level of activity (e.g., total population) in that strata is specified. WastePlan will then take the results of each substream and aggregate them into a total waste-stream quantity and composition analysis.

Finally, the waste streams can change over the defined planning period in three ways. The user can define a percentage change in the waste-generating factor, in the total number of waste-generating units, or in the composition of each of the waste-stream components.

Collection

Once the waste streams have been generated, the collection systems are modelled. First, the physical and financial characteristics for the range of collection equipment (trucks and containers) that might be used in the various systems for collecting each waste stream are described. Combinations of this equipment can then be "selected" in order to model the effects of various alternative collection systems. For collection systems that require the active participation of the waste generators (e.g. source-separation recycling or composting programs) participation and capture rates can be defined for each subsector identified in the Generation Program. Specific collection system characteristics, such as crew size, collection efficiency, average miles from the route to the given facility, miles per hour traveled, and collection frequency, are then defined for the selected collection equipment. The Collection Program will then calculate the total number of vehicles and containers required to collect the given waste stream, the capital and operating cost of each collection system, the total miles travelled, along with some of the other factors needed to assess the characteristics of the alternative collection systems. Where the total number of required vehicles and containers cannot be modeled or where collection programs simply charge either a fixed collection cost per household or per ton, total collection costs will be determined by identifying the unit collection cost and multiplying by the total number of units.

Facilities

Once all of the waste streams have been "collected" within the model, they can be routed to the portion of the model that includes each of the potential facilities that will be evaluated in the plan. Using the WastePlan Default Data report, WastePlan will model each type of facility that could accept any of the waste streams. These facilities will include materials buy-back centers, drop-off locations, and intermediate processing centers for recyclables; commercial dump-and-sort operations; windrow compost facilities and in-vessel composting facilities with front-end separation; transfer stations; waste-to-energy facilities of all types, including modular and field-erected mass-burn plants and refuse-derived-fuel facilities, with or without front-end materials separation and processing; and ashfills and landfills.

WastePlan can then calculate, for a facility of a given size and type, the number of facilities required, the land area needed for each facility, the building size, the types and amount of required equipment, the capital and operating costs, the amount of any revenues from materials recovery or energy production, and the quantity of residue produced. In the case of waste-management options that would require only a single facility to process and/or dispose of all its targeted waste stream, WastePlan will determine the required facility size and then calculate its cost structure from given unit-cost factors.

Scenario Development

Once the data for waste streams, collection systems, and processing/disposal facilities is loaded in, WastePlan can produce a scenario based on a given set of assumptions very quickly. Alternative scenarios in which either specific assumptions from prior scenarios are changed, or in which entirely different collection and/or processing/disposal facilities are considered, can then be developed.

Model Output

The WastePlan model will produce, depending upon the complexity of the scenario and the level of detail requested by the user, output reports of 50 to 60 pages or more. The material in these outputs will include:

- a detailed description of the quantities and composition and physical properties of the waste streams generated both in aggregate and by subsectors;
- a description of the physical requirements, e.g. the numbers and types of collection vehicles used for each program, and the basic land, building, and equipment requirements for each type of facility;
- a summary of all costs, including total and per-ton capital and operating costs for each type of waste-management program, and for the overall scenario.

WastePlan will also produce summary reports that provide the total cost of each waste-management scenario and each subsystem component, the total tonnage handled by each subsystem component, and the per-ton costs overall and by subsystem.

For More Information

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Appendix 2

Cancer Potency Factors and Reference Dose Responses for Hazardous Substances

Table A.1
Carcinogens: Potency Factors and Isophorone Equivalents

Pollutant	Cancer Potency	Isophorone Equivalents
Acenapthene		
Acenapthylene		
Acetone		
Acetophenone		
Acrylonitrile	5.40E-01	138
Aluminum		
Ammonia		
Anthracene		
Antimony		
Arsenic	5.00E+01	12821
Barium		
Benzene	2.90E-02	7
Benzo(a)anthracene		
Benzo(a)pyrene		
3,4-Benzoflouranthene		
Benzo(k)flouranthene		
Benzo(ghi)perylene		
Benzoic Acid		
Beryllium	4.30E+00	1103
Biphenyl		
Bis(2-ethylhexyl)phthalate	1.40E-02	4
1,3-Butadiene	1.80E+00	462
2-Butanone		
Butyl benzyl phthalate		
Cadmium	6.10E+00	1564
Carbon disulfide		
Carbon tetrachloride	1.30E-01	33
Chlorine		
Chlorobenzene		
Cloroethane		
Cloroform	6.10E-03	2
p-Chloro-m-cresol		
2-Chlorophenol		
Chloroprene		
Chromium		
Chrysene		
Copper		
Coke oven emissions		
p-Cresol		
Cyanide		
2,4-D		
4,4-DDT	9.70E-06	2.49E-03
Dibenzo(a,h)anthracene		

Carcinogens: Potency Factors and Isophorone Equivalents

(continued)

Pollutant	Cancer Potency	Isophorone Equivalents
1,4-Dichlorobenzene	2.40E-02	6
Dichlorobromomethane		
1,1-Dichloroethane		
1,2-Dichloroethane	9.10E-02	23
1,1-Dichloroethylene	6.00E-01	154
1,2-trans-dichloroethylene		
2,4-Dichlorophenol		
1,2-Dicloropropane	6.80E-02	17
1,3-Dicloropropene	1.80E-01	46
Diethyl phthalate		
2,4-Dimethylphenol		
Dimethyl phthalate		
Di-n-butyl phthalate		
4,6-Dinitro-o-cresol		
2,4-Dinitrotoluene	6.80E-01	174
2,6-Dinitrotoluene	6.80E-01	174
1,2-Diphenylhydrazine	8.00E-01	205
Endosulfane sulfate		
Ethylbenzene		
Ethylchloride		
Ethylene oxide	3.50E-01	90
Fluoranthene		
Fluorene		
Fluoride		
Hexachlorobenzene	1.60E+00	410
2-Hexanone		
Hydrogen chloride		
Hydrogen fluoride		
Hydrogen sulfide		
Indeno(1,2,3-cd)pyrene		
Iron		
Isophorone	3.90E-03	1
Lindane		
Lead		
Magnesium		
Manganese		
Mercury		
Methane		
Methylene chloride	7.50E-03	2
4-Methyl-2-pentanone		
Napthalene		
Nickel	8.40E-01	215

Carcinogens: Potency Factors and Isophorone Equivalents

(continued)

Pollutant	Cancer Potency	Isophorone Equivalents
Nitrobenzene		
PAHs	1.15E+01	2949
Parachloronitrocresol		
Pentachlorophenol		
Phenanthrene		
Phenol		
Propylene	2.40E-01	62
Pyrene		
Selenium		
Silver		
Sodium hydroxide		
Styrene	3.00E-02	8
Sulfides		
2,3,7,8-TCDD	1.50E+05	38461538
2,3,7,8-TCDF		
Tetrachloroethylene	5.10E-02	13
Thallium		
Thiocyanates		
Tin		
Toluene		
1,1,1-Trichloroethane	5.70E-02	15
Trichloroethylene	1.10E-02	3
Trichlorofluoromethane		
2,4,6-Trichlorophenol	1.10E-02	3
1,2,3-Trichloropropane		
Triethanol		
Vanadium		
Vinyl chloride	2.30E+00	590
Xylenes		
Zinc		

Table A.2
Noncarcinogens: Reference Dose, 1/RD and Xylene Equivalents

Pollutant	Reference Dose, oral	1/RD	Xylene Equivalents
Acenapthene	6.00E-02	17	33
Acenapthylene			
Acetone	1.00E-01	10	20
Acetophenone	1.00E-01	10	20
Acrylonitrile			
Aluminum			
Ammonia	9.71E-01	1	2
Anthracene	3.00E-01	3	7
Antimony	4.00E-04	2500	5000
Arsenic	1.00E-03	1000	2000
Barium	5.00E-02	20	40
Benzene			
Benzo(a)anthracene			
Benzo(a)pyrene			
3,4-Benzoflouranthene			
Benzo(k)flouranthene			
Benzo(ghi)perylene			
Benzoic Acid	4.00E+00	0.25	1
Beryllium	5.00E-03	200	400
Biphenyl	5.00E-02	20	40
Bis(2-ethylhexyl)phthalate	2.00E-02	50	100
1,3-Butadiene			
2-Butanone			
Butyl benzyl phthalate	2.00E-01	5	10
Cadmium	5.00E-04	2000	4000
Carbon disulfide	1.00E-01	10	20
Carbon tetrachloride	7.00E-04	1429	2857
Chlorine			
Chlorobenzene	2.00E-02	50	100
Cloroethane			
Cloroform	1.00E-02	100	200
p-Chloro-m-cresol	2.00E+00	0.5	1
2-Chlorophenol	5.00E-03	200	400
Chloroprene	2.00E-02	50	100
Chromium	1.00E+00	1	2
Chrysene			
Copper	3.71E-02	27	54
Coke oven emissions			
p-Cresol	5.00E-02	20	40
Cyanide	2.00E-02	50	100
2,4-D	1.00E-02	100	200

Noncarcinogens: Reference Dose, 1/RD and Xylene Equivalents

(continued)

Pollutant	Reference Dose, oral	1/RD	Xylene Equivalents
4,4-DDT	5.00E-04	2000	4000
Dibenzo(a,h)anthracene			
1,4-Dichlorobenzene	7.00E-01	1	3
Dichlorobromomethane			
1,1-Dichloroethane	1.00E-01	10	20
1,2-Dichloroethane			
1,1-Dichloroethylene	9.00E-03	111	222
1,2-trans-dichloroethylene	2.00E-02	50	100
2,4-Dichlorophenol	3.00E-03	333	667
1,2-Dicloropropane			
1,3-Dicloropropene	3.00E-04	3333	6667
Diethyl phthalate	8.00E-01	1	3
2,4-Dimethylphenol	2.00E-02	50	100
Dimethyl phthalate	1.00E+00	1	2
Di-n-butyl phthalate			
4,6-Dinitro-o-cresol			
2,4-Dinitrotoluene			
2,6-Dinitrotoluene			
1,2-Diphenylhydrazine			
Endosulfane sulfate			
Ethylbenzene	1.00E-01	10	20
Ethylchloride			
Ethylene oxide			
Fluoranthene	4.00E-02	25	50
Fluorene	4.00E-02	25	50
Fluoride	6.00E-02	17	33
Hexachlorobenzene	8.00E-04	1250	2500
2-Hexanone			
Hydrogen chloride			
Hydrogen fluoride			
Hydrogen sulfide	3.00E-03	333	667
Indeno(1,2,3-cd)pyrene			
Iron			
Isophorone	2.00E-01	5	10
Lindane	3.00E-04	3333	6667
Lead	1.40E-03	714	1429
Magnesium			
Manganese	2.00E-01	5	10
Mercury	3.00E-04	3333	6667
Methane			
Methylene chloride	6.00E-02	17	33
4-Methyl-2-pentanone			

Noncarcinogens: Reference Dose, 1/RD and Xylene Equivalents

(continued)

Pollutant	Reference Dose, oral	1/RD	Xylene Equivalents
Napthalene	4.00E-03	250	500
Nickel	2.00E-02	50	100
Nitrobenzene	5.00E-04	2000	4000
PAHs			
Parachloronitrocresol			
Pentachlorophenol	3.00E-02	33	67
Phenanthrene			
Phenol	6.00E-01	2	3
Propylene			
Pyrene	3.00E-02	33	67
Selenium	3.00E-03	333	667
Silver	3.00E-03	333	667
Sodium hydroxide			
Styrene	2.00E-01	5	10
Sulfides			
2,3,7,8-TCDD			
2,3,7,8-TCDF			
Tetrachloroethylene	1.00E-02	100	200
Thallium	7.00E-05	14286	28571
Thiocyanates			
Tin	6.00E-01	2	3
Toluene	3.00E-01	3	7
1,1,1-Trichloroethane	9.00E-02	11	22
Trichloroethylene			
Trichlorofluoromethane	3.00E-01	3	7
2,4,6-Trichlorophenol			
1,2,3-Trichloropropane	6.00E-03	167	333
Triethanol			
Vanadium	7.00E-03	143	286
Vinyl chloride			
Xylenes	2.00E+00	0.5	1
Zinc	2.00E-01	5	10

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