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THE FEASIBILITY OF RECYCLING PLASTIC WASTES: AN UPDATE

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ABSTRACT

This article updates the findings of the author's 1986 book on plastic recycling entitled *The Economic Feasibility of Recycling: A Case Study of Plastics Waste.* Recent developments and trends are reviewed in five main areas: new technologies; recent environmental findings; the development of new institutional structures to facilitate markets for recycled materials and the flow of relevant information; legislative and regulatory trends; and the costs of waste disposal. It is argued that recent technological developments have promoted recycling, but have failed to overcome the problems of separating plastics from other similar wastes and have contributed little to recycling contaminated plastics. It is also argued that recent environmental findings have done little to ease the controversy about the effects of plastics when landfilled or incinerated. The article suggests that recent developments in institution building and the rapid enactment of regulations and legislation that directly or indirectly affect recycling have been most important in encouraging additional recycling. Unfortunately, some government actions are inconsistent, reflecting the significant uncertainties faced by decision makers. The movement toward more recycling has also been encouraged by recent increases in the cost of disposal.

1. INTRODUCTION

The author's 1986 book entitled *The Economic Feasibility of Recycling: A Case Study of Plastic Wastes* discusses numerous economic, institutional, environmental, regulatory, and technological issues relevant to the feasibility of recycling plastic wastes during the coming decade [1]. This article updates recent developments in this rapidly changing and controversial area. Each of the following sections begins with a brief review of the major findings of my book and then discusses recent developments that either encourage or discourage further plastics recycling.

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2. TECHNOLOGY UPDATE

As was the case in 1986, the percentage of all plastic wastes that is recycled remains relatively small. Less than 1 percent of post-consumer plastic wastes is currently recycled, compared to an estimated 29 percent for aluminum, 21 percent for paper and paperboard, and 7 percent for glass. This section discusses recent changes in the technology available to separate and recycle plastic wastes and how those developments have affected the overall feasibility of recycling.

Plastics are usually divided into two main groups. Thermoplastics, which account for about 80 percent of all resins produced domestically, can be melted and reformed into new products. The remainder, which are theromosets, cannot be melted and reformed because of their cross-linking molecular bonds. Recycling technologies are typically divided into four groups—primary, secondary, tertiary, and quaternary. Primary recycling refers to recycling a product into its original form; secondary recycling refers to melting and reforming a plastic product into a new product that has less demanding physical and/or chemical properties; tertiary recycling refers to processes such as pyrolysis and hydrolysis which convert the plastic wastes into basic chemicals or fuels; and quaternary recycling refers to burning the plastics and retrieving their heat energy.

The 1986 book concluded that although primary recycling has historically been used to recycle a large percentage of clean manufacturing waste (the typical estimate is about 75%), primary processes require very low contamination levels and can be ruled out for essentially all post-consumer plastics and the portion of manufacturing waste generally referred to as nuisance plastics.[1] However, from a technological perspective, it was concluded that one of the remaining forms of recycling can be used to recycle any plastic waste, regardless of its type or contamination level. If contamination prohibits the use of secondary or tertiary processes, plastic wastes can simply be burned to retrieve their heat energy, which is roughly equal that of coal on a per pound basis.

If one, however, takes the more narrow view that recycling includes only primary or secondary processes, the technical limitations were found to be quite severe if the goal is to recycle a large percentage of all plastics in the waste stream. The primary problem was identified as one of obtaining a stream of plastics that is not highly contaminated with other wastes. Although separating plastics from other similar materials in the waste stream, such as paper, and separating individual resins was a technical possibility, the processes were

[1] Some people object to the term "nuisance plastics" because of its negative connotations. The term is, however, commonly used to refer to plastics that have historically been disposed of because they cannot be recycled due to unacceptable contamination levels or unacceptable physical or chemical properties. Obviously, the classification of a manufacturing waste as a nuisance plastic may change as the constraints to recycling those wastes are lifted.

complicated, not highly reliable, and not considered a viable alternative to burning or landfilling.

The capability to obtain a relatively clean plastic waste stream without resorting to expensive and complicated separation technologies was identified as the key to secondary recycling and most tertiary processes. If a relatively clean thermoplastic waste stream could be obtained, several existing secondary and tertiary processes could be applied. Higher valued products could be produced if contamination levels could be lowered and the stream limited to one or a small number of thermoplastics. Because thermosets cannot be melted, those resins could not be recycled in a secondary sense; and tertiary recycling was prohibited by their cross-linking molecular bonds. Thermosets were said to be limited to filler materials and fuel. I estimated that given the technological, institutional, economic, and regulatory constraints at that time, a maximum of about 25 percent of all post-consumer and manufacturing nuisance plastics could realistically be considered a candidate for recycling in processes that require low-contamination plastic wastes.

Since 1986 there has been moderate activity to develop new recycling technologies. However, the developments have for the most part been limited to "fine tuning" technologies that were available several years ago, rather than developing radical new approaches. Most attention has been focused on recycling plastic wastes composed of a single resin or clean commingled wastes composed primarily of thermoplastics.

In the area of secondary technologies, work continues to improve the properties of products made from commingled thermoplastics. The typical approach is to heat a mixture of waste in which at least 50 percent (and preferably 80%) is thermoplastic and mold the mixture into bulky products that compete with lumber or concrete. Processes such as the ET/1 from Belgium, Superflow from Ireland, and Recycloplast from West Germany–which are similar in design to secondary processes available in 1986–are currently the focus of attention and have recently been adopted commercially in the United States. These processes differ in terms of the percentage of non-thermoplastic contamination that is acceptable and in the types of products that can be produced. For example, the ET/1 and Superwood technologies are more suited to the manufacture of lumber substitutes, while Recycloplast is claimed to have the capability to produce smaller and more intricate products. These secondary technologies are in their infancy in terms of commercial use and currently depend on relatively clean industrial waste and/or commingled post-consumer plastics obtained from states that collect segregated plastics through curbside recycling programs.

Although some progress has been made in recycling commingled plastics, the primary focus of secondary recycling in recent years has been on PET (polyethylene terephthalate) beverage bottles. The beverage deposit laws that currently exist in at least eleven states have generated a relatively clean and dependable plastic waste stream. In excess of 90 percent of all PET bottles in those states are now collected, and about 16 percent of all PET bottles used in the United States in 1987 were recycled. Information about the specific processes used to separate the HDPE (high-density polyethylene) bases and aluminum caps from the PET portion of the bottles–i.e., the major challenge in recycling this particular plastic waste–is for the most part proprietary. The processes are, however, believed to be similar to a separation process originally developed by Goodyear and made available to the public in the early 1980s. Once clean PET flake is obtained, numerous secondary applications are possible. The majority of recovered PET is currently used as fiberfill in pillows and elsewhere. Another popular use of recycled PET is in the manufacture of industrial strapping. Because of potential contamination problems, recycled PET is not currently used to manufacture food packaging.

Relatively little attention has been given to developing new tertiary and quaternary processes in recent years. Tertiary and quaternary processes that utilized plastics as the primary input and which had commercial promise in 1986 have not been accepted well in the marketplace. Some encouraging work is currently being done in some academic and national laboratories on fundamental ways to break the interlinking bonds of thermosets.[2] And recently some large corporations, such as Mobil Chemical, Eastman Kodak, and DuPont, have announced R&D plans for tertiary processes to recycle clean thermoplastic waste. Little information is, however, available to suggest if commercial applications are likely to follow in the near to intermediate term. In addition, some industry-sponsored organizations are examining processes that could be utilized to recycle PET bottles in a tertiary sense. Unfortunately, little if any research is currently focused on the tertiary recycling of plastics that are heavily contaminated with other materials in the municipal waste stream.

Some R&D has occurred in the United States since 1986 to develop new separation systems that can separate plastics from other wastes more effectively and at lower cost. For example, the August 1988 issue of *Modern Plastics* reports that a Toledo, Ohio company is developing a process based on separation by water to segregate polymers of different types. Although the process is being developed to process industrial scrap that contains no more than three resins, the developer claims the process will also be applicable to post-consumer wastes. The catch is that individual households will be required to source separate plastics from other materials. The process will not be applicable to plastics in the general waste stream.

R&D in the area of plastics separation has been more active in Europe. For example, a new wet granulation system was recently introduced in the United States to process dirty plastic films from packaging and industrial wastes. Other claims have been made in the industry literature that some European countries

[2] See, for example, reference [2] for information on potential tertiary approaches for recycling thermosets.

are having moderate success in mechanically separating plastics from other municipal wastes. These new technologies are not used extensively in the United States.

In some municipalities in the United States, the separation of plastics is currently accomplished by hand rather than by mechanical means. However, few would argue that this labor intensive separation method can economically divert a significant percentage of plastic wastes from landfills or incinerators. As was the case in 1986, the key to recycling a large percentage of plastic wastes to make new plastics products or to recover high-valued chemicals is dependent on the segregated collection of plastics and/or the future development of viable technologies to separate plastics from the general waste stream. Until separation technologies improve or collection systems are altered, the recycling possibilities for the vast majority of all plastic wastes remain limited to incineration with heat recovery.

In summary, although work has continued to develop new technologies to recycle and separate plastic wastes, the resulting marginal technological advances have not made a large contribution to the overall feasibility of plastics recycling. Recent incentives and disincentives to recycle are much more dependent on rapidly changing environmental, institutional, regulatory, and economic constraints.

3. ENVIRONMENTAL UPDATE

I have argued that the primary reason for the public controversy about plastic wastes is the uncertainty about the environmental impacts of plastics disposal [1]. At the time of my book's publication, one could present evidence in defense of the position that plastics when landfilled or incinerated cause significant environmental degradation. One could also cite studies and data to argue that plastics disposal is of no great environmental concern. A large quantity of new information is now available on this issue. Unfortunately, that new information has not led to any consensus about the environmental effects of plastics when landfilled, incinerated, or recycled. Environmental questions remain the main source of public apprehension about plastics.

3.1 Plastics in Landfills

There are two schools of thought about plastics in landfills. One school argues that plastics are not acceptable in landfills because they do not degrade. Some argue that because plastics do not degrade and do not compact easily, they allow leaching of potentially toxic substances. Others argue that when plastics are not distributed evenly in landfills, they result in "spongy" areas once the landfill is completed, thus limiting the potential uses of the landfill following closing. Yet others argue that plastics are not acceptable simply because they are bulky and require a significant amount of space in the landfill. According to recent data from the EPA (Environmental Protection Agency), plastics account for 7.2 percent of the weight of the typical U.S. municipal waste stream, and by the year 2000 the percentage is projected to increase to 9.8 percent. On a volume basis, the percentage is two to three times larger.[3] The potential problems posed by plastics in landfills are exacerbated by the growing concern about landfill capacity and cost. The EPA projects that 50 percent of all major U.S. cities will exhaust their current landfill capacities by 1990. And in some states landfill capacity is not being increased because of political and/or other reasons.

The other school of thought about plastics in landfills argues that plastics are of little concern because of their non-biodegradability. Because plastics do not degrade, at least rapidly, they do not contribute to either liquid or gaseous toxic substances. In addition, when plastics are distributed evenly with other waste materials, the plastics are claimed to provide structural stability to the landfill site after it is closed. As other wastes degrade, plastics are claimed to support the soil above the waste level.

3.2 Plastics When Incinerated

Even more controversy exists about the environmental effects of plastics when incinerated. Again there are two schools of thought. Some plastics, especially PVC, can produce significant levels of hydrogen chloride. About one half of the weight of PVC is composed of hydrogen and chloride, which combine during burning to form hydrogen chloride. The hydrogen chloride then reacts with water to form hydrochloric acid. One school of thought argues, therefore, that plastics are not acceptable for incineration on the basis of their contribution to acid rain.

Probably the most concern has, however, been raised by the production of furans and dioxins, which are widely considered to be carcinogenic. Several reports have suggested that there may be a link between the burning of plastics—in particular PVC—and the production of furans and dioxins. And although this claim has recently been discredited by a study sponsored by the State of New York, the potential connection between plastics and these carcinogens continues

[3] Recent information indicates that the volume contributed by plastics to landfills is as much as three times the weight contribution. For example, *Waste Age* recently reported that a study by John Schlegel of International Plastics Consultants estimated that plastics constituted 6.8 percent by weight and 25.4 percent by volume of packaging waste in 1984 and projected the numbers to increase to 9.4 percent and 31.4 percent by the year 2000, respectively. Another study by William Rathje, a University of Arizona archaeology professor, involved the excavation of three modern landfills and found that 4.8 percent of the weight and 16.3 percent of volume were composed of plastics.

to be mentioned in books and articles.[4] In the New York State study, no link was found between the burning of PVC or any other plastic and the production of dioxins or furans. Variations in combustion efficiency were, however, found to correlate highly with changes in dioxin and furan emissions.[5]

The latest apprehension about plastics incineration concerns heavy metals pollution. Heavy metals, such as lead, cadmium, and mercury, are contained in some of the additives in commonly used polymers. Suspicions have been raised that plastics may play a role in metal emissions by forming particulates to which metals attach and escape from the stack. Plastics may also contribute to heavy metals in incinerator ash—a growing concern from both environmental and cost perspectives. At this point in time there are no good data to confirm or deny these suspicions.[6]

The other school of thought concerning plastics in incineration argues that plastics are of no great concern if current emission-control technologies are used properly. In fact, the incineration of plastics may be advantageous because of the high Btu contents of most plastics. The high heat produced when plastics are burned helps to incinerate other materials not so easily burned. Other arguments have been made to defend plastics incineration. For example, Graff reports that recent tests in Canada show that scrubbing technology can remove 99.9 percent of dioxins from stack gases [6]. Some argue that technology is readily available to control HCl emissions. Yet others argue that the potential environmental effects of municipal solid waste (MSW) incineration have been given more attention than they deserve. Magee has argued that the overall air pollution effects of current and planned waste incinerators are trivial when compared to the effects of large-scale polluters, such as coal-fired electricity generation plants [7]. According to Magee, only 0.2 percent of total air emissions currently come from solid waste incinerators in the United States.[7]

[4] For additional information on the New York State study, see [3] or [4].

[5] It is interesting to note that no nationwide standards exist for dioxins emissions from waste-to-energy facilities in the United States. In 1986 Sweden became the first country to issue specific dioxin regulations.

[6] The September 1988 issue of *Waste Alternatives* reports that data are available from Sweden on the amounts of metals in components of the municipal waste stream [5]. The Swedish studies show that plastics in the municipal waste stream contribute 26 percent of the cadmium, 5 percent of the lead, and 10 percent of the mercury of the total quantities of those metals in the waste stream. Plastics contributed the largest percentages of metals of all components in the waste stream, with the exception of products made predominantly from those metals. Paper was the second highest source of metals.

[7] Note that the United States currently landfills about 90 percent of its solid waste. About 5 percent is incinerated, and the remaining 5 percent is recycled. Some have speculated that as much as 40 percent of U.S. MSW will be processed by incineration with heat recovery by the year 2000.

3.3 The Development of Degradable Plastics

Degradability is currently perceived by many as "the" solution to the potential environmental problems associated with disposing of plastics.[8] And since 1986, significant efforts have been devoted to developing new polymers that degrade by light or microorganisms. However, degradable plastics pose two significant problems that have yet to be addressed satisfactorily. The first is the effect that mixing degradable plastics with non-degradable plastics will have on future efforts to recycle commingled plastics. Processes that are currently receiving a lot of attention that could recycle mixtures of resins—such as the ET/1 and Superflow processes—could be threatened by degradable plastics, which are difficult to identify and separate from non-degradable resins. Degradables could therefore indirectly worsen the environmental consequences of plastics by eliminating some recycling possibilities for conventional polymers. The second potential problem concerns direct environmental effects. Although biodegradables and photodegradables are often touted as being environmentally safe, the products of degradation are not understood well, nor are the potential impacts on animals that might ingest the degraded materials.[9]

3.4 Implications for Recycling

Recent developments in the environmental area both encourage and discourage further plastics recycling. The increased concerns about the environment in general and the specific concerns about plastics have encouraged both the public and private sectors to intensify their recycling efforts. Unfortunately, the current responses to the perceived environmental problems have at times been misdirected—the recent emphasis on degradables being a case in point. The environmental effects of recycling or disposing of plastics have historically been controversial and subject to significant uncertainty. And recent developments in this area have not in general promoted a consensus on the issues. If anything, the issue has become more controversial as old questions linger and new questions—such as those concerning dioxins, furans, and metals—draw more attention.

[8] There are two basic approaches to degradability—photodegradability and biodegradability. Photodegradable plastics require at least a minimum amount of direct sunlight to initiate the degradation reaction. Biodegradables consist of two basic types—polymers that are completely digestible by bacteria (used for some medical purposes, such as soluable stitches for surgery) and polymers that contain additives that are digestible and which leave a relatively weak polymer. Both types of plastics can be produced at the present time. Resin costs is the major obstacle to the additional use of these plastics.

[9] A report by the U.S. General Accounting Office found that little work has been done to develop standards for "degradables" or to understand the products of their degradation [8].

4. INSTITUTIONAL UPDATE

A major finding of my previous research is that plastics recycling is often hindered by institutional constraints that discourage the formation of required markets for waste materials and recycled products. Those same institutional constraints were also concluded to slow or prohibit the flow of information about available technologies, environmental impacts, economic viability, and regulatory issues.

Plastics recycling often requires the cooperation of plastic manufacturers, consumers, waste processors, and the public sector to overcome nontrivial barriers. And there are numerous arguments why each of these parties when acting individually has both incentives and disincentives to contribute to recycling efforts. If any one of the required parties faces a net disincentive to recycle, that party can, in effect, block a recycling effort that from a social perspective would result in positive net benefits. The formation of institutions through which cooperation and bargaining can occur was suggested as one means of "smoothing out" the incentives and disincentives among the various parties, such that the true social benefits of recycling can be realized.

The recent development of institutional structures that facilitate market formation and the flow of information is a major step towards encouraging plastics recycling. Several specific examples can be cited for both the public and private sectors.[10]

4.1 Industry Sponsored Groups

Industry sponsored groups formed in recent years have greatly facilitated the flow of information about various aspects of recycling, provided financial support for the development of new technologies and the preparation of reports on topics such as environmental effects and market assessments, and helped solidify industry's position on some controversial issues. For example, The Plastics Recycling Foundation (PRF), which is funded by both industry and state government, has been instrumental in developing and publicizing technology to recycle PET bottles. More recently, PRF has entered the commingled, secondary-recycling field with their purchase of an ET-1 machine and initiation of a pilot program for curbside collection of plastic containers in New Jersey municipalities. The containers, which are made from various resins, are being manufactured into lumber-like products using the ET-1 machinery.

Another industry sponsored group, the National Association for Plastic Container Recovery based in Charlotte, North Carolina, has set a goal of recycling 50 percent of all PET bottles by 1992. The group, which is sponsored

[10] Note that recent developments in the area of government legislation and regulation are discussed in Section 5 of this article.

by several large resin producers, will indirectly promote the use of PET for beverage bottles by facilitating post-consumer uses.

Industry sponsored organizations, such as the Society for the Plastics Industry (SPI), are providing detailed information about the opportunities for plastics recycling and about the firms currently involved in recycling activities. The SPI has also proposed that industry adopt a voluntary digital and letter code that would identify the resin contained in a product. The code, which may facilitate separation in some cases, would affect bottles exceeding sixteen ounces and other containers exceeding eight ounces.

The Council for Solid Waste Solutions, another recently formed industry-sponsored group, will sponsor technical research and public education to increase plastics recycling. The group, sponsored by several major resin producers, recently announced it will spend $8.5 million to conduct research on plastics recycling and disposal and to promote government relations. Among the R&D topics to be addressed are minimizing collection cost, plastics separation, emissions from plastics when incinerated, and methods to characterize degradability.

Actions by individual companies are also promoting technology and market development. For example, General Electric Plastics and Luria Brothers have recently announced plans to collect and recycle engineering resins based on polycarbonate, thermoplastic polyester, and other polymers from scrapped automobiles. These parts will be collected before automobiles enter an automobile shredder—the typical approach to separating the metallic and non-metallic components in automobiles. Another example is the Solid Waste Management Solutions Group formed at Mobil Chemical Company. The stated objective of that new group is to develop and implement methods for recycling and disposing of plastic wastes.

4.2 Public Sector Actions

At the public-sector level, the EPA, through its Solid Waste Task Force, has recently set a goal of recycling at least 25 percent of all municipal waste by 1992. Although EPA has no power to enforce the goal directly, the stated objective acts as moral suasion for industry and local and state governments to increase all recycling activities. The task force has also called for federal actions to promote markets for secondary goods, which may include additional federal procurement of secondary goods (note that some procurement currently occurs under the Resource Conservation and Recovery Act). Two additional actions are also being considered: the development of a national recycling council to explore international markets, and research to investigate how states might use tax incentives and loans for industries using or processing secondary materials.

An EPA official has stated that the plastics area is one of two areas in which the federal government should take the lead in promoting recycling. EPA has also directly encouraged the plastics industry to promote recycling by product design and possibly by color coding different types of plastics. Recently, the EPA announced plans for the establishment of a national clearinghouse for information relevant to all forms of recycling. Actions at the state and local levels are also setting recycling goals and creating or promoting institutions that facilitate plastics recycling. Specific examples are given in the following section.

5. LEGISLATION AND REGULATION UPDATE

In 1986, local, state, and federal governments were beginning to pass specific legislation and implement specific regulations that directly or indirectly affected plastics recycling. Since 1986 legislative and regulatory activities have mushroomed at the local and state levels; and that movement is now reaching the federal level of government. Although a review of all the specific bills and regulations that affect plastics recycling is beyond the scope of this article, a review of some examples helps to identify the direction in which this movement is headed.

5.1 Local and State Actions

Numerous actions have been taken at the local and state levels that, in general, promote recycling. For example, the National Solid Waste Management Association (NSWMA) reports that at least six states currently require local jurisdictions to offer or provide recycling as an option to households. At least two of those states–New Jersey and Rhode Island–require some separation of waste materials at the source, meaning the household or business. Oregon was one of the first states to promote recycling. Its 1983 Opportunity to Recycle law requires that municipalities with populations over 4,000 must provide recycling drop-off centers and offer curbside collection of recyclables at least once per month. Household participation remains voluntary. Oregon also supports educational activities that appear to be successful. Although only seventy localities are covered by the law, more than 110 have established recycling programs. Many of the state laws set goals for recycling–usually about 25 percent, but they range between 15 percent to 50 percent–and may have strong economic measures that take effect if the goals are not met.

A 1987 law passed in New Jersey labeled the "Mandatory Recycling Act" requires households to separate certain materials and gives municipalities until 1989 to achieve a recovery rate of 25 percent. The state government requires local governments to design their own programs and provides $8 million to those local governments in start-up aid. The program is funded by a tax on landfill use of $1.50 per ton and requires that a minimum of three materials be recycled– with the specific materials to be selected by the local governments. While these actions have not in general been directed specifically at recycling plastics, they have indirectly encouraged plastics recycling by 1) fostering the formation of channels to collect recyclable materials and 2) providing moral suasion for consumers and plastic manufacturers to promote recycling.

Mandatory bottle deposits are probably the best known state measures that have directly promoted plastics recycling. At least eleven states currently have bottle deposit laws of some form. Typically, the deposits apply to beverage bottles of all types and are usually five cents per bottle.[11] These laws have been the key to the most publicized plastics-recycling success story—i.e., PET beverage bottle recycling.

Several states offer incentives for firms involved in recycling activities. For example, Oregon offers income tax credits for the purchase of recycling equipment and facilities. New Jersey offers a 50 percent investment credit for recycling equipment. Indiana offers property tax exemptions for buildings, equipment, and land use for recycling operations. Wisconsin offers sales tax exemptions for equipment and facilities and some business property tax exemptions for some recycling equipment. North Carolina offers industrial and corporate tax credits and exemptions for recycling equipment and facilities. Other state actions include direct subsidies, grants, technical assistance, and low-interest loans.

In addition, some states give preference to recycled goods through government procurement and other programs. For example, Oregon allows their state departments to pay up to 5 percent more for recycled products that contain either 50 percent industrial waste or 25 percent post-consumer waste, as compared to products made from virgin materials. Vermont has set goals for purchasing recycled goods—25 percent by 1990 and 40 percent by 1993. The procurement program in New York provides a 10 percent price preference and requires a recycled content of at least 40 percent to qualify for the preference. California's law provides a 5 percent price preference and requires recycled content to be 50 percent, including 10 percent post-consumer waste. The National Solid Waste Management Association (NSWMA) reports that at least eighteen states have some type of procurement laws for recycled products. Keller reports that nineteen states and four local governments have laws in place that favor recycled products [10], covering more than 60 percent of the total U.S. population. Further, at least thirteen additional states have considered legislation in 1988 to establish or expand their procurement programs.

A recently passed law in Florida requires localities to reduce landfilling by 30 percent by 1993, mostly by increased recycling. Taxes and fees on a variety of products will be used to encourage recycling projects. The heart of the new legislation is, however, the provision that requires that a one cent charge be assessed on every type of retail container sold (i.e., plastic, glass, plastic-coated paper, aluminum, and other metals) that does not reach a 50 percent recycling

[11] Roth reports that bottle reclamation rates average 90 percent or better in states with bottle deposit laws [9].

rate by October 1, 1992. The fee will rise to two cents if the target is not met by October 1, 1995. California recently passed a beverage bottle law that has similar provisions.

While the focus of most states has been on recycling in general, some states are now focusing specifically on plastics recycling. For example, the state of Massachusetts recently issued a report calling for a sustained, aggressive effort to make plastics recycling work in that state [11]. Although other states have mandated curbside collection of separated wastes, Massachusetts is the first state to call for the separate collection of plastics. Glass, cans, and newspapers will also be collected. The plan calls for 45 percent of all rigid plastic containers to be recycled by the year 2000. To get the plan started, the state will help fund construction by 1990 of at least two production-sized plants, one for recycling polyolefins and one for recycling mixed plastics.

At the regional level, several Northeastern states have joined together to promote recycling. The June 1988 issue of *Waste Age* reports that "The Coalition of Northeastern Governors (CONEG) is advocating a coordinated, comprehensive solid waste management policy incorporating source reduction and recycling, refuse-to-energy, and landfilling" (p. 8). The coalition will work to promote secondary markets; provide information to residents about risks, choices, and benefits; investigate which materials can be recycled; set standards for waste facilities; and establish regulatory schemes for incinerator ash.

Another important set of state and local actions has indirectly affected the overall viability of plastics recycling—i.e., actions to reduce or prohibit the use of plastics in particular applications or to mandate that some plastics be degradable. Recall from an earlier section that mixing degradables with nondegradables may severely constrain the types of recycling technologies that can be used.

Most of these actions have been directed at banning or limiting the use of plastic packaging and/or proposing packaging or product taxes. (Packaging materials are estimated to account for as much as 30 percent of the total municipal waste stream.) Measures are being considered in several states that would require some or all packaging to be biodegradable. Although several measures have passed, many more bills are currently pending.

The recently passed bans on selected plastic packaging in Suffolk County, New York and Berkeley, California are good examples of local initiatives. These laws can be criticized for being somewhat arbitrary and for being inconsistent across retail markets. In the opinion of most experts, the benefits of the laws will be insignificant in terms of reducing either the size or toxicity of the municipal waste stream. These particular laws are, however, most important for the general message they send. Local governments in some cases view plastics as a major problem in the municipal waste stream—either because of the quantity of waste contributed by plastics or because of perceived environmental problems. And in some cases, plastics have become a scapegoat for the severe problems some localities are currently experiencing in disposing of their municipal wastes.

Several states are proposing a tax, ranging from one to five cents per package, on materials used to package consumer products. For example, some legislators in Massachusetts have recently called for a packaging disposal tax of three cents per layer on non-food products retailed in that state. Others in that state are calling for bans on the use of certain plastics in packaging and for restricting all packaging to contain only one resin. The recently passed Florida waste bill requires as of January 1, 1990 that any plastic shopping bags used by retailers in that state must degrade within 120 days.

Several additional states are considering legislation that would require all or most packaging materials to be degradable. Some examples: A proposed Vermont law would establish a five cent per package tax on goods sold at the wholesale level if the wholesale dealer does not certify that at least half of the packaging sold in the state by that firm is manufactured from recycled materials. A Missouri bill would prohibit any manufacturer, retailer, or wholesaler from selling products transported in containers using any petroleum-based, non-biodegradable materials. A proposed California law would require all one-time plastic containers and packaging to be either recyclable or biodegradable. A recently passed Maine law prohibits the use of non-degradable individual food and beverage containers by food services at state or local municipal facilities or functions. Sales and use tax incentives for degradables are provided in Iowa.

Several states, including Washington and Oregon, have proposed to require all disposable diapers sold in their states to be biodegradable. And at least sixteen states now ban non-biodegradable plastic yokes on six-pack beverage containers.

5.2 Federal Actions

Incentives at the federal level have been much less specific than at the state and local levels. In fact, previous to the passage of the Resource Conservation and Recovery Act in 1976, the federal government had little to do with plastics recycling or municipal waste management in general. Prior to 1976 the federal role was defined by the 1965 Solid Waste Disposal Act, which authorized federal involvement in R&D in solid waste management, and by the 1970 Resource Recovery Act, which strengthened the federal government's R&D activities.

RCRA's subtitle D addresses municipal waste by, for example, mandating regulations on landfills and incinerators, establishing procedures for states to develop solid waste management plans, and calling for procurement guidelines for recycled materials.[12] Yet, under RCRA the states retain primary responsibility for municipal waste management.

[12] EPA recently established guidelines for federal procurement of recycled paper, re-refined oil, remanufactured tires, and building insulation made from recycled materials. Note that the standard for insulation may include some plastics. For example, McDonalds restaurants has recently initiated a program to recycled its polystyrene containers for non-food purposes—one product being insulation. For additional information on recent federal procurement actions, see [10].

Another statute that has implications for state and local MSW management is the Clean Air Act, which in its reauthorized form may impose stricter standards on incinerator emissions. The Public Utility Regulatory Policies Act (PURPA), which requires utilities to purchase electric power from independent suppliers, such as electricity-producing incineration facilities, indirectly promotes incineration. Finally, the Energy Act of 1978 provided an investment tax credit for recycling equipment from 1978 to 1983. That particular incentive has been discontinued.

Action at the federal level to address the problem of municipal waste has quickened recently. For example, new legislation has been introduced in the U.S. Senate to reauthorize RCRA, which officially expired in September 1988. The Baucus Bill [Senator Max Baucus (D-MT)] calls for more federal involvement in MSW management and will probably be debated in the current session of Congress. Labeled "The Waste Minimization and Control Act," the bill sets ambitious goals, such as 25 percent recycling in four years, a 10 percent reduction in municipal solid waste within four years, waste minimization performance standards to be implemented within ten years, federal assistance to states to promote waste reduction and recycling opportunities, and federal procurement of recycled goods. Each state would be forced to develop a solid waste plan. The legislation would also establish a $7.00 per ton fee on new, unused materials to be utilized in packaging, including plastics.

Another example of proposed federal statutes is the Recyclable and Degradable Materials Act of 1988. If the provisions of this act should become law, they would mandate that within ten years all nondurable consumer goods made or sold in the United States be recyclable or composed of degradable materials. This legislation is an example of the recent movement against the use of conventional plastics in packaging.

Other federal actions have also been directed at degradable plastics.[13] For example, recent legislation introduced by Senator John Glenn (D-OH) would stimulate the market for biodegradables by forcing the federal government to give preference to buying degradable plastic products. In addition, Senator Sam Nunn (D-GA) supports degradables and amended the Department of Defense (DOD) authorization bill for 1989 to require DOD to study the feasibility of

[13] At the request of Senator John Glenn, the General Accounting Office (GAO) published in September 1988 a report on degradable plastics [8]. The GAO report found that the federal government and the private sector are only making limited efforts to develop standards for degradable plastics, which in the opinion of the authors has seriously hurt R&D efforts. The report says that "virtually no testing of degradable plastics has been done . . . . " Testing remains necessary to resolve two basic technical uncertainties about the performance of degradable plastics in the environment: the rate of degradation and the safety of the end products. The report also states that several bills, including one by Senator Glenn, have been introduced in the U.S. Congress to promote or mandate the use of degradable plastics.

using biodegradable plastics made from corn. Recently enacted federal legislation requires that within two years any plastic beverage yokes be degradable, unless the EPA determines that the by-products of degradation pose a greater threat to the environment than non-degradable yolks.

The recently passed United States-Japan Fishery Agreement Approval Act of 1987 places restrictions on the dumping of plastics at sea and calls for two government studies–one by EPA to study methods to reduce plastics pollution in the environment, with emphasis on recycling, degradability, and the development of incentives, and another by the Department of Commerce to study the effects of plastic materials on the marine environment and provide recommendations to prohibit, tax, or regulate all sources of plastic materials that enter the marine environment.

Forthcoming regulations concerning incinerator ash management and air emissions either from EPA or as mandated in a revised Clean Air Act could have implications for the acceptability of plastics in the waste stream, and thereby influence the viability of plastics recycling. In particular, regulations on dioxin emissions from incinerators may be forthcoming, which will bring additional emphasis to the hotly debated relationship between PVC and dioxins. Potential regulations concerning heavy metal emissions will also bring additional attention to plastics.

5.3 Implications for Plastics Recycling

The numerous actions at all levels of government that impact on plastics recycling directly or indirectly have in most cases promoted, but in other cases discouraged, additional recycling. Some measures directly mandate that recycling occur, others indirectly make the option of recycling more attractive, and yet others promote alternative responses to the "plastics problem"–i.e., measures such as degradability and source reduction.

It is increasingly clear that all levels of government view plastics as a components of the waste stream that requires some type of public-sector attention. Unfortunately, the rules and regulations currently being imposed are in some cases inconsistent; and the public sector has not as yet established what the overall goal should be with respect to plastic wastes. This lack of consensus is a reflection of the great technological, environmental, and institutional uncertainties currently faced by public-sector decision makers. And until more credible information is available about the option of recycling as compared to the options of disposal, degradability, and bans on the use of plastics, it can be expected that government actions will continue to vary in terms of purpose and scope. Although additional recycling will likely result from public-sector incentives, the uncertainties associated with future government programs will make the adoption of recycling by private firms a risky venture.

6. COST UPDATE

Curlee presented estimates of the costs and potential revenues from various secondary, tertiary, and quaternary recycling operations [1]. The costs of landfilling and incinerating waste were also reviewed. The main conclusion was that the current quantity and quality of information about the expected cost and revenues associated with different recycling technologies do not justify any definitive conclusions about the competitiveness of recycling with disposal. However, given the caveat about the quantity and quality of available information, the numbers suggest that in many parts of the country where disposal costs are high, recycling of plastics as a relatively uncontaminated waste appears to be competitive with or superior to disposal. In other words, the expected net losses associated with several recycling operations were estimated to be lower than the costs of disposal. In 1984 the average cost of landfilling in the United States was $10.59 per ton in 1984 dollars. The average cost of waste-to-energy incineration facilities was $17.26 per ton in 1984 dollars.

Since 1986 little additional cost information about existing or developmental recycling technologies has been made available publicly. And the information that has been made available is subject to great uncertainties. We do, however, have updates on the costs of disposal. The costs of disposal have increased enormously in recent years. In 1987 the national average cost of landfilling had increased to $20.36 per ton and waste-to-energy incineration had increased to $33.64 per ton in 1987 dollars. In 1986 the average cost of landfilling was $13.43 and the cost of waste-to-energy incineration was $30.42 in 1986 dollars. What may be more shocking is the range of landfilling costs across regions in 1987–ranging from a low of $3.15 per ton to $75.00 per ton. Costs of landfilling by region were: West–$10.01 (1986), $10.75 (1987); South–$10.95 (1986), $12.27 (1987); Midwest–$10.86 (1986), $12.71 (1987); and Northeast–$20.59 (1986), $39.23 (1987).[14]

Given the success of PET beverage bottle recycling and the current interest in secondary processes for recycling commingled plastics, those technologies appear to be superior cost alternatives to disposal. Although definitive conclusions are not possible at this time, the rapidly increasing cost of waste disposal in some regions of the country suggest that the economic viability of plastics recycling in some geographical locations will become less questionable.

Additional publicly available cost and revenue information is needed. And although cost information about specific proprietary technologies is not likely to surface, more generic cost information about classes of technology should be forthcoming. The recent initiative by the U.S. EPA to form a clearinghouse for information about disposal and recycling may greatly facilitate this end.

[14] This information was obtained from the March 1988 issue of *Waste Age* magazine, which conducts a yearly survey of disposal facilities around the country.

7. CONCLUSIONS

The degree to which plastic wastes will be recycled in the coming decade and coming century will depend on a complex set of technological, environmental, institutional, regulatory, and economic issues. My 1986 book presents various conceptual arguments and empirical evidence concerning the importance of these issues to the overall feasibility of recycling plastics. This article updates recent developments in these important areas and discusses how recent findings and recent trends are either promoting or discouraging additional recycling.

From a technological perspective, recent developments have been both encouraging and discouraging. On the one hand, recent refinements of secondary processes to recycle commingled plastics are promoting the recycling of segregated post-consumer plastics and relatively clean manufacturing wastes—manufacturing wastes that would in the absence of these technologies be classified as nuisance plastics. In addition, PET bottle recycling processes are becoming more sophisticated; and recent R&D in the area of tertiary recycling of manufacturing waste is encouraging. On the other hand, the lack of significant R&D to separate plastics from other similar wastes or to recycle plastics in a more contaminated form is discouraging. The vast majority of plastic waste continues to enter the municipal waste stream along with many similar materials; and separating plastics remains a difficult and expensive chore. For this majority of the plastics waste stream, recycling opportunities remain limited to incineration with heat recovery.

Environmental issues remain the main catalyst for debate about plastics. Concerns about plastics in landfills persist. Incineration continues to be an unpopular option with environmentalists, with plastics being a primary focus of attacks. The old concerns about the association between plastics and acid rain continue; and new concerns about the potential connections between plastics and furans, dioxins, and heavy metals are drawing additional attention to plastic products. Although recent studies are providing more information for informed decisions, the uncertainties about plastics and environmental degradation remain high. These uncertainties have in general encouraged both the public and private sectors to promote plastics recycling. In some cases, however, environmental uncertainties have indirectly discouraged recycling by promoting alternative approaches, such as degradable plastics.

Institutional changes in recent years have been encouraging and are largely responsible for the positive image that plastics recycling currently enjoys. The public sector has been moderately successful in developing or promoting institutions that facilitate the formation of markets for recycled goods and encourage the exchange of information. The private sector, largely in response to moral suasion by the public sector and pressures by various environmental groups, has recently formed several groups to facilitate information dissemination and promote R&D. These developments are slowly breaking down misconceptions about plastics recycling and are helping decision makers to focus on the issues of greatest concern.

Regulatory and legislative initiatives are occurring at a rapid rate at the local, state, and national levels and have, in general, encouraged recycling. Unfortunately, a close examination of those actions shows there is currently no clear consensus on why these actions are being taken. More to the point, recent regulatory and legislative actions that directly or indirectly impact on plastics recycling are in some cases inconsistent. The hodgepodge of recent actions reflect the growing concern about plastic wastes, but also reflect a lack of consensus about why plastics are important.

Finally, although little new information is available about the expected cost and revenues associated with new recycling technologies, the costs of disposal are documented fairly well. Incineration and especially landfill costs continue to escalate rapidly. Further, recently proposed EPA regulations for landfills and likely forthcoming regulations for incinerators will only make the relative costs of disposal more expensive. On an avoided cost basis, recycling various waste materials, including plastics, is currently viable in some regions of the country where disposal costs are high.

The issues that face the public and private sectors in their decisions about plastics recycling are complicated and controversial. If additional progress is to be made in this area, decision makers must acknowledge the different dimensions of the problem, reduce the uncertainties associated with key issues, and make progress toward forming a consensus on why plastics are important.

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