How Green Was My Electricity?
Designing Incentives to Co-optimize Waste Management and Energy Development in New England

By

Walker Larsen

B.A. Environmental Studies and Political Science
Bates College
Lewiston, ME (2001)

Submitted to the Department of Urban Studies and Planning
in partial fulfillment of the requirements for the degree of

Master in City Planning

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2008

Author__

Department of Urban Studies and Planning
May 14, 2008

Certified by__

Dr. Jonathan Raab
Department of Urban Studies and Planning
Thesis Supervisor

Accepted by_

Professor Langley Keyes
Chair, MCP Committee
Department of Urban Studies and Planning

How Green Was My Electricity?
Designing Incentives to Co-optimize Waste Management and Energy Development in New England

By

Walker Larsen

Submitted to the Department of Urban Studies and Planning
in partial fulfillment of the requirements for
the degree of Master in City Planning

Abstract

Waste management is a complex issue, often out of sight and mind, but with the potential for significant negative environmental, social, and economic impacts. Electricity resource planning is equally complex and can potentially lead to equally negative consequences when done poorly. This is especially so within New England, the geographic boundary of this thesis due to significant physical constraints on land and electricity resources. Historically these two processes have been dealt with nationally as very separate issues. However, there has been recent acknowledgement within both public and private camps regarding the potential overlaps of waste management and energy development, which includes electricity resource planning. This thesis has endeavored to analyze the current state of waste management and energy development policy to further expose the potential benefits of increased coordination. With this accomplished, the thesis further provides policy recommendations designed to co-optimize waste management and energy development to decrease dependence on landfill disposal and increase the installed capacity of non-fossil fuel-based electricity resources in New England. The author believes substantial environmental, economic, and social benefits can be gained through increased waste management and energy development coordination, and that this thesis will move decision-makers and citizens alike to take action.

Thesis Supervisor: Dr. Jonathan Raab
Title: Lecturer, Department of Urban Studies and Planning

Acknowledgements

I would like to extend my gratitude to Dr. Jonathan Raab for patiently guiding me through the complexities of the New England electricity system. I also appreciate that he took seriously my interest in exploring the overlaps with waste management and agreed to supervise this project.

I would also like to thank Professor Nicholas Ashford whose sustainability research, specifically regarding cleaner production and toxics reduction, helped me to better formulate my ideas around this thesis topic. I also appreciate his willingness to serve as my reader for this work, especially after I realized I would not be able to devote significant effort to the subjects he was likely most interested in seeing me explore.

I may never have become interested in this topic had I not had the opportunity to intern with CLF Ventures, Inc. My colleagues encouraged my newfound interest in the potential to use waste as fuel to generate electricity, and allowed me the freedom to fully develop my understanding of the relevant issues.

Finally I would like to thank Liz for helping to keep me on track over the course of this project, and for devoting a significant amount of her time to fixing the little things so I could concentrate on solving the larger issues.

Table of Contents

Chapter 1:

Introduction and Background

When human decision systems (be they individuals, or collective bodies such as governments) confront environmental problems, they are confronted with two orders of complexity. Ecosystems are complex, and our knowledge of them is limited, as the biological scientists who study them are the first to admit. Human social systems are complex too, which is why there is so much work for the ever-growing number of social scientists who study them. Environmental problems by definition are found at the intersection of ecosystems and human social systems, so one should expect them to be doubly complex.

-- John S. Dryzek, *The Politics of the Earth,* 8

Solid waste is a very difficult fuel and waste management a stern and critical task master.

-- Walter R. Niessen, *Combustion and Incineration Processes,* 480

1.0 Introduction

The New England region is energy poor and imports mostly natural gas to fuel electricity generation. Coal, oil, and nuclear power also make up part of the electricity fuel mix, but there is a concerted effort to increase the amount of renewable electricity generated. Renewable electricity choices are generally made for a given location based on the availability of specific renewable resources. In New England this translates into primarily electricity generation using wind and wood-based biomass, with some additional renewable electricity from landfill gas capture and combustion. Regional effort is being made to expand biomass-based electricity sources, especially through state-by-state renewable portfolio standards.

All six New England states have some form of renewable electricity legislation. Massachusetts, Maine, Connecticut, Rhode Island, and New Hampshire all have mandatory renewable portfolio standards (RPS) while Vermont has a voluntary measure that seeks to achieve similar results. These individual pieces of legislation all seek to expand the installed capacity of renewable electricity in New England to help offset the need for fossil fuel-based electricity.

New England is also a relatively small, densely populated area, and like other areas in the US it is running out of space for all of its waste. There is a need to both reduce the amount of waste that is placed in landfills and increase the installed capacity of electricity. Waste-to-energy (WTE) combustion facilities currently operate in New England, treating around 50% of the waste streams in Massachusetts and Connecticut respectively, and a lesser rate in other states (MA DEP 2006; CT DEP 2006). These facilities do not contribute substantially to the installed electricity capacity, providing about 333 MW of total regional electricity[1] (ISO-NE 2008), and are primarily designed to lessen the amount of waste that is landfilled. Despite this method, New England continues to generate significant amounts of waste that require landfill space.

Pre-landfill WTE technologies may now be a viable alternative to fossil fuel-based electricity generation. Since the Clean Air Act of 1990 such facilities have been required to install pollution control systems that have reduced many emissions by as much as 99% (Williams 2004). The remaining 1% is still considered unacceptable by many, and combustion of waste directly or the combustion of gases derived from wastes does produce carbon dioxide. However, the use of these technologies has the potential to divert significant portions of the waste stream away from landfills, thereby decreasing landfill space requirements and preventing the release of toxic pollutants and greenhouse gases via faulty landfill practices.

Many modern processes produce waste, and electricity generating technologies have been developed that make use of these different waste streams. These include anaerobic digestion and biomass gasification, generation technologies that use organic wastes as fuel and are already included in many state renewable portfolio standards. These technologies, and their RPS inclusions, set the precedent for the additional inclusion of other appropriate technologies that utilize appropriate waste products as fuel. This discussion will also consider the objections of zero waste advocates who rightly point to the potential problem of creating a reliance on electricity generation that requires waste as a fuel source. By using the term zero waste with electricity generation, I am attempting to link electricity generation using waste streams with zero waste principles, and to do so in a way that can harmonize both concepts to the greatest extent possible.

[1] This number is based on claimed capability, not name-plate capacity.

Ultimately I will recommend policies to co-optimize waste management and energy development using *zero waste with electricity generation* (ZWEG) processes, a term created for this thesis.

1.0.1 Thesis Project Goal

There are two basic concepts driving this thesis. First, I assume that renewable electricity generation facility owners are the appropriate actors to influence with economic incentives mandated by new regulation. If it is economically beneficial to generate electricity from specific waste streams, actors who generate electricity will put pressure on actors higher up the waste stream to manufacture products, sort waste, or both in a way that allows them to be eligible for renewable electricity incentives.

Second, RPS legislation is designed to encourage the use of certain fuel sources, often using specific energy generating technologies. This type of legislative structure appears to be ideal for creating incentives for source separation of the waste stream. In other words, if properly designed, the RPS will include specific ZWEG technologies powered by specific kinds of waste.

However the RPS may not be the best renewable electricity regulation for achieving the goals of this thesis, and renewable electricity regulations and incentives may not ultimately be the best way to achieve waste reduction in connection with increased electricity generation. Additional regulations and incentives specific to waste management practices will be required to accompany renewable electricity policies in order to affect the changes sought by this thesis. Policy analysis will also examine other existing renewable electricity regulations and incentives, along with regulations and incentives for waste management, and may show that existing policies work against each other, or that there are no existing structures capable of achieving the desired outcome. The goal of this policy analysis is to make recommendations to strengthen good incentives, weaken perverse incentives, and suggest new incentives if appropriate.

Waste and energy have historically been viewed as separate issues to be managed separately. This thesis will expose the interrelated aspects of waste management and electricity generation, and design a truly integrated waste management policy structure that increases regional electricity generating capacity while also reducing regional landfill space needs and reusing and recycling materials to the greatest extent possible.

There are examples throughout New England of public policies designed to address some of these issues, and regional and local groups and companies are endeavoring to be early adopters and advocates of what is beginning to be viewed as the logical and beneficial integration of waste and energy management. These examples include composting regulations and incentives in Vermont (Porter 2008), early discussion of anaerobic digestion for yard waste in Boston (Ryan 2008), clean-wood biomass combustion for combined heat and power in New Hampshire (Concord Steam website), construction and demolition debris gasification in New Bedford (Ze-Gen website), and the existing Deer Island anaerobic digesters that treat sewage from the greater Boston area (Deer Island website). The policy analysis done in this thesis will result in incentive recommendations designed to further encourage the development of ZWEG technologies and processes that will treat waste in an environmentally acceptable manner that also increases regional electricity generating capacity, while also attempting to be consistent with principles of zero waste.

1.1 Scope of Research

This thesis evaluates current policies related to waste management and renewable electricity respectively, and makes policy recommendations aimed at coordinating waste management and electricity generation. This is not an engineering evaluation of waste management and electricity generation technologies and processes. Historically waste-to-energy facilities have been evaluated to a great extent based on environmental impact relative to other means of electricity generation; the fossil fuels coal and natural gas, and renewables such as wind and solar. However, WTE is more than a means of electricity generation; it is also, and perhaps primarily, a means of waste management, made more economical and efficient through energy/electricity recovery. Therefore this research project is an attempt to more fully analyze the policy structure surrounding WTE as it relates to both electricity generation and waste management. When the dual benefits of waste management and electricity generation are optimized through more targeted and comprehensive policies, WTE should be viewed as a significant piece of the sustainability puzzle. Whether this will be the case for traditional combustion WTE, or whether new processes will have to be adopted around the concept of ZWEG remains to be seen.

New England is the geographic focus of this work. This is appropriate due to its relatively small size and lack of large-scale energy resources which makes both waste management and energy generation pressing policy concerns (Denison 1990). New England is also a clearly defined electrical sub-grid, in relation to the national US electrical grid. The electricity in the region is managed by the New England Independent System Operator (ISO-NE), which coordinates the region's restructured electricity markets to ensure the proper alignment of supply and demand.

This thesis is not a treatise on zero waste and is not intended as a handbook for achieving zero waste. Waste-to-energy processes are considered by many zero waste advocates as completely incompatible with the goals and values of a zero waste system. However many of the values and goals of the zero waste philosophy can be adapted to create inclusive, coordinated policies for waste management and electricity generation that also encourage cleaner production, material reuse and recycling, and an overall dramatic reduction in actual waste. The role of zero waste, with regards to this thesis project, is to give an indication of where we should be aiming as a society so the policies we develop as intermediate steps are consistent with our ultimate goals. In other words, if true zero waste is the goal, any WTE projects undertaken should be as consistent as possible with that goal; hence the term zero waste with electricity generation (ZWEG). However, this analysis is not primarily focused on influencing the extraction and production stages of resource cycle.

Rather, this is primarily a thesis concerned with recovering energy from our waste stream, specifically focused on electricity generation that can be added to the general grid. However, any policy package designed to effectively manage waste in addition to encouraging electricity generation will have to account for waste management techniques that do not produce electricity. In fact, waste management practices such as composting and recycling can result in significant energy savings. These savings can be quantified, and it therefore seems reasonable to include all aspects of waste management in a truly comprehensive policy package. Thus while this thesis more explicitly details waste management processes that generate electricity, the policy recommendations are inclusive of a wider range of waste management strategies that can contribute to a greater net supply of electricity.

Table 1.1 provides a very basic comparison of the various existing options for waste management and electricity generation. This table is elaborated upon in Appendix C to provide additional information for comparing WTE options to fossil fuel-based electricity generation and to landfill waste management, topics that are not fully discussed on the main body of the thesis.

Table 1.1 Summary Comparisons of Electricity and Waste Management Options

Fuel/ Technology	Fuel Type	Fuel Transport	Capital Cost	O&M Cost	Emissions/ Pollution[2]	Electricity Transport
Coal	Fossil	Far	High	High	CO2+	Local/ Regional
Natural Gas	Fossil	Far	High	High	CO2+	Local/ Regional
Oil	Fossil	Far	High	High	CO2+	Local/ Regional
WTE (Incl. biomass)	Mixed (fossil and organic	Local/ Regional	High	High	CO2+	Local/Regional
Wind	Wind	N/A	High	Med	N/A	Regional/ Farther
Solar	Sunlight	N/A	High	Med	N/A	Local/ Regional/ Farther
Hydro	Water	N/A	High	High	N/A	Local/ Regional/ Farther
Landfills	Mixed Waste	Local/ Regional/ Far	Low	High	Leachate & Methane +	Local/Regional
Recycling	N/A	Local/ Regional Material Collection	Med	Med	Odors/ Toxins	N/A (form of energy conservation)

[2] To conserve space in this table only the major source of pollution is listed. The "plus" symbol after a pollutant indicates that there are other pollutants associated with the emissions.

1.1.1 Redefining Waste

Before proceeding it will be useful to briefly discuss the term waste. Waste can generally be thought of as the unwanted by-product of a process designed to create a specific product. Anything that results from the production process that is not part of the desired end-product is waste. Modern society has come to accept waste as a part of life, and deals with it for the most part by disposal. In this thesis I try to address this issue by adopting some zero waste principles. Waste as we currently think of it does not have to be discarded. Many waste steams contain material that remains very useful. Some of this usefulness can be realized through reuse or recycling or durable, non-organic material. Some of this usefulness can be realized through composting organic material. I argue that a heavy reliance on reduction, reuse, and recycling will in fact reduce the actual amount of waste we generate, while hopefully changing societal perceptions of waste.

However, reduction, reuse, and recycling are not the only possibilities. I believe that processes that divert waste and generate electricity are useful, as well as complementary with efforts to reduce, reuse, and recycle. More will be said on this throughout the thesis, but ultimately the goal is to move waste management from the back of people's minds to the front of their everyday lives. As a society we need to realize how wasteful our lifestyle is, and endeavor to stop generating waste through improved production processes, as well as processes that manage production discards for reuse and recovery rather than disposal. In other words, processes may continue to generate by-products, but these by-products should no longer be thought of as waste; they should be inputs for other useful processes, including electricity generation.

1.1.2 Co-optimization vs. Balance

In this thesis I state my intention to co-optimize waste management and energy development, rather than an intention to try to balance competing goals. The term co-optimize was coined by Ashford in the article "*Using Regulation to Change the Market for Innovation*," (Ashford et al. 1985).

Regarding the subject matter of this thesis, the term refers to the intention to create a policy environment in which waste management is optimized and energy development is simultaneously optimized. The policy design does not seek to compromise benefits of one system to achieve an acceptable "balance." Co-optimization is not a zero sum game; it is a win-win game in which the policy solution is greater than the sum of its parts.[3] My focus on co-optimization is therefore a key component and consideration for subsequent policy recommendations.

1.1.3 Thesis structure

The remaining sections in Chapter will focus on providing background information regarding renewable energy and waste management with energy recovery. This will provide context for the rest of the thesis.

Chapters 2 and 3 provide detailed analysis of existing and potential new policies that influence waste management and energy development. Certain policies are specific to waste management while others are specific to energy development. This thesis seeks

[3] Ashford describes co-optimization in the context of sustainability: "Underlying a regulatory strategy based on an assessment of technological options is a rejection of the premise that regulation must achieve a balance between environmental integrity and industrial growth, or between job safety and competition in world markets. Rather, such a strategy builds on the thesis that health, safety, and environmental goals can be co-optimized with economic growth through technological innovation" (Ashford et al. 1985, p. 420).

to coordinate these policies to co-optimize waste management and energy development. Chapters 2 and 3 provide the policy analysis required to recommend appropriate new policy options.

These new policy recommendations are made in Chapter 4. The concluding chapter provides a detailed account of the incentive structure that will be necessary to actually co-optimize waste management and energy development, and do so in a way that is as consistent as possible with principles of zero waste.

1.2 Actors

Waste management and electricity generation historically have been two separate areas of concern. Thus the actors may be divided into two general categories of waste management actors and electricity actors. The policy recommendations of this thesis are designed to influence actors in both categories

Table 1.2 Waste Management Actors

Public	Private
US EPA	Private waste haulers
State-level Environmental Depts.	Private landfill owners/operators
Municipal-level Dept. of Public Works, etc.	Private WTE facilities
Municipal-level health boards, etc.	Residential waste producers (private citizens)
Municipal landfills	Commercial/Industrial waste producers
Municipal waste haulers	Institutional waste producers
Government waste producers	

Table 1.3 Electricity Actors

Public	Private
DOE	Privately owned/operated generation
IRS	Privately owned/operated service providers
FERC	Residential customers
State-level Energy Depts.	Commercial/industrial customers
ISO-NE (quasi-public)	Institutional customers
Municipal/public utilities	Investor owned utilities
Government customers	

There is existing overlap between these actors, and there is some level of coordination. The goal of this thesis is to more clearly define the overlaps and suggest beneficial opportunities for increased policy coordination. These actors must coordinate their activities and work together to realize the most significant gains in terms of environmental protection and increased human health and safety associated with electricity production and waste management.

In addition to the actors who directly influence policy and are directly influenced by policy, there are a variety of industrial and environmental organizations that advocate and oppose the use of WTE both as a means of waste management and as a means of electricity generation. Waste-to-energy became popular in the 1980s and has since established strong industry support (IWSA website; SWANA website; Fickes 2007; Geiselman 2007; Kiser 2003; O'Connell 2003; Ursery 2005; Williams 2004) On the other hand, the lack of environmental controls, and other perceived problems, has lead to highly organized and vocal opposition (GAIA 2006; GRRN website; Blue Ridge Environmental Defense League [BREDL] website; Concerned Citizens of Russell 2006; Platt 2004; Mikey 2005).[4]

[4] Complicating matters for opposition groups is a 2003 letter from Marianne Lamont Horinko, who was the US EPA Assistant Administrator for the Office of Solid Waste and Emergency Response. In the letter, sent to then ISWA President Maria Zannes, Horinko states that due to adherence to Clean Air Act standards, operating WTE facilities generate electricity "with less environmental impact than almost any other source of electricity" (Horinko 2003).

1.3 Renewable Electricity: Current Context

1.3.1 What is renewable electricity?

There are many debatable definitions for renewable electricity put forth by all manner of organizations, but the most relevant and applicable are the codified definitions of the federal government and the state governments that have enacted renewable energy legislation. Financial incentives that support renewable energy and renewable electricity are distributed by the public sector, and thus a company or technology is only eligible for the incentives if it meets the legislated definition of the governing body.

Federal Definition

The Federal Renewable Electricity Production Tax Credit provides one of the more widely recognized definitions, with waste-to-energy projects generally falling under the following categories: open-loop biomass, landfill gas, or municipal solid waste. The federal rules are specific with regards to which biomass fuel sources qualify as renewable and which do not.

The exact definition and details of which fuels qualify and which do not are provided by IRS Notice 2006-88, and are as follows:

Section 45(c)(3)(A) defines the term "open-loop biomass" to mean:

- Any agricultural livestock (including bovine, swine, poultry, and sheep) manure and litter, including wood shavings, straw, rice hulls, and other bedding material for the disposition of manure (agricultural livestock waste nutrients); or
- Any solid, nonhazardous, cellulosic waste material or any lignin material which is segregated from other waste materials and which is derived from--
  - Any of the following forest-related resources: mill and harvesting residues, precommercial thinnings, slash, and brush;

- o Solid wood waste materials including waste pallets, crates, dunnage, manufacturing and construction wood wastes, and landscape or right-of-way tree trimmings; or
- o Agricultural sources, including orchard tree crops, vineyards, grain, legumes, sugar, and other crop by-products or residues.

The term "open-loop biomass" does not include:

- manufacturing or construction wood waste that has been pressure treated, chemically treated, or painted;
- municipal solid waste as defined in Section 45(c)(6);
- gas derived from the biodegradation of solid waste;
- paper products that are commonly recycled (for example, office paper, newspaper, paperboard, and cardboard);
- closed-loop biomass as defined in Section 45(c)(2); or
- biomass cofired with fossil fuel in excess of the minimum amount of fossil fuel necessary for startup and flame stabilization.

The full definition of open-loop biomass help to show the various forms of waste that are already considered acceptable renewable electricity fuel and those wastes that are not. From the above definition the reader can see that generally "clean" forms of biomass waste qualify as renewable electricity fuel. Wastes that are "contaminated" by contact with other solid waste, such as unsorted municipal waste, do not qualify because the waste may contain plastics, metals, and other material with the potential to release toxins when thermally treated.[5]

Energy Information Administration Definition

The Energy Information Administration (EIA) has recently struggled with how municipal solid waste should fit with the definition of renewable electricity. It has come up with a definition that includes MSW, but differentiates between the biogenic and non-biogenic waste components. In other words, according to the EIA, only the biogenic component of MSW should qualify as renewable, and thus only the portion of energy

[5] Recyclable paper products do not qualify because this material should be recycled rather than used as a biomass fuel.

generated by the biogenic portion of the waste should qualify as renewable energy (EIA 4–5).[6]

Other Definitions

There are a plethora of informal definitions in addition to the various formal government definitions. Most are based on carbon emissions and the ability of the energy generating fuel source to regenerate. While sunlight and wind are stronger in some places than in others and are not constant sources of power, they also do not run out. There is a good deal of rhetoric surrounding definitions of renewable energy, and for this reason I find the more straightforward engineering definitions to be the most useful.

The book Environment, Construction, and Sustainable Development defines renewable energy as an energy source for which no fuel resources are depleted, outside of construction of the conversion facility, and which results in no polluting emissions or effluents during the conversion process (Carpenter 2001). This definition should not preclude biomass-based energy resources. If biomass is harvested sustainably the resource should not be depleted. Also, waste biomass from sustainable processes should be regarded as renewable under this definition. Although the authors may disqualify biomass energy on the basis of carbon dioxide emissions that will be emitted through either direct combustion or combustion of the product gas from a gasification process.

The book Sustainable Energy: Choosing Among Options provides a similar definition, and includes a time qualification. That is, the authors ask the question of over what period of time a fuel resource must be renewable to be considered a source of

[6] Biogenic waste is the organic portion of the waste, such as food and other organics that breakdown and decay naturally. Non-biogenic waste is made up of plastics and other non-biodegradable waste stream components.

renewable energy. Fossil fuel resources cannot be restocked during a human lifetime, or even over the course of several generations. On the other hand, wood and plant biomass can be re-grown every few years or at least within a human lifetime. If the biomass is sustainably harvested it will continue to be available as a fuel source at no net loss of the resource. Wind blows more or less constantly and the sun will be shining for a long time to come. Thus much of the definition for what qualifies as a renewable energy source is based on time in addition to environmental impact; the authors also state that renewable energy should not contribute to net gains in emissions. Unlike the previous definition, this allows for biomass decay and combustion that emits greenhouse gases since that same carbon was absorbed and stored by the biomass as it was growing. Thus no net carbon has entered the atmosphere, assuming the biomass is grown and harvested in a sustainable manner (Tester et al. 2005).

This last definition touches on an important point. The question of whether or not an energy resource is renewable is a question of whether or not the fuel that powers the resource is renewable. In other words, none of the current electricity generating technologies are capable of perpetual electricity generation without continuous fuel inputs. Wind and solar technologies convert wind and sunlight into electricity, but they still require wind and solar inputs to produce electricity. The technologies that convert the wind and sunlight into electricity are not renewable; the wind and sunlight are renewable. Thus discussions of renewable energy resources that use biomass, or waste, must consider whether the biomass or waste inputs are renewable fuels. It is therefore critically important to consider how biomass is harvested, and where the waste inputs originate. Wood burning boilers cannot be considered renewable energy resources if massive deforestation results from their use. However, if forests are managed sustainably the resource can be considered renewable. But biomass must be replanted, or allowed to re-grow, in a quantity sufficient to replenish whatever was harvested. The carbon cycle is only neutral if new biomass is planted to absorb the carbon that is released by conversion into energy.

A similar issue is presented by the use of waste as a fuel to generate electricity. There is a common misconception in the WTE industry that waste is a renewable fuel, because we constantly generate waste. However this is a semantic argument, since the only reason the waste stream is "renewable" is because our society throws so many things away. The waste stream would be less renewable if we adopted principles of zero waste to reduce the amount of waste we generate. Thus waste may not be a strictly renewable fuel source for electricity generation, but it is necessary to treat the waste that we generate, and treatment processes that recover energy provide a greater benefit than treatment processes that simply bury waste in the ground. More will be said about waste stream volumes in subsequent chapters. The basic point for this section is that the question of whether or not an energy resource is renewable is really a question of whether or not the fuel source is renewable, not whether the conversion technology is renewable.

1.3.2 Current and proposed incentives for renewable electricity

Current federal and state legislation and economic programs do provide support for qualifying sources of renewable electricity. Examples of these incentives are listed in Table 1.1 below, along with the Feed-in Tariff and Alternative Energy Portfolio Standard which are proposed or potential options in New England.[7] The RPS and other incentives will be explored in more detail in Chapters 2 and 3, to elaborate on their applicability to electricity generation using waste streams.

Table 1.4 Incentives for Renewable Electricity

Incentive	Type	Agency
Renewable Portfolio Standard	Fixed quantity requirement	State
System Benefit Charge	Electricity consumer charge (supporting a fund for projects)	State
Production Tax Credit[8]	Electricity generator tax credit	Federal (IRS)
Feed-in Tariff	Fixed price requirement	State (likely)
Alternative Energy Portfolio Standard[9]	Fixed quantity requirement	State (likely)

Each of the current renewable energy standards of the six New England states supports biomass gasification and landfill gas capture through renewable portfolio standards. However only half of the states include anaerobic digestion and only Connecticut includes municipal solid waste combustion, as a Class II resource.[10] While the state RPS's also include support for renewables such as wind and solar, the sources described above and listed in Table 1.2 are the resources with the potential to generate electricity using waste streams as fuel.

[7] Vermont currently does have a Feed-in Tariff in place for the anaerobic digestion of cow manure, and Massachusetts has proposed legislation that includes an Alternative Energy Portfolio Standard.
[8] The Federal Production Tax Credit is tiered. Wind, geothermal, and closed-loop biomass receive a credit of $0.02/kWh. Open-loop biomass resources, landfill gas, and MSW resources receive a $0.01/kWh credit.
[9] The AEPS would differ from the RPS in the technologies and fuel types it supports. It would be designed to support efficient electricity resources that are not necessarily renewable, such as highly efficient natural gas-powered turbines that capture both heat energy and electricity.
[10] The state provides a smaller incentive for Class II renewable resources in order to create a greater incentive to develop Class I resources.

Table 1.5 Summary of Technologies for Waste Management with Electricity Generation, Eligible for New England Renewable Portfolio Standards
(Source: Database of State Incentives for Renewable Energy website)

	Combustion	Anaerobic Digestion	Biomass Gasification	Landfill Gas Capture
CT	●		●	●
MA			●	●
RI		●	●	●
VT		●	●	●
NH		●	●	●
ME			●	●

1.4 Waste-to-Energy: Current Context

Waste-to-energy has a long, contentious history. The practice of incinerating waste has been around for thousands of years. The developments of technologies that recover energy are more recent but still date back to the early 1900s (Tammemagi 1999). Technologies that further convert the heat energy into electricity are much more recent. Throughout much of its history WTE was not subject to pollution control regulations and was primarily viewed as a means to reduce the volume of waste that needed to be put in a landfill. Modern incineration and combustion technologies are expensive however, so interest in WTE has followed a boom and bust cycle that closely mirrors the availability of cheap landfill space and the price of energy. That is, when land becomes scarce, or when regulations were enacted that made it more difficult to landfill, it became more economical to invest in WTE (Tammemagi 1999). Similarly, WTE gained popularity during the energy crisis in the 1970s as the price of energy went up, which also made investment in WTE more economical (Landy 1998). These booms have generally been followed by busts as energy prices drop or more land is opened for landfills or perhaps most importantly, as pollution regulations require expensive pollution controls and the public becomes wary of the technology due to perceived negative impacts on the environment and human health and safety (Melosi 2005).[11]

WTE seems to be nearing another boom cycle, especially in New England where land continues to be a scarce commodity and energy prices are high. While public opposition is still great (McLean 2008), it seems that a reasoned discussion of the WTE-related options is currently more viable than in the past few years.

1.4.1 Current WTE incentives

Incentives for waste-to-energy overlap with renewable electricity incentives, and also include incentives for waste management. Any technology for electricity generation that uses a waste stream as fuel is a form of waste management, to some extent.[12] Incentives relevant to WTE are listed in Table 1.6 below, and will be examined in more detail in Chapter 2.

---

[11] Additionally, in the preface of his book, Niessen (2002) states that some of the reason for decreased interest in WTE in the 1990's was due to less pressure on landfills resulting from successful recycling programs. Thus waste diversion has been proven as an effective and relatively cheap way to alleviate some land use concerns. However, recycling doesn't remove organics from the waste stream, which are the main source of landfill emissions and which are useful inputs for anaerobic digestion.

[12] Niessen (2002) argues that the primary purpose of waste incineration is cost-effective, reliable waste management, and energy recovery should only be considered if it is also cost-effective and does not interfere in any way with the primary objective of waste management.

Table 1.6 Incentives for Waste Management with Electricity Generation and Disincentives for Landfill Disposal

Incentive	Type	Agency
Renewable Energy Production Tax Credit	Electricity generator tax credit	Federal (IRS)
Renewable Portfolio Standard	Fixed quantity requirement (for electricity)	State
Tipping Fees	Payments by haulers/individuals to waste management facilities	Private business
Disincentive	**Type**	**Agency**
Resource Conservation and Recovery Act	Federal landfill regulations	Federal (EPA)
Waste Bans	State landfill regulations	State
Landfill NIMBY	Indirect disincentive	Local (health board or similar)

1.4.2 ZWEG: Beyond WTE

The term waste-to-energy has historically referred exclusively to the combustion of solid waste with energy recovery in the form of using the heat to produce steam. This steam was first used for heating and later to turn electricity generating steam turbines. Recently however, some other technologies have been adapted for waste treatment with energy recovery, specifically designed to generate electricity more efficiently and with a less harmful impact on human and environmental health. These technologies include anaerobic digestion, pyrolysis, and gasification. Often pyrolysis and gasification are used together to more effectively reduce the volume of the waste fuel source and reduce the concentrations of toxins and other contaminants in the resulting product gas.

This product gas is the main distinction between traditional WTE and newer methods designed for electricity generation. Rather than using the heat of combustion to produce steam, the newer thermal treatments convert the waste directly into a gas. In the case of anaerobic digestion the gas is essentially methane, which is produced by the decay of the organic component of the waste. With pyrolysis and gasification, the waste is converted into a synthetic version of natural gas, referred to as syngas. Once cooled and cleaned of contaminants syngas can be used just like natural gas. However it does not have as high a thermal value as real natural gas[13] (Williams 2005). This is a problem shared by all forms of renewable energy, however. Fossil fuels are highly concentrated energy, formed over very long periods of time. Appendix B provides additional information on these conversion technologies.

The goal of this thesis is not simply to evaluate new technologies and choose a winner to carry the banner of WTE forward. Waste management is more than technological treatment; it is a process made necessary by the inefficiencies of our society. Waste streams are created by the linear process of production and consumption. Manufacturers produce goods which consumers purchase. Packaging for goods is generally discarded immediately, while the goods themselves may be consumed as food or otherwise used for some amount of time before also being discarded. To some extent, concerns over landfill space create a public incentive to consume less. A potential problem with expanding the capacity for WTE is that there will no longer be a perceived waste volume problem. WTE processes reduce waste volumes by as much as 90%, alleviating a lot of pressure on landfills. WTE also uses the waste as a fuel, and therefore will continue to need the fuel source to continue generating electricity. This creates a disincentive to reduce the volume of waste at the source (i.e. we should discard as much

[13] Williams (2005) states that syngas has a low to medium calorific value, which varies depending on whether the gasification process uses air or pure oxygen. Pure oxygen produces a syngas with a higher calorific value. Syngas on the low end is equal to 4-6 MJ/m^3 (3,792 – 5,688 Btus) while medium value syngas is equal to 10-15 MJ/m^3 (9,480 – 14,220 Btus). For comparison, natural gas has a calorific value of 37 MJ/m^3 (35,076 Btus).

as we please in order to fuel our power plants). This is not a sustainable method of electricity generation or material consumption, and is the complete antithesis of zero waste.

This thesis therefore endeavors to move beyond WTE for waste management and electricity generation to zero waste with electricity generation (ZWEG). WTE is a form or waste management that also happens to be able to generate electricity via heat and steam. It is not a process with accompanying technologies that have been developed to co-optimize waste management and electricity generation. ZWEG is a concept that is intended to co-optimize these two important and formerly distinct processes. By considering the needs of both waste management and electricity generation, processes for waste management can be designed to maximize their ability to divert waste from landfills and recover and reuse as much of this material as possible. The remaining waste streams can be source separated, because waste management will be designed with electricity generation in mind as well, such that organics will be the inputs for anaerobic digestion or composting. If designed properly and as intended, there should be very little waste remaining after recycling and reuse, and additional diversion to organics. What is left can be consolidated to be used as an input for thermal waste treatment technologies that generate electricity. The goal of ZWEG will be to generate as much electricity as possible, as efficiently as possible, using as little waste as possible. Zero waste is not about simply diverting waste from landfills to other uses; it is about completely remaking our production system so that it is a closed-loop system producing as little waste as possible. The ZWEG concept must therefore be implemented with this in mind, so that it does not create a disincentive to the source reduction of waste.

I recognize that this will be difficult to achieve, if not impossible. I remain committed to idea that waste management and energy development can be co-optimized in a manner that is at least not inconsistent with zero waste. But I am also aware that this co-optimization may ultimately preclude complete harmonization with zero waste.

1.4.3 WTE as Renewable Energy

Traditional renewable electricity technologies, such as wind and solar, still have environmental impacts. While the process of electricity generation does not release greenhouse gas or other emissions, there are construction, operation, maintenance, and disposal impacts. Solar arrays and wind farms take up significant amounts of land, and must be located where the renewable resource (wind or sunlight) is most prominent. On the other hand, WTE facilities can be built in most any location, including close to urban centers that generate waste and use electricity and heat. Facilities can be built in existing industrial parks rather than open green space. Such a location would lend the additional benefit of existing utility lines, likely including transmission.

In addition, WTE and ZWEG facilities are dispatchable and can supply the grid with base-load electricity. Wind and solar electricity resources are intermittent, only generating power when the renewable resource (sunlight or wind) is available. Thus the grid has to accept electricity from these resources whenever electricity is being generated, and has to supplement their contribution when they do not generate electricity. WTE and ZWEG facilities can be turned on and off, and can be operated non-stop. There is a lot of value associated with electricity resources that can reliably supply electricity. For this reason WTE and ZWEG facilities would provide a significant benefit to the New England electricity system.

The value of being a dispatchable resource has the additional benefit of providing an alternative to fossil fuel-based peaking and base-load power. A distributed network of ZWEG facilities should be able to offset a substantial amount of fossil fuel electricity. Perhaps more importantly, the ZWEG facility network could serve peak capacity needs. Peaking plants are historically dirty and expensive, and are allowed to be so because they are at times necessary to ensure a sufficient supply of electricity. Because WTE and ZWEG facilities are dispatchable, they could meet peak demand needs, and do so in a cheaper and less environmentally destructive manner.

Part of the argument in support of WTE and ZWEG focuses on the supposed carbon neutrality of certain waste stream components as part of the surface carbon cycle, as opposed to the net carbon gain generated by removing fossil fuels from where they have been stored in the earth's crust. Another part of the argument focuses on the massive energy savings potential of recycling and reuse, which can and should be a part of a comprehensive waste management strategy that includes energy recovery in the form of electricity generation. In other words, using certain portions of the waste stream as fuel for electricity generation avoids the need to use fossil fuels for that purpose.

However, as zero waste advocates are quick to point out, WTE also creates a reliance on a waste stream as a fuel supply, which could discourage reduction in the long term, or at least during the life of the WTE facility. Waste supply contracts must often be in place before investors will commit to building a facility (GRRN website).

1.5 WTE and Zero Waste

The zero waste concept was born from the ideology that encouraged us to reduce, reuse, and recycle, known as the three R's, but endeavors to go further. In an essay titled "The Death of Recycling," Paul Palmer (2007) laments the current state of recycling; a business that needs an input to produce the product. Waste has become the input so there is no longer an emphasis on reduction and reuse since the economics of recycling require a continuous stream of recyclable waste. Recycling is essentially another form of waste management and does nothing to address waste source reduction goals.[14]

In addition to being more about waste source reduction than waste management, the zero waste philosophy is concerned with the entire production cycle. The current system is linear, following a path of resource extraction, industrial production, consumption, and finally disposal. Zero waste advocates envision more of an actual cycle than a linear path. That is, resources are constantly reused and kept in the production cycle. This alleviates the need for virgin resource inputs, so less resource extraction is required for production. Production processes in turn are designed to better incorporate recovered materials and emphasize clean production, doing away entirely with the use of toxic chemicals. Industry and manufacturing thereby becomes cleaner and safer for workers and the environment. Products are designed to be recycled and reused and industries work together to provide each other with production inputs.

---

[14] There is a distinction, perhaps semantic, between *source reduction* and reduction. Source reduction refers to reducing the amount of waste that is produced, period. Reduction can be synonymous with diversion, referring to a reduction in the amount of waste that is landfilled, but having no impact of the amount of waste that enters the waste management system. Thus, recycling reduces waste by diverting waste from landfills to other uses. It does not contribute to source reduction, and actually promotes a continued stream of recyclable waste to support the recycling market.

Consumers also consume less stuff, because products will be more durable. Consumables that are discarded are not viewed as waste. Rather these discards are collected and processed at resource recovery facilities. The sorting process is labor intensive, but will be safe due to the lack of toxics in the products. Thus many new jobs are created to support this system. Useful products are recovered and put back into the production process, and the cycle begins again. This is a very simplified explanation of zero waste but is sufficient to express the substantial societal changes necessary to achieve a true zero waste economy (Eco-Cycle website).

A zero waste society is a highly desirable goal, but one that seems more than a little idealistic. The magnitude of required change is substantial and will therefore be extremely difficult to achieve. This is not to say that people should not endeavor to affect this kind of change, but that intermediate steps may be useful and necessarily while changes are slowly made. Thus the goal of this thesis is to provide an alternative to true zero waste that will not prevent the eventual adoption of a full-scale zero waste economy and production cycle. By stating that policies can be designed to support both electricity generation using waste and zero waste I am not claiming that ZWEG is completely compatible with zero waste. Rather I am arguing that it may be a useful tool both in the interim and as a smaller piece of the eventual solution. However, in order to be a useful tool, the regulatory and incentive structure must support waste management and energy systems that are not incompatible with true zero waste.

1.6 Next Steps

A lot of work remains to be done in order to optimize the coordination between waste management and electricity generation. Various authors have argued that integrated waste management (IWM) must be a part of the future of waste management, and it must include consideration of beneficial resource recovery, including energy recovery (Denison and Ruston 1996; Tammemagi 1999; Petts 1994). There is an obvious hole in the existing policy structure that results in a lack of comprehensive consideration of options for optimal waste management, and often completely ignores the impact of waste management choices on other areas. There is also a lack of coordination between actors responsible for the oversight of waste management and actors responsible for energy development. In order to begin to solve the problem, the existing policy framework must be analyzed to determine which policies are assisting the effort for coordination and which may be hindering it. Subsequently, recommendations can be made to fix the existing policy problems and implement new beneficial policies.

Chapter 2:

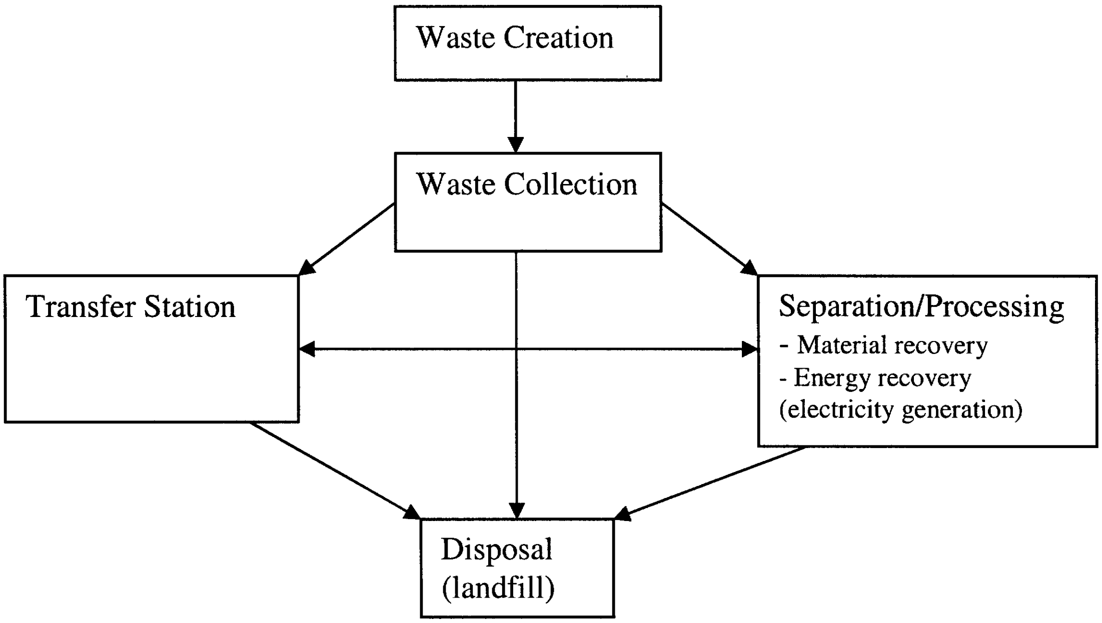
Analysis of Existing Incentives and Policies

2.0 The process of waste disposal to energy recovery

2.0.1 Waste Flow Description

The current process for waste management is linear, and it is in part tied to the overall linear makeup of the production cycle. Resources are extracted from the earth and transported to industrial and manufacturing facilities. The resources are processed into products people use, such as electricity or materials. Consumers purchase these products, use them, and then ultimately dispose of them. Waste management actors take over at this point and generally weigh options based primarily on economics and partially on how options fit with current hierarchies for waste management and disposal. Figure 2.1 models a generic waste management system. Energy recovery, which includes electricity generation, is often a part of the waste management hierarchy, if not explicitly mentioned in the structure. However, energy recovery is not currently at the top of most hierarchies, and in fact is most often seen as a final alternative for diversion before placing remaining waste in a landfill. Energy recovery as a form of waste management is actually equated with landfill disposal in some waste management hierarchies, which can be seen in Table 2.1. Alternatives to energy recovery and disposal, such as source reduction, reuse, and recycling, are generally given more priority in most current waste management systems.

Figure 2.1 Model of the Current System of Waste Management[15]
(Adapted from Williams 2005, p. 370)



2.0.2 The Waste Management Hierarchy

The waste management system illustrated in Figure 2.1 is supported by a widely agreed-upon waste management hierarchy. On paper, most waste management hierarchies resemble Figure 2.2., with reduction and prevention at the top (highest priority) and landfill disposal at the bottom (the option of last resort). Table 2.1 lists the waste management hierarchies from the six New England states.

[15] Disposal in a landfill can incorporate landfill gas-to-energy projects that recover landfill gas to generate electricity. This practice obviously relies on landfills. Conversely, this thesis seeks to reduce landfill reliance by diverting gas-producing waste from landfills and capturing the gas/energy more effectively via ZWEG processes and technologies. Some residual from these projects may require landfill disposal, but will not generate landfill gas.

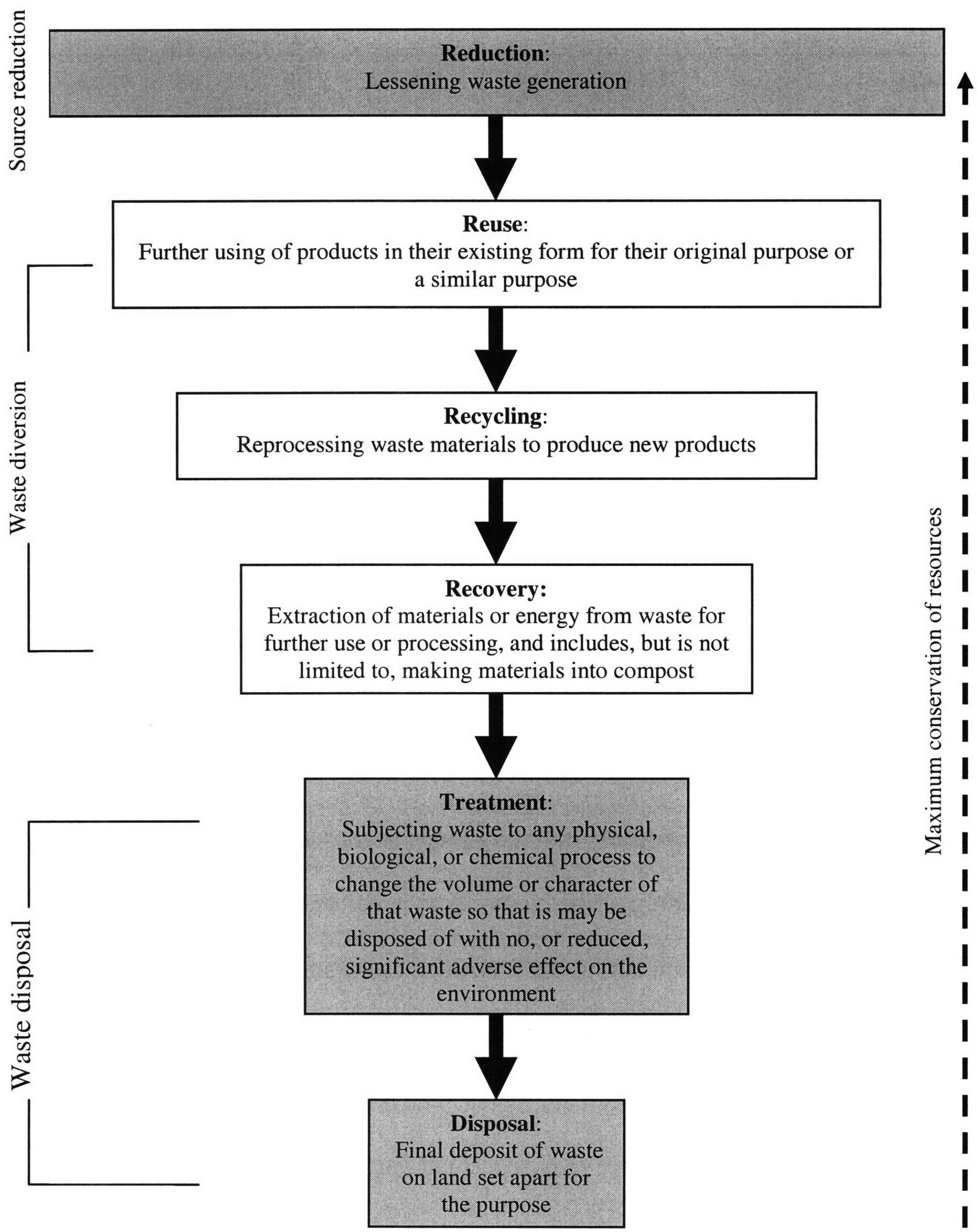
Table 2.1 New England State Waste Management Hierarchies: Hi/low – Top/down

CT (CT DEP 2006)	MA (MA DEP 2006)	ME (ME SPO 2007)	NH (NH DES 2006)	RI (RI DEM 2005)	VT (VT DEC 2006)
Reduction	Reduction	Reduction	Reduction	Reduction	Reduction
Recycling	Recycling/ Composting	Reuse	Recycling/ Reuse	Reuse	Reuse
Composting	Disposal	Recycling	Composting	Recycling/ Composting	Recycling
Energy recovery (WTE)		Composting	WTE	Incineration/ Disposal	Composting
Disposal		Volume Reduction (includes WTE)	Incineration (without energy recovery)		Disposal
		Disposal	Disposal		

The idea is to try to divert as much waste as possible from landfill disposal by not generating waste in the first place, or reusing and recycling as much of the generated waste as possible. By looking for beneficial uses for waste streams, we prevent waste from taking up space in landfills and damaging the environment.

Figure 2.2 is actually a very forward-thinking zero waste-based version of the standard waste management hierarchy. It is also a good visual model as it resembles an inverted pyramid. Part of the idea of this type of hierarchy is that you deal with more volume at the top than at the bottom; diverting more discarded material closer to the source of the waste. Thus the top of the hierarchy is wider than the bottom, indicating that the goal for waste management is to reduce as much as possible, then reuse and recycle as much as possible from what is left, and finally dispose of whatever remains after all other options for diversion have been attempted. The hope is that this remaining bit of waste will be minimal and therefore require a small amount of space. Most hierarchy models are much simpler, and more closely resemble the New Hampshire and South Australia waste management hierarchy models shown in Figure 2.3.

Figure 2.2 Example of a Waste Management Hierarchy
(Adapted from: http://www.oag.govt.nz/2007/waste-management/part1.htm)



In practice, waste management hierarchies are not so idyllic. Tammemagi (1999) claims that most waste management hierarchies actually rely primarily on landfill disposal, followed by recycling, then reduction, and lastly look to combustion with energy recovery. This is supported by the actual waste management numbers for the six New England states, displayed in Table 2.2. In every state combustion and landfill disposal combined account for 50% or more of the waste management system. This analysis gets us to the heart of the issue of waste management and electricity generation. Most government bodies of various levels support and put forth waste management hierarchies that mirror Figure 2.2. But in practice, the public sector plays only a partial role in the greater system and there are insufficient policies in place to ensure that a desirable hierarchy wins.

Table 2.2 New England State Waste Management Percentages

	CT (CT DEP 2006)	**MA** (MA DEP 2006)	**ME** (ME SPO 2007)	**NH** (NH DES 2006)	**RI** (RI DEM 2007)	**VT** (VT DEC 2006)
Recycled	30	35	36	30	23	35
Combusted	57	35	35	17	N/A	N/A
Landfilled	4	15	25	44	N/A	N/A
Exported[16]	9	14	4	7	N/A	N/A

Private waste haulers and management companies have to do what is most economical in order to continue operating. Currently it is cheaper to landfill than to process. Markets for recycled materials are strong, so there is a strong incentive to recycle. Capital costs for new waste-to-energy (WTE) plants are high, and some states, such as Massachusetts, have actually placed a moratorium on the construction of new WTE facilities. Thus, the current system of incentives around waste management and

[16] Exported waste is combusted or landfilled in another state, presumably because the out-of-state option is cheaper.

energy recovery support the perversion of the waste management hierarchy. In order to begin to shift the system toward one that resembles Figure 2.2 the economics of waste management and the regulations that guide the system will have to change. The question is how. Which incentives are currently consistent with the model waste management hierarchy in Figure 2.2, and which are preventing its adoption?

Figure 2.3 New Hampshire Waste Management Hierarchy
(Source: http://www.des.state.nh.us/SWTAS/hierarchy.htm)

Simultaneously, an important question for this thesis is whether the hierarchy in Figure 2.2 is accepting enough of energy recovery for electricity generation, and whether electricity generation should be given more priority in a new waste management hierarchy. For example, Tammemagi (1999) places WTE at the same level as recycling in his revised hierarchy. The incentive analysis in section 2.2 will in part look to see whether and to what extent it may make sense to assign a higher priority to electricity generation.

2.0.3 Beyond Integrated Waste Management

Integrated waste management essentially means that whenever a conversation regarding waste management takes place, all options should be placed on the table so that the optimum mix can be selected. In other words, if a municipality is updating its waste management system, perhaps based on a revised waste management hierarchy, it should consider recycling, landfilling, waste-to-energy, composting, resource recovery, and anything else that may be appropriate for that specific geographic location. The new plan will be the best combination of processes, designed to work in combination. Thus, for example, waste reduction and recycling can be coordinated with a smaller scale WTE facility and an even smaller landfill (Tammemagi 1999; Denison and Ruston 1996).

However IWM is a waste management system, not an electricity generation system. Energy recovery can be a part of IWM, but it is not currently fully integrated. Thus while the concept of IWM is a useful starting point for conversions about improved, comprehensive waste management, it is not sufficient to achieve the goal of co-optimized waste management and energy development. The policies and incentives proposed in this thesis will demonstrated that the need for increased coordination goes beyond coordinated waste management to include regional, inter-agency coordination between both environmental and energy departments. Only then will is be possible to implement ZWEG technologies and processes.

2.1 Incentives that maintain and support the current system

The above discussion of the process for waste management and the potential for energy recovery is focused primarily on waste management. The process models and hierarchies depict waste management strategies and only allude to electricity generation by including the term "recovery" as a possible form of diversion. The emphasis on waste management is necessary but also part of the obstacle for increased electricity generation. The nature of waste streams requires adherence to strict waste management procedures, at least within the current system. That is, at this time WTE is considered primarily to be a form of waste management rather than a form of electricity generation and is therefore regulated primarily by environmental and waste management agencies rather than energy agencies. For that reason the majority of existing incentives around waste management with electricity recovery are waste management incentives. There are some electricity and energy incentives that are relevant, but the majority of what follows will focus primarily on the impacts of waste management policies and economics. Implicit in this analysis are a lack of electricity incentives and a lack of coordination between waste management and electricity actors.

2.1.1 Economics

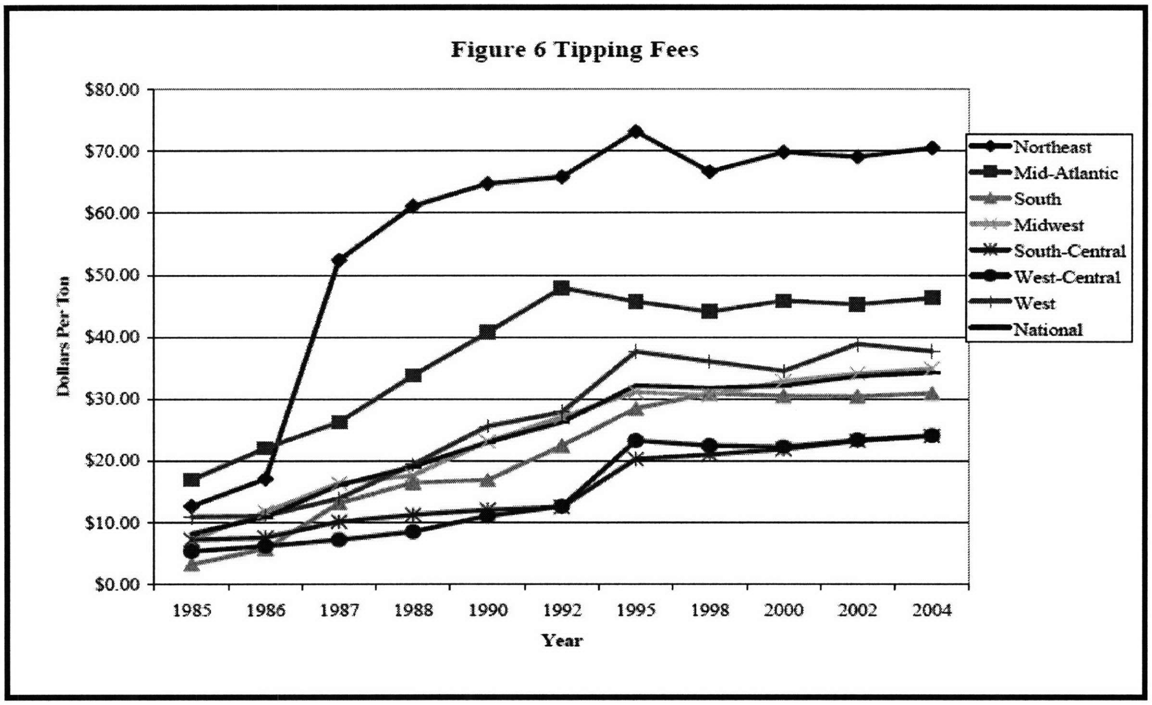
Tipping fees

Tipping fees are the main source of revenue for any waste treatment facility. The tipping fee is the fee paid by the waste hauler to the facility operator for the privilege of "tipping" the contents of the waste hauling truck onto the property of the waste treatment facility. More waste will go to wherever it is cheapest to tip the trucks, and if tipping fees are cheaper than other options, such as processing for reuse or recycling, straight dumping will win. In New England there is less and less available landfill space, so tipping fees have become quite high. As tipping fees climb, other options for waste management become more economical and it becomes more reasonable to implement regulations such as waste bans for certain materials. Unfortunately, even when regulations are in place to prevent dumping of certain materials, the economics will often carry the day.

In the case of WTE, waste is thermally treated to reduce its volume and generate heat and electricity. In the days before energy recovery, incinerator operators earned all their revenue from tipping fees. Energy recovery, especially when this includes the sale of electricity as *renewable* electricity, allows the tipping fees to be lower while also increasing the financial stability of the WTE facility (Denison and Ruston 1996).

Figure 2.4 US Tipping Fees by Region

(Source: NH DES Solid Waste Report to the Legislature 2005, September 2006)



Cheap landfills and expensive processing

While tipping fees at landfills within the New England region are the most expensive in the U.S. and becoming more expensive, there are still options for cheap disposal relatively nearby. For example, construction and demolition waste may be banned from disposal in Massachusetts landfills in order to encourage processing and reusing and recycling. However, since processing is expensive, it may be cheaper to ship the waste out of state for disposal in a landfill. Thus, to some extent, the waste will be diverted from landfills in Massachusetts, but the informal market structures ultimately support disposal rather than economic development around a new construction and demolition waste processing economy. Until it is just as cheap or cheaper to process this waste in Massachusetts, it will continue to be sent elsewhere. This example is indicative of waste management problems throughout New England.

Existing markets

There are also well-established markets that support and are supported by the existing waste management system. Figure 2.1 is a very basic generalization of the system, but within that structure there are many private companies that haul waste, sort waste, consolidate waste, ship waste, treat waste, and ultimately store waste indefinitely in landfills. Contracts have been established and infrastructure has been put in place to ensure that waste is managed safely and efficiently. Any revision to the existing system has the potential to disrupt these economic transactions, and must therefore be implemented carefully. However, while the current system does manage waste, it does not do so in a manner consistent with a desirable waste management hierarchy. Thus the goal of many municipalities, and the US EPA,[17] is to disrupt the current system and shift it to one that supports more reduction and reuse. Because the existing markets and infrastructure are so well established, it will be rather difficult to actually disrupt anything. Concerted public intervention with strong market supports will likely be needed, and, if designed well, will encourage greater economic development through the establishment of expanded complimentary waste management infrastructures.

High capital costs for technology-dependent solutions

The high capital costs of high-technology options for waste treatment do not make these economical in the current system. It is simply much cheaper to dispose of waste in landfills or even to recycle and reuse materials. Waste-to-energy facilities are power

[17] The US EPA has adopted a waste management hierarchy that prioritizes reduction first, followed by recycling and composting, and finally relying on combustion and landfill disposal to manage any remaining waste.

plants with expensive machinery for thermal treatment and pollution control. However, at some point the economics of energy recovery may begin to make sense, and it may be desirable to support energy recovery with subsidies given current concerns about the direction of waste management and concerns about dependence on fossil energy sources. The current system is not supportive of technological solutions, but it may be necessary to implement economic support for options that provide electricity with minimal environmental impact and are consistent with a better waste management hierarchy.

Tipping can alleviate some of the pressure of high capital costs when electricity-generating facilities use waste as fuel inputs. However, tipping fees in New England are high and an electricity generation facility will be more competitive if it does not have to rely on tipping fees for revenue. The President of Ze-Gen explained that his company will seek to rely primarily on electricity sales. In doing so, it will be able to offer very low tipping fees to construction and demolition processors. The low tipping fees offered by Ze-Gen will create an economic incentive for processors to bring their sorted C&D waste to Ze-Gen, thereby providing the company with a means to generate electricity (Davis interview). The high capital costs for facility construction, operation, and maintenance tend to make this difficult in practice, especially for traditional WTE combustion facilities that do not produce electricity as efficiently as gas-based technologies.

Conversely, Jeffery stated that Wheelabrator, a waste-to-energy company, has not been impressed by the pilot tests for newer WTE technologies such as gasification (Jeffery interview). The economics and conversion efficiencies do not appear to be favorable. Wheelabrator will therefore continue to focus its efforts on improving combustion technology economics and efficiencies. Thus tipping fees and electricity sales will continue to be important, and any additional incentives associated with renewable or alternative energy will help to lower the front-end tipping fees.

Commodity markets for interstate transport and trade of Municipal Solid Waste

Finally, municipal solid waste (MSW) is considered a commodity and is therefore subject to the regulations and economics of interstate commodity markets. These markets are regulated by federal rules that protect and monitor trade between states. Thus, the economics of waste transport between states are complicated by rules that protect interstate commerce without regard for the potential negative economic and environmental impacts associated with the exportation and importation of MSW.

States previously tried to control waste imports and exports, which is referred to as flow control. Congress, and the court system, has routinely struck down these state attempts to restrict interstate waste flows. There is currently proposed legislation in the House that would allow states more control over the flow of waste (H.R. 274 Solid Waste Interstate Transportation Act of 2007). Most recently, in February of 2007, this bill was referred to the House subcommittee on Environment and Hazardous Materials. No action has been taken in over a year, and Congress has historically taken no action to change the rules around interstate waste transport, thereby maintaining support for the current system.

2.1.2 Legal and political issues

There is a general lack of a strong regulatory system for waste management and a large reliance on market forces. There are certainly laws on the books that regulate waste management, the most important of which is the Resource Conservation and Recovery Act (RCRA). However, RCRA creates rules for operating landfills and other waste disposal and storage areas, but leaves the operation and maintenance of these locations to private companies or municipalities.

In general, waste is managed at the municipal level. Federal and state governments create rules for some aspects of waste management, but rely on cities and towns to implement the rules. These municipalities often do not seem to have the resources to support waste reduction initiatives or to establish programs for reusing and recycling. Thus while it is useful for the EPA or the state environmental office to provide information about waste management hierarchies and to set goals for waste reduction and recycling, little is accomplished in form of real programs by these means. Little will continue to be accomplished without additional economic support. Add the plethora of private waste management companies to the mix and the problem only becomes more complicated by the differing objective of public and private entities

There is also a lack of coordination between public waste management regulators and public energy regulators. Again using Massachusetts as an example, the state Division of Energy Resources (DOER) is responsible for determining whether a given source of electricity is eligible for the state renewable portfolio standard. However, it is up to the state Department of Environmental Protection (DEP) to decide whether a given facility can be built and operated based on environmental laws. It seems that while the DOER may be interested in increasing the installed capacity of electricity generation within the state, and trying to create incentives for certain forms of energy through the RPS, the DEP has the deciding say as to whether any new capacity is acceptable based on environmental criteria. I am not presenting this example as a critique of environmental laws and safeguards for public and environmental health. However, through interviews with the MA DOER (Breger interview) and the MA DEP (Fischer interview) it became clear that there is a distinct separation of responsibilities. It is therefore important to recognize that different regulatory agencies may have different priorities, especially around issues such as waste management and energy development that may be viewed as unrelated. If energy development is to become an acceptable and well-managed form of waste management, these agencies will need to establish procedures for better inter-agency coordination.

Finally, when regulation for waste management are implemented they may have unintended negative consequences, especially with regards to the potential for simultaneous energy development. Ze-Gen's Davis provided the following example. Massachusetts law requires construction and demolition (C&D) waste to be processed before it can be disposed of. The intention is to recover and recycle as much of this waste stream as possible, and thereby divert it from landfill disposal. However, processing is expensive and it is cheaper to ship the waste out-of-state for disposal. The result is that C&D waste is not put in Massachusetts landfills, but it is also not properly processed to maximize recovery and recycling. Additionally, from the perspective of energy development, that C&D waste is lost as a fuel source for electricity generators in Massachusetts. Regulation can be a strong tool for managing waste streams and designing waste management hierarchies, but if processing requirements and waste bans are implemented without sufficient regard for perverse economic consequences the regulations may not achieve their intended results.

2.1.3 Private sector management

The above discussion of the current waste management system has already provided some information about the role of the private sector in waste management and electricity generation. Most waste management companies are set up to operate in the current system, and most are not focused on electricity generation. Just as the regulatory agencies are separate, so are the industries for waste management and energy development.

Private waste management companies are comfortable with the status quo, as evidenced by their interest in developing energy systems that operate within the current system. Landfill gas recovery is one example. It makes sense to manage the gas being generated by existing landfills, but it does not make sense to continue to create landfills with the goal of capturing the gas for electricity generation. If electricity generation is the goal of a system, landfill gas capture is a very inefficient means to that end. The process is more time consuming and is less capable of total gas management. It is in the interest of waste management companies with landfills and infrastructures that benefit from landfills to try to encourage their continued use. If energy recovery in the form of electricity generation is going to fit into a new waste management hierarchy, the waste management infrastructure for hauling and processing will probably have to change dramatically. Private companies will have to be properly motivated to change.

2.1.4 Technical challenges

Modern WTE facilities are complex technological achievements. Boiler controls are capable of achieving very high combustion efficiencies and pollution control equipment has reduced many emissions by upward of 90%. However, these facilities are very dependent upon technological controls to operate at optimum efficiency. Additionally, most of the newer technologies that claim to have little to no environmental impact have not yet been tested and proven on a commercial scale. Gasification technologies have been around for many years, but have only recently been put to use for waste management with electricity generation. It is therefore too early to tell whether these systems will be successful, but current pilot are promising. As stated above, Wheelabrator is not convinced that any of these technologies will prove to be economically viable. Thus if the technologies are found to be well-suited to co-optimize waste management and energy develop it will be in the interest of public officials to subsidize their deployment for integration in a ZWEG system.

Historically, energy facilities that generate energy using waste combusted the waste directly. Various methods of processing and burning have been developed to maximize the combustion efficiency, thereby lessening harmful emissions and more fully recovering the energy stored in the waste. In this method of WTE, air or oxygen is important to maintain a high burn temperature.

Gasification and pyrolysis are now being used in combination to accomplish similar waste management results, reducing the physical volume of inputs, while being designed with electricity generation in mind. Combustion systems generate a lot of heat, and use the heat to make steam to drive electricity generating steam turbines. There is a loss of efficiency in electricity conversion associated with these multiple steps, which is why combustion systems lend themselves well to combined heat and power. Gasification uses heat in a very low oxygen environment to gasify inputs, rather than directly combusting the inputs. The gas can then be cooled and passed through gas cleaning devices to remove toxins and impurities. The resulting cleaned syngas is very similar to natural gas, or the biogas generated by anaerobic digestion. In other words, it contains a high level of methane. The gas can then be combusted in standard gas turbines to generate electricity. At smaller scales, this process is more efficient at generating electricity than direct waste combustion (Asami et. al. 2002).

Unfortunately both gasification and direct combustion rely on technology to control harmful emissions. The systems used in direct combustion are well established and proven to reduce emissions of toxins such as mercury and dioxin. Gasification and gas cleaning technologies are not to the point that syngas can be considered environmentally benign, but there is a lot of research and development going toward accomplishing this goal, particularly in Europe and Japan where WTE is more widely deployed. The Swiss use WTE to treat 75% of their waste, while Japan treats 50% "without any adverse health impacts" (Tchobanoglous and Kreith 2002). It is generally agreed that gasifying solids and burning the resulting syngas is cleaner than burning the same solids directly (Neissen 2002). The toxics in the solid are still present, but they can be removed prior to combusting the gas. This can be more effective at trapping toxic emissions than traditional in-stack methods.

Processing and sorting heterogeneous waste streams is also very complicated, but an essential part of a waste management system that encourages reusing and recycling. It is also necessary in order to prevent toxic material from entering thermal treatment processes. The emissions of these facilities are directly dependent upon the material that comprises the fuel. Upfront sorting and processing is an important step in the process, and will become more important if waste management with electricity generation becomes a major part of future waste management and energy development strategies. Processing and sorting is also an economic issue since it is more expensive to thoroughly process and sort waste streams.

A more thorough description of combustion WTE and pyrolysis/gasification can be found in Appendix A, along with a description of anaerobic digestion.

2.1.5 Societal (perception) barriers

Finally, there are societal perceptions of waste management and electricity generation that support the current system. The biggest public perception barrier to WTE is that combustion of waste is bad; that it is harmful to the environment, harmful to people, and creates the wrong kind of waste management incentive by encouraging waste generation as a fuel source for power. New technologies for the thermal treatment of waste with electricity generation attempt to circumnavigate these concerns, but ultimately encounter the same opposition. Societal concerns are not without merit since the emissions from technologies that generate electricity from waste are made more or less toxic by the composition of the waste inputs. In other words, cleaner fuels result in cleaner emissions. Thus public opposition can be a response to the type of waste proposed as a fuel source, rather than opposition in general to any type of power plant.

The use of construction and demolition waste as a fuel is especially contentious. On the one hand this debris contains a lot of wood waste that is ideal for combustion or gasification. On the other hand there are a lot of toxic chemicals in construction materials, and if the C&D waste is not properly sorted, or if any part of the clean wood becomes contaminated, the thermal processes used to generate electricity could also lead to toxic emissions. Technologies do exist to sort C&D waste and to control emissions, but the risk of toxic emissions cannot be reduced to zero and it remains difficult to convince people to even accept a minimal level of risk. A developer in New Hampshire who had been trying to start an MSW gasification facility recently encountered significant opposition. He suggested that people had bad memories of incinerators from the 1980's and are very reluctant, if not totally unwilling, to give newer, potentially cleaner technologies an opportunity (McLean 2008).

Other societal barriers to change are more or less a reflection of the average person's ability to put waste out of sight and mind, and desire not to have to deal with waste management at the level of the individual. When curbside sorting of waste and recyclable material requires more effort from individuals, people are less likely to participate. People have also developed a comfort and reliance on the linear production and waste model that seems to make modern life more convenient, even though it creates more waste.

Additionally, public opposition to the siting of new landfills makes it difficult to construct new facilities. While not a direct incentive for WTE, these problems for landfills make it less difficult for new WTE. However, there is certainly strong opposition to new WTE facilities as well and the use of WTE to treat waste does not preclude the need for landfills. The residuals from the thermal treatment, while generally about 10% of the volume of the original waste stream will still need to be disposed of in a landfill (Denison and Ruston 1996).

2.2 An Alternative Hierarchy of Waste Management

In practice, many waste management systems do not adhere to the hierarchies that are supposedly behind them. The US EPA solid waste hierarchy prioritizes source reduction and reuse at the top, followed by recycling and composting, with disposal through incineration and landfilling at the bottom (EPA MSW Basic Information website). However, directly under this declaration on the EPA website the statistics for waste management show that only about 33% of waste is recycled or composted, while 12% is combusted and 55% is sent to landfills. Thus 67% of waste in the U.S. is managed by the lowest priority option in the EPA waste management hierarchy.

The numbers are similar for many locations in New England, as shown in Table 2.2, although most have been able to divert a large portion of the waste stream away from landfills and into recycling and compost programs. Regardless, the creation of hierarchies has not yet resulted in a significant shift in actual waste management systems. Most hierarchies simply incorporate existing strategies in different orders, which does little to create incentives for real change; the hierarchies are not accompanied by economic support for the infrastructure changes that could support a new system in which a higher percentage of the waste stream would be dealt with by the higher priority options in the waste management hierarchy.

For example, a well designed plan for ZWEG would focus primarily on reducing the volume of waste at the source by something like 50%.[18] After that the policies would support reuse and recycling for at least 50% of the waste stream that still exists. Subsequently, as much of the remaining 50% as possible would be diverted to the ZWEG infrastructure. Any remaining waste for the original waste stream, along with any residuals from electricity generation, will be disposed of in a landfill. At this point, the waste going to the landfill should be no more than 10% of the original, source reduced waste stream.

Any new system for waste management with electricity generation will have to work within a waste management hierarchy like the New Hampshire model presented in Figure 2.3. But most importantly it will have to be accompanied by the right incentives so that the hierarchy can actually function as intended. This will mean that public agencies will have to coordinate efforts for regulation and economic support to properly motivate

---

[18] Source reduction would be accomplished through the adoption of zero waste policies for a more cyclical production process. Industries would design production processes that use fewer raw materials, use more reused and recycled material, and generate less waste. Industries would also coordinate their production activities to trade waste products which may be useful inputs for other industrial processes. Thus the total waste stream will be something like 100 tons rather than 200 tons, meaning that starting waste stream will actually be 50% smaller than it used to be. Rather than having to divert 50% of 200 tons to reuse and recycling, the ZWEG processes will only have to divert 50% of 100 tons.

private companies. Section 2.4 begins to lay out the kind of incentives that will be necessary to support such a system.

2.3 Existing incentives that need to be strengthened

2.3.1 Regulations for waste disposal

Pay-as-You-Throw and mandatory recycling (for reduction)

Pay-as-you-throw (PAYT) waste management programs are being implemented in many municipalities throughout New England. The idea behind this system is that individuals pay for waste management services based on the number of waste containers or bags they put out for curbside pickup. It becomes more expensive to put out more than one container, and therefore more expensive to generate waste. The goal of PAYT programs is to encourage recycling, which does not cost more. In other words, under a PAYT system it is cheaper to recycle more material and generate less actual waste.

Enforce landfill regulations and waste bans

Some states implement waste bans for certain materials. A waste ban is a law that makes it illegal to put certain types of waste into a landfill. Reasons for waste bans can vary, but include the health and safety concerns associated with toxic materials as well as a way to force diversion. Waste has to be managed by some means, so materials can only be banned from landfill disposal if an alternative to disposal is available. Additionally, that alternative needs to be economical or it will be very difficult to maintain the waste ban; as previously stated, waste tends to find the cheapest treatment option which can mean illegal dumping or shipment out-of-state for disposal where there is no ban.

Many waste bans are therefore implemented in conjunction with public funds to support alternative management options and infrastructure. The success of some waste bans sets the precedent for the use of a combination of regulation and economic incentive to effect change toward a more desirable waste management hierarchy. For example yard debris is banned from landfill disposal in Massachusetts. This waste is collected separately from other residential waste for composting. Massachusetts is considering a similar ban for food waste, but will first need to consider how to support the expansion of the existing composting infrastructure.

A waste ban also needs to be enforced, and this means the implementing body needs to have the resources to monitor waste management and disposal operators and the capacity to punish violators. Stronger enforcement of existing landfill regulations, be they associated with RCRA or state-level waste bans, will go a long way to help divert material from landfills. However, again, these regulations must be enacted in conjunction with support to establish or expand markets for waste management alternatives to landfill disposal.

Expand organic waste diversion

New England states currently include composting as a waste management option, but most also recognize that current capacity and infrastructure are inadequate. As mentioned above, increased support for composting includes the potential for banning compostable material from landfills while providing economic support to expand the infrastructure for diverting this material to composting facilities. Financial assistance should also seek to increase composting capacity throughout New England. The current Massachusetts Solid Waste Master Plan has a goal to increase state composting capacity (MA DEP 2006), and Vermont has already taken steps to do so (VT DEC 2006). Increasing the ability of the region to divert organic waste from landfills will be a huge step toward decreasing landfill needs. It also makes more sense to divert this waste stream to local uses since organic waste is too heavy to transport economically over long distances.

Anaerobic digestion could provide an economical means of organic waste diversion due to the economies of scale of the organic waste stream of a city. Ostrem (2004) determined that an anaerobic digestion facility would be ideal for on-site organics waste management and electricity generation at the Hunt's Point Market in the Bronx. It seems likely that similar systems could provide waste management and electricity benefits to urban centers throughout New England.

Since increased electricity generation will also benefit the region, it seems that environmental agencies could support the creation of an anaerobic digestion infrastructure as a complimentary means of organic waste diversion. Anaerobic digestion, when done with appropriate organic inputs, will provide a soil amendment similar to compost while also producing methane gas in a controlled environment. The gas is similar to gas generated in landfills, but the production efficiencies can be optimized and the gas can be better managed. You get all of the benefits of landfill gas capture without the environmental costs of dumping the waste in a landfill. Waste that is fed into a digester can also be source separated, or otherwise sorted to remove unwanted material.[19] This will optimize digestion and gas production, as well as help prevent the inclusion of toxins.[20]

Strong domestic, regional, and local markets for recycled material

To the extent reasonable, it could be beneficial to support more local processing and use of recycled material. While markets are currently strong, much of the paper and plastic that is collected in New England is actually shipped to Canada and Asia to be processed into new products. Such long transportation distances are not ideal from an environmental perspective, but it is good that there is such a strong financial incentive to recycle.

According to Schuren of the Toxics Action Center, this incentive still supports local and regional jobs associated with the collection and initial consolidation and processing of recyclable material (Schuren interview). For this reason, and because it seems to make some economic sense to ship paper and plastic long distances[21], it may ultimately make the most sense to focus limited public resources on the strengthening and expansion of regional capacity for composting and anaerobic digestion to divert the organic portion of the waste stream, while maintaining support for the existing paper and

[19] Anaerobic digestion (AD) is best accomplished with wet organic material, such as food waste. Too much dry waste decreases the efficiency of gas production. Conversely, composting requires a balance of wet and dry material. This should allow composting and AD to be complimentary; especially in urban areas were a significant portion of the organic waste will likely be wet material like food.

[20] Landfill gas-to-energy projects capture gas that is released by all the decomposing material in the landfill, which can include material that produces toxic emissions. Biogas from an anaerobic digester may therefore burn more cleanly than gas from a landfill.

[21] Paper and plastic are lighter than organic waste and do not tend to decompose rapidly. For these reasons is it is less costly to ship paper and plastic over long distances. While the environmental impact of shipping paper to China is significant, the recycling market overseas is strong and it does support domestic recycling programs and the accompanying collection and consolidation jobs. No such market will ever be established for organic waste because it is heavy and decays quickly, so it makes sense to devote limited public and private resources to support for local and regional organics waste diversion.

plastic recycling system. This sentiment was shared by Dubester from the Center for Ecological Technology (Dubester interview).

2.3.2 Regulation for electricity

Renewable Portfolio Standard (RPS)

Renewable Portfolio Standards (RPS) essentially mandate that electricity providers purchase a specific percentage of their power from renewable sources (EPA *Guide to Action*). Each state sets its own percentage target and defines which resources qualify. While an individual electricity generator is not guaranteed a market for its electricity, it is much more likely that a power provider will buy the power due to the mandate created by the RPS. The RPS has so far not been enacted at the federal level, but 26 states and the District of Columbia have introduced and adopted independent legislation. Additionally, three states, including Vermont, have adopted non-binding, voluntary renewable energy standards (EERE website).

Renewable Energy Credits (REC) are usually a component of an RPS. The REC is a separate credit from the actual electricity meant to represent the monetary value of the environmental benefits provided by renewable electricity (EPA 2006 *Guide to Action*). The REC system also makes it easier for the state to track purchases of renewable electricity and thereby more easily ensure the RPS is being met by all electricity providers. REC's can be purchased separately from the actual electricity, and thereby grant an additional revenue stream to producers of renewable electricity. Additionally, a provider in Massachusetts could purchase REC's from a qualifying renewable electricity generator in another eligible location, such as Connecticut. Even though the electricity is generated and distributed in Connecticut, the Massachusetts electricity provider is helping to fund renewable electricity and is thereby able to meet the RPS requirement. A qualification is that the electricity being generated in Connecticut must meet the Massachusetts standards, but if it does the provider can purchase REC's from wherever they are cheapest.

If an electricity provider cannot purchase enough renewable electricity to meet the percentage standard set by the RPS it can make a payment-in-lieu. This means the electricity provider can simply pay into a fund as a sort of penalty for not meeting its RPS obligation. However most RPS's are designed to discourage this practice in order to promote the development and deployment of installed renewable electricity capacity. Reliance on the payment-in-lieu is discouraged by making the cost of the payment higher than the expected cost of purchasing renewable electricity.

Some state standards include anaerobic digestion and systems that use waste biomass as fuel as eligible renewable electricity resources.[22] These electricity resources are consistent with the concept of ZWEG, assuming they are modified to co-optimize waste management and energy development. Facilities that use waste as an input for electricity generation may be able to receive tipping fees, as is the case with traditional WTE combustion facilities. However, due to the generally high regional tipping fees for landfills and combustion facilities, it would be better if any ZWEG facilities were able to generate revenue primarily via electricity sales rather than tipping fees, per the Ze-Gen

---

[22] Landfill gas technically can be included as a RPS-qualifying form of WTE, but landfills should be a waste treatment method of last resort and should not contain the materials that decay to produce landfill gas. These materials should be separated and treated for energy recovery using another, more efficient method such as anaerobic digestion or a thermal treatment.

model. This would allow the facilities to be a more economical waste management option. Eligibility for RPS economic benefits would be useful to help make electricity generation the primary source of revenue.

Federal Renewable Electricity Production Tax Credit (PTC)

The federal Production Tax Credit (PTC) provides a qualifying new facility a tax credit based on each kilowatt of electricity it generates, for a period of 5 to 10 years depending on the fuel type. It is an important piece of national legislation because it can make a project much more economical, or, when used in a partnership flip,[23] it can serve to attract financially secure investors. Investors in the wind and solar industries claim that the credit has made a lot of the deployment of these renewables possible. Since it is a national incentive, it can be used anywhere in the US to assist with the development of a qualifying renewable electricity source.

The PTC can currently be applied to MSW combustion WTE projects and both open- and closed-loop biomass projects.[24] As mentioned in an earlier footnote, the PTC does not provide the same incentive to all eligible resources. Closed-loop biomass and wind resources each receive a credit of $0.02/kWh respectively, while open-loop biomass, MSW resources, and landfill gas receive only $0.01/kWh. However, although

[23] Partnership flips are generally used for wind projects, but could be useful for any renewable electricity project that is eligible for tax credits. Essentially, an investor partners with the renewable electricity developer and owns a majority percentage of the project. The investor is then eligible for a percentage of the tax credits equal to its percent ownership of the project. After the tax credit period is done, the project developer buys out the majority of the investor's project ownership. The point of the flip is to secure upfront financial support for the project by enticing an investor who can benefit from the tax credits. The IRS recently released "safe harbor" guidelines for partnership flips (IRS *Rev. Proc. 2007-65*)

[24] Closed-loop biomass denotes biomass electricity projects that "grow" a biomass product for the sole purpose of using that biomass to power the electricity facility. In other words, the system is a closed loop. Open-loop biomass refers to biomass electricity projects that use outside sources of biomass as a fuel. The language of the PTC defines the types of biomass that qualify for the open-loop provision.

the credit may be less for electricity projects that use waste stream for fuel, ensuring the continued availability of this tax credit will in turn ensure the continued viability of new electricity generating projects that do not rely on fossil fuels.

System Benefit Charges (SBC)

A System Benefit Charge (SBC) is a small fee added to the bill of electricity customers that feeds into a pot used to provide benefits to the electricity system. These benefits can be in the form of efficiency retrofits, rebates for energy efficient appliances, and other demand-side management options. The charge can be used for almost anything that will provide real benefits to the electric system and its customers, and therefore could be used to support electricity projects that use waste as fuel (EPA 2006 *Guide to Action*). These charges are currently most often used to support energy efficiency measures and other demand-side electricity programs, but some states have set up separate charges that are used to support renewable electricity projects.

Due to the existence of RPS legislation, the federal production tax credit, and the potential for other electricity incentives I feel that the SBC should be not be used to directly support renewable or clean energy development. Rather, the SBC for clean energy development could be applied to system-wide transmission enhancements that would benefit new electricity generation facilities. Thus, the benefit of the SBC would not be direct economic support, but the charge would provide a *system benefit* by covering the cost of infrastructure development. Resolving transmission issues associated with a distributed electrical system will be important to the success of ZWEG processes, but it will also be exceedingly complex and resolution is beyond the scope of this thesis.

2.4 Existing perverse incentives that should be minimized

2.4.1 Regulation for cheap waste disposal

There are existing regulations for landfills, most notably RCRA, which require stringent environmental controls to prevent water and air contamination from dumping activities. These regulations, in combination with growing land scarcity have caused the cost of landfill activities to increase. Landfilling is still almost always the least-cost waste management option. It simply requires less work to dump a heterogeneous waste stream in a single place without sorting or processing, even if the waste must be transported a considerable distance. As existing landfills begin to reach their designed capacity and as fewer new landfills are sited, the cost of landfilling will likely increase. This will be translated into higher tipping fees for areas that use these landfills.

There is no reason to wait for this to happen, however, since it could cause a scramble that may result in environmentally harmful waste management alternatives. While it may not be possible or desirable to increase the cost of landfilling to make diversion options more economical, more should be done to make diversion costs competitive with landfilling. This will allow existing landfills to last longer and will put waste management on a more sustainable path; a path that could include huge potential for new sources of electricity generation.

2.4.2 Regulation for expensive waste disposal

Landfills are generally a cheap means of waste management, but landfills in New England are not necessarily the cheapest option. There is not a lot of space in the region and tipping fees are fairly high already. As a result, some waste is actually exported between New England states and exported out of the region to areas where the cost of landfill dumping is less expensive. The option for cheap disposal in other regions undermines the potential for useful diversion within the region. In other words, if it's cheaper to send unprocessed waste to Ohio than to process it and recycle it in New England, the waste will go to Ohio (Davis interview). Public agencies need to assign more resources to support the development of regional and state-by-state infrastructure and expand capacity for diversion economies around processing and recovering more material from the waste stream. Inroads are being made for construction and demolition debris, but the costs of processing are still high. Since is it less cost-effective to transport organic waste over long distances it may be easier to develop an economical system for diversion and recovery of this part of the waste stream.

2.4.3 Site Assignment or other local and state permitting requirements

The Massachusetts DEP is responsible for general state-wide oversight of waste management goals. However, the siting of individual waste management facilities is the responsibility of local boards. The nature of waste management certainly requires careful evaluation of sites and proposed activities, but the current system seems to simply add another level of red tape to an already complicated and uncoordinated system. The federal government has broad goals and a few regulations for waste management. The state has more focused regional goals and a few more regulations. But the actual task of waste management is left up to individual cities, towns, and municipalities, and is often carried out in practice by private companies.

Suggesting a change around local permitting is complicated. It may be beneficial to allow state-level control so that facility siting can be better coordinated. However, this could also lead to strong local opposition without appropriate means for local participation. Some sort of change in the permitting process could make it easier to site facilities that are in line with state and federal goals for waste reduction and diversion, or that increase installed electricity generation capacity. Thus, the steps for permitting could be designed to make it easier to site a composting facility or anaerobic digester and harder to site a landfill, easier to site a recycling or materials recovery facility than to site a basic transfer station. While these facilities would have a definite local impact, oversight and coordination at the state or regional level could help ensure appropriate facility distribution and provide financial support to create the infrastructure necessary for its operation.

2.4.4 Landfill gas incentives for renewable electricity and carbon offsets

Landfill gas can currently be captured and used to generate electricity, and thereby qualifies for either renewable electricity credits or carbon offsets. There is a very good reason for creating this incentive, since the gas produced by landfills has a high percentage of methane, a very potent greenhouse gas. There are a lot of landfills currently operating, and it is costly to install the gas control equipment. The economic incentive created by the renewable electricity and carbon offset programs likely contributes to a significant reduction in emissions, and does help to increase the installed capacity of electricity generation.

However, this system provides a means by which landfills come to be seen as beneficial. The rules around incentives for landfill gas should be designed to encourage gas capture at existing landfills, but should also ultimately discourage landfill use and encourage use of technologies that more efficiently produce and capture biogas. Anaerobic digestion accomplishes the same result as landfill gas production but with a smaller land requirement and more efficient use of the methane gas.

Change in the incentives should come in the form of timeline requirements that are designed to encourage the implementation of landfill gas–to-energy projects, but that restrict the amount of waste that can be continued to be dumped over time. The goal of the revisions should not be to encourage expanding existing landfills, since continued dumping may become desirable if the landfill operator can continue to benefit from electricity sales for a longer period of time.[25]

---

[25] Some portion of the electricity sales from landfill gas capture should also be required to be placed in a long-term landfill management fund. Even after landfills are closed and no longer generate enough biogas to economically generate electricity, they still release emissions into the air and have the potential to negatively impact the surrounding environment. Electricity sales from landfill gas are a newly realized benefit. Electricity generation is also basically a more expensive form of gas management, which is required at a basic level by EPA regulations. Thus, landfill operators are receiving financial benefits from an activity they are more or less required to do for environmental protection reasons. I believe it is reasonable to also require that a portion of this revenue be used to ensure long-term environmental protections.

2.4.5 Commodity Markets and Interstate Commerce Rules

Interstate commerce rules apply to the open economic competition of all commodities. Municipal solid waste is defined as a commodity and it is therefore subject to interstate commerce rules. Since interstate commerce is the responsibility of the US Congress, states have little ability to control waste flows into and out of their borders. The states with the lowest tipping fees tend to receive the most waste. Efforts to place economic disincentives on out-of-state waste dumping are met with lawsuits and are generally struck down in court because, "[s]tate and local governments wishing to place restrictions on interstate shipment of solid waste (that they do not place on waste generated within the state) may do so only if authorized by the Congress," (McCarthy 1999).

The problem is that states have a limited capacity for waste disposal. States are responsible for managing waste, not the federal government. This leads to a disconnection between managing in-state waste and having no control over out-of-state waste that makes planning difficult. States can provide disposal capacity based on the amount of waste generated in the state and projections for future amounts of in-state waste. If a state works with a local government to site a new landfill, thereby increasing disposal capacity, the tipping fees in that state may decrease due to the additional supply of disposal space. The state may have approved the additional landfill in order to alleviate in-state disposal problems, but it cannot prevent haulers from brining in waste from out of state. The intended life of the landfill may be shortened and state disposal needs may once again be compromised

Rhode Island seems to have found a way around this problem, basing a legal claim on the "market participant" doctrine to successfully litigate to prevent out-of-state dumping in its central landfill (LeFrancois v. Rhode Island, D.R.I. 1987). The "market participant" doctrine, derived from Hughes v. Alexandria Scrap (U.S. Supreme Court 1976), essentially allows a state to act in its own interest with regards to state-owned waste management facilities. Since Rhode Island has only one landfill, it has actually banned out-of-state waste completely. These issues are succinctly described by the Institute for Local Self Reliance (ILSR):

> Although garbage receives commerce clause protection, and restrictions on its movement have only been narrowly tolerated, some legislative action has been upheld in the courts. When a landfill is publicly owned, legislation restricting wastes on the basis of origin will apparently be upheld due to the "market participant" exemption. Additionally, solid waste districts that limit imported waste may withstand judicial scrutiny if the burden of landfill restrictions is borne equally by those within and outside of the state, (ILSR 1991, p. 2).

There is federal-level legislation in the House that would grant states more authority over the interstate shipment of waste (H.R. 274). If the responsibility of waste management lies at the state and local level, then Congress needs to give state and local governments all the tools and powers necessary for proper management.

The interstate transport of waste is a tricky issue, like most issues associated with the co-optimization of waste management and energy development. On the one hand, states and local governments are left somewhat helpless by the current system. On the other hand, if given too much authority, it's possible that local and state governments could cause serious waste disposal problems by cutting off some waste flows. It is reasonable to think that a substantial part of this problem could be dealt with through source reduction, but it would take time to stem waste flows. Local bans would essentially be the same as state waste bans, and if implemented improperly, without adequate support for alternatives, environmental and human health problems could arise due to illegal dumping, or extremely long distance waste hauling. A middle ground between Congressional control at the national level and state and local control may be able to provide a more beneficial and practical solution.

2.5 The Need for Something New

This chapter focused on strengthening certain incentives that will be helpful in realizing change and minimizing or removing perverse incentives that directly or indirectly prevent change. Simply overhauling the existing incentives will not be enough to effect change sufficient to implement a useful waste management hierarchy that can support appropriate electricity generation as:

1. a desirable form of energy recovery,
2. a beneficial form of waste management, and
3. being consistent with higher priorities for waste reduction and material reuse.

The maintenance and strengthening of existing incentives will need to be accompanied by new policies and programs that create additional incentives and add further support to good existing strategies. Specifically, new incentives should include incentives that focus more resources on electricity generation. Chapter 3 provides the details of potential new policy tools that seeks to co-optimize waste management and electricity generation, while also harmonizing waste management with principles of zero waste.

Chapter 3:

Analysis of Potential New Incentives and Policies

3.0 Co-optimizing Waste Management and Electricity Generation

3.0.1 Initial considerations

The language of any new policy should be designed to remove perverse incentives that currently block the adoption of programs that could help realize better waste management hierarchies. New policies should include at least strategies to overcome the barriers created by these perverse incentives. The economics of waste management, including transport, processing, and disposal, are currently the most dysfunctional piece of the co-optimization puzzle. Policies that help sort out these problematic economic issues will be critical to overall success.

Chapter 2 stressed that existing good incentives must be maintained and suggested this includes maintaining support for renewable portfolio standards (RPS) and the federal renewable electricity production tax credit (PTC), perhaps with some adjustments for better inclusion of certain waste streams as fuel sources. Other existing programs that should be expanded include regulatory and financial support from state and federal agencies for waste reduction and recycling, with a specific goal of expanding organic waste processing capacity. Finally, states should continue to implement waste bans as appropriate, and provide additional resources to enforce these bans.

Additional and well-coordinated new incentives will help to support these efforts and will encourage public and private actors to adhere to the widely touted waste management hierarchies that are not currently being met. New incentives can also be designed to coordinate efforts for waste management and electricity generation to ensure goals for both are achieved in an efficient and environmentally friendly manner. In fact, raising the profile of the potential benefits of electricity generation will be a crucial part of any new policy structure, together with incentives to support the expansion of electricity generation that uses waste streams for inputs.

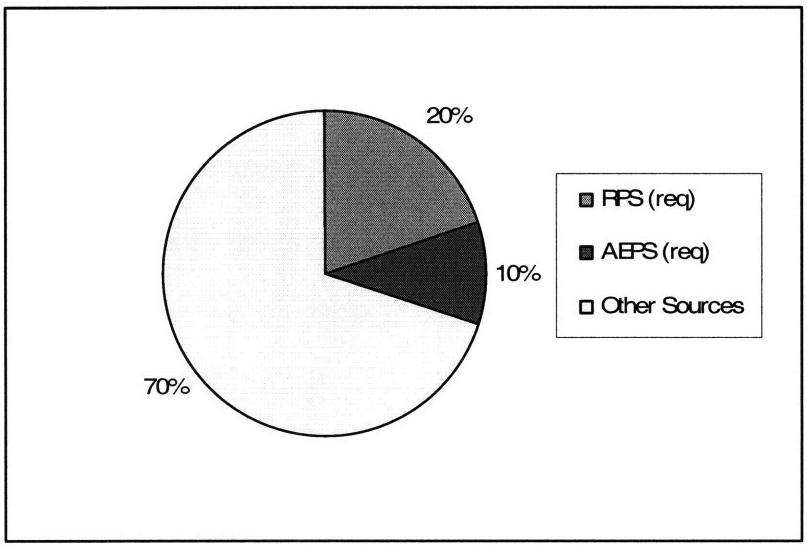
3.0.2 New and Expanded Regulations and Incentives

Alternative Energy Portfolio Standard

Proposed legislation in Massachusetts includes a provision for an alternative energy portfolio standard (AEPS). This standard would be similar to an RPS in that it would require a certain percentage of electricity to come from specific, defined sources. There would also be a similar accompanying economic incentive. However, fuels and technologies that qualify as "alternative" are not as desirable as those that qualify as "renewable." Thus the quota, as designed by the proposed Massachusetts legislation, would be somewhat less than the quota for renewable electricity. The standard could still provide an excellent means for creating incentives for electricity generation from waste streams. The debate around whether or not waste streams are a renewable source of energy could be avoided to some extent, and those fuels and technologies that are currently controversial could be adopted under the AEPS.

The AEPS, as it has been developed for the Massachusetts legislation, includes technologies for combined heat and power (CHP). Most technologies for generating electricity from waste-stream inputs make excellent CHP units. Combustion always generates heat as a primary energy source before the heat is used to produce steam and thereby generate electricity via steam turbines. Gasification technologies also generate some heat, although this is often recycled in the system to assist with the gasification process. Ultimately, thermal waste treatment technologies lend themselves to use as CHP units. Other technologies that treat waste and generate electricity, such as anaerobic digestion, do not create heat. However, anaerobic digestion is more widely considered to be a source of renewable electricity and therefore eligible for RPS incentives. Adopting an AEPS for CHP could be a good way to maintain support for existing electricity generating projects using waste inputs, without additional controversy concerning the renewability of the fuel source.

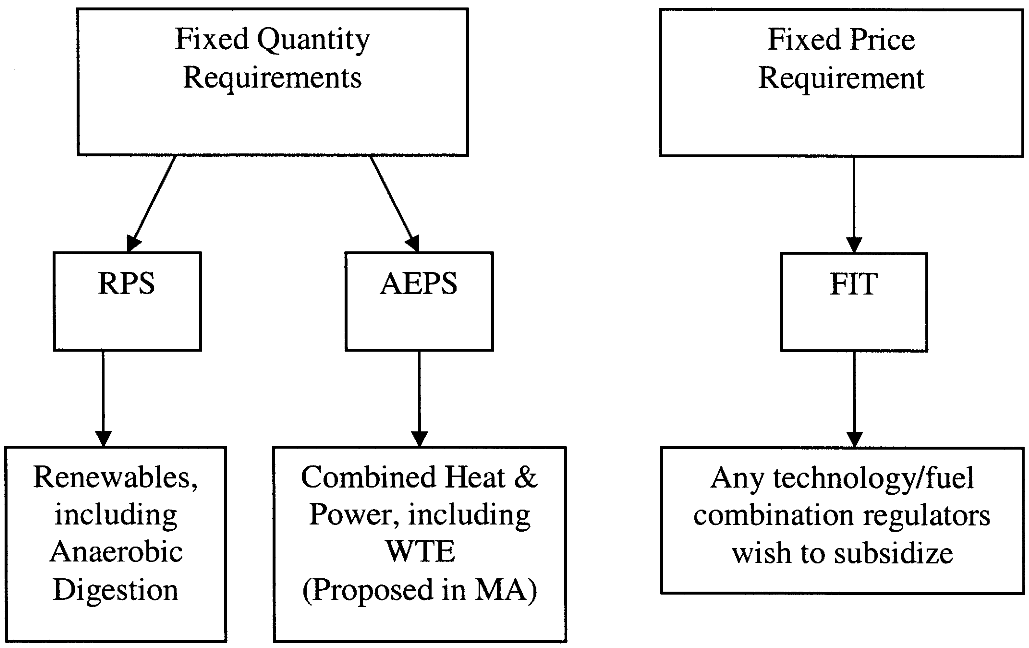
Figure 3.1 Sample Electricity Requirements (%) for a State with a RPS and AEPS



Just like under the RPS, the AEPS could create the incentive for specific technologies and fuels. The quota would be less than that for the RPS, but this would be potentially consistent with the goals of the waste management hierarchy. If a top priority of the hierarchy is waste diversion through recycling and composting, the most compatible form of electricity generation would be anaerobic digestion. Thus, the waste management hierarchy and the RPS could be coordinated to create the strongest incentives for the development of an infrastructure and economy around anaerobic digestion of organic waste. The same hierarchy could include secondary diversion priorities for additional energy recovery, which could be coordinated with the AEPS to encourage development of thermal treatment technologies for some waste streams. This is demonstrated with sample percentage requirements in Figure 3.1. The role of biomass combustion or gasification is less clear; it could arguably fit under either energy portfolio standard.

The AEPS is an energy policy and quota option that will likely be adopted at the state level in some form in the near future. It will be important to ensure that this type of portfolio standard includes language to create support for electricity generating technologies that use waste streams. It will be most useful if the policy language makes explicit reference to the dual goal of waste management and electricity generation, and creates provisions for coordination between relevant state regulatory agencies.

Figure 3.2 State-level Energy Standards – Existing and Potential



Feed-in Tariffs

Feed-in Tariffs (FIT) are a kind of economic incentive for renewable electricity, and are currently most popular in Europe. The FIT is similar to the RPS, but rather than set a percentage of renewable electricity that providers must purchase, the FIT mandates that electricity providers will buy electricity from any qualifying renewable generator at a pre-specified price and usually for a specific period of time. This system creates a secure, long-term market for renewable electricity and therefore makes facility construction and operation a financially secure investment (Rickerson and Grace 2007). A FIT does not have to be associated with renewable electricity generation, and so the concept could be used to support any new electricity generating technology that requires the security of long-term purchasing agreements to attract investors. Biomass energy projects could definitely benefit from a FIT program, as could any form of thermal waste treatment with electricity generation.

Any electricity project with high capital costs will need to operate and generate revenue for a decade or more in order to pay back the initial investment. The FIT can make the initial investment much less risky by guaranteeing electricity sales for a significant portion of this time period. Thus the FIT gives a greater financial incentive than the RPS/REC system and provides a more secure investment environment, which makes it easier for project developers to secure financing. The FIT provides significant economic support for emerging electricity generating technologies with which investors may be unfamiliar.

A FIT can be designed much like an RPS, in that it can be designed to create incentives for specific technologies. With regards to waste management and electricity generation, a FIT policy could be created to guarantee electricity sales for certain thermal treatment technologies that use specific, sorted waste streams as fuel. As with the AEPS, the FIT may be best put to use as a support for technologies that are not already eligible for support under the RPS. Alternatively, the FIT could be used to support biomass energy projects since these are somewhat different than wind or solar projects that do not require fuel purchases. In other words, both a wind energy development and a biomass energy development are subject to high capital costs. However, the "fuel" for the wind project is a free resource, while the biomass project will have to obtain fuel. If the biomass facility can incorporate waste it may be able to generate revenue via tipping fees. However, as discussed below, the goal of ZWEG processes is to reduce the quantity of waste in the waste stream which would lower the amount of waste available to biomass facilities and likely result in a the need to purchase some amount of fuel. The FIT could therefore be a very useful incentive for ZWEG projects.

This is consistent with suggestions from Kingsley of Innovative Natural Resource Solutions. He mentioned that broadening the types of fuels that can be used in biomass energy projects would help to promote the expansion of biomass energy resources in New England due to increased fuel availability and lower fuel purchasing costs (Kingsley interview). However, he stated that such an expansion would not be, and should not be, compatible with a RPS since the fuels will likely not be renewable. A FIT could provide exactly the right kind of economic support for just this type of system, and could do so even if part of the fuel mix were properly sorted waste streams.

One of the potential benefits of a FIT policy could be the name of the concept. By naming the portfolio standards "renewable" and "alternative," policy-makers limit the number of electricity generating technologies that can qualify, and include implicit qualitative criteria. The FIT makes no mention of renewable or alternative energy technologies. It is a "value-less" economic incentive that can be applied to any technology that generates electricity.[26] Thus while there may still be opposition to support for certain technologies that generate electricity using waste, the opposition will not be based on semantics or values about the extent to which a technology or fuel is renewable.

[26] In practice the FIT has been used exclusively to support clean technologies. There are existing incentives for historically dominant energy resources, such as those that use fossil fuels, and the investment risks are generally understood. There is no need to create new incentives to encourage further development of fossil fuel-powered resources. Conversely, new technologies have unknown risks and must compete in a highly competitive market. Thus while the FIT does not mention renewable technologies by name, it is an incentive designed with renewable energy support in mind.

A FIT is, however, very much a form of top-down regulation that forces electricity providers to purchase electricity from generators they may have chosen to avoid. The FIT may support projects that are not economical or practical for a given location, and may support technologies that ultimately prove to be flawed.

There is precedent in Europe, however, for the benefits of the FIT. Germany has used the FIT with great success to help install a significant amount of wind energy capacity. This support has been expensive, and underscores the difference in energy priorities between different nations. European governments and citizens seem to feel that strong financial support for renewable energy development should be a budgetary priority. In the US the RPS seems to be popular because it creates a requirement for renewable energy, but leaves the financial incentives to the private market. The FIT is arguably better at facilitating energy development, but it is more expensive and requires a strong hand from the government.

In practice, in the US there is precedent for compatibility of the FIT and RPS. Vermont has a form of a fixed-price incentive specifically for electricity generated by anaerobically digested cow manure. This program works in conjunction with the state renewable portfolio goal, but creates a specific economic incentive to encourage manure digestion as a part of the renewable portfolio goal. California recently adopted a similar fixed-price measure specifically to encourage electricity generation at waste water treatment facilities. Just like Vermont, the waste water FIT works in conjunction with the California RPS. In other words, both in Vermont and California, while electricity distributors are required to buy electricity at a fixed price from manure digestion and waste water treatment respectively, these electricity purchases also count toward meeting the RPS percentage requirement. These programs are consistent with a statement by Rickerson and Grace that "judging from the current and proposed fixed price tariffs at the state level, it seems more likely that feed-in tariffs will continue to emerge as limited fixed price incentives or payments targeting specific policy goals," (Rickerson and Grace 2007).

Long-term electricity contracts

One of the major benefits of the FIT is that it facilitates the adoption of long-term power purchase agreements between electricity generators and electricity providers. As discussed above, this creates a less risky investment environment, and thereby allows power plant developers with new generation technologies to more easily secure project financing. The RPS provides a benefit once the power plant is operational and the knowledge that the plant will be eligible for this incentive provides for some investor confidence. However, if a long-term power purchase contract were in place, investors would be even more confident and financing would be even easier to secure. Thus, an energy policy that includes the RPS but also mandates long-term contracts between generators and distributors could be a good balance and alternative to a full-blown FIT system. Rhode Island currently has proposed legislation to include long-term contracts within its RPS program.

Long-term contracts have the potential for problems since they generally lock in a price for the period of the contract. Electricity prices tend to vary significantly over time and this variation could put one of the contracted parties in a difficult position down the road. If the price of electricity goes up and the contract guarantees a fixed price, the distributor will benefit because they are able to buy the electricity for the original lower price. If the price of electricity goes down, the generator will benefit because the distributor will have to continue to pay the original higher price.

Fixed prices and long-term contracts are also problematic in New England due to the competitive electricity market and forward capacity market managed by the regional independent system operator. Given the competitive nature of the electricity market, and the fact that generators and distributors are subject to competition, it is difficult to promote the idea of locking into a contract between only two parties. Even if the price of electricity is allowed to fluctuate within a supply contract, it's entirely possible that a given generator will not be able to compete economically with other generators in the open market, and thus the contracted distributor could still end up paying more for electricity.

While long-term contracts are good for the financial security of generation facilities, they are potentially problematic for distributors. This is true regardless of the technology used to generate the electricity. Although, given that electricity generated by waste stream inputs may be able to receive tipping fees, facilities that manage waste and generate electricity may be able to use tipping fees to subsidize the cost of electricity to a degree. This type of economic strategy makes the facility more dependent on tipping fees, and may not necessarily provide any more economic stability.

Long-term fuel supply contracts

Long-term fuel supply contracts are another incentive with great potential benefits, but also the potential to create significant problems. The issues are similar to those associated with long-term power purchase contracts. Fuel costs money, and the cost of fuel can fluctuate over time. However, there is a distinction between fuel that is purchased, such as would likely be the case for wood biomass, and fuel that is viewed more as a waste stream and could therefore actually generate tipping-fee revenues for electricity generating facilities.

Fuel supply can be just as critical to project financing as a market into which electricity can be sold. Investors are unlikely to support a project if there is no guarantee of a sufficient fuel supply over the life of the plant. Historically, WTE solid waste combustion facilities have entered into contracts with nearby municipalities to lock in a guaranteed supply of waste to power the facilities. This has lead to a variety of problems for the contracted municipalities.

First of all, municipalities pay tipping fees to dispose of their trash. The contract may lock in a price, but the cost of operating and maintaining the WTE facility and the cost of other disposal options may change over time. Many municipalities have been forced to continue to provide waste to WTE facilities even though it becomes a more expensive option. The WTE facility owners may also pass operational cost increases on to their customers in the form of higher tipping fees. This was sometimes the case when facilities were forced to upgrade environmental and emission controls to comply with the Clean Air Act. When a supply contract is in place, the customers are forced to continue to tip their waste at the WTE facility while paying more to do so.

Another problem is that the contracts for supply state that the municipality must supply the WTE facility with a specific minimum amount of waste. This is good for the WTE facility, and a similar contract would be good for any facility that generates electricity using waste stream inputs. This can create a disincentive to reduce waste, and thereby be in direct conflict with the top priority of the waste management hierarchy. This is an issue that will have to be addressed through regulations and incentives because it does not make economic sense to make substantial capital investments if there is no guarantee there will be a sufficient economical supply of fuel to power the facility for its designed operating life.

This is one of the primary dilemmas of co-optimizing waste management and electricity generation, especially given the objective of this thesis to design electricity policy that is consistent with principles of zero waste. The policy must consider waste management processes that seek to reduce waste first and foremost. The question then is whether after the waste stream is reduced, and after maximum diversion is achieved through recycling and material recovery, is what remains in the waste steam sufficient and appropriate to use as a fuel to generate electricity? Will there be sufficient supply to meet the requirements of a long-term supply contract? I will attempt to provide a numeric example, but the concept is complicated by semantics and the terminology of waste reduction. The most recent solid waste master plans, or similar reports, from each of the six New England states provides a total waste tonnage for the region of around 26 million tons of waste per year. Since these reports contain numbers that are several years old, and the amount of solid waste generated is increasing, I will assume the regional amount of solid waste is around 30 million tons per year. I will use this number as the starting point to discuss the potential impact of reduction and diversion measures on the use of waste fuel for electricity generation.

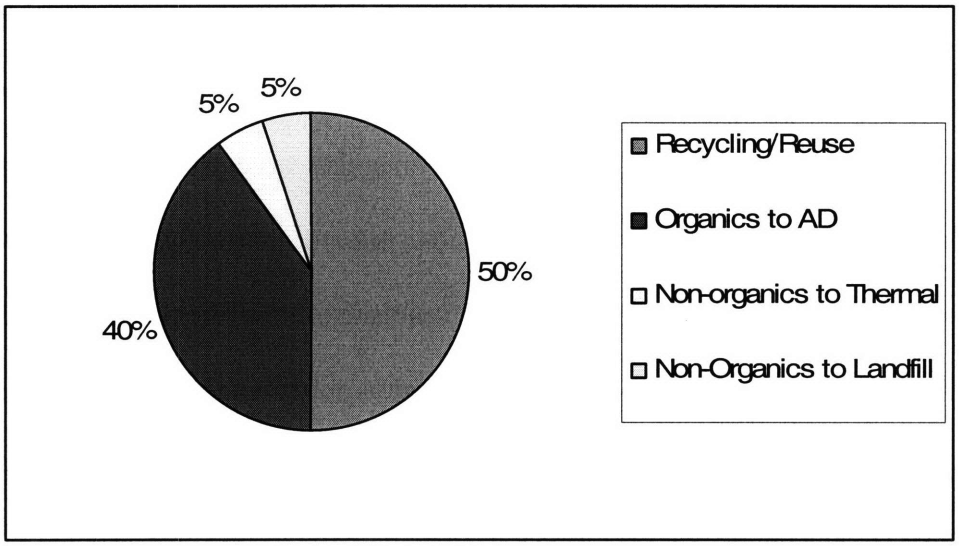
Source reduction is a top priority in the waste management hierarchies of each state. For the purposes of this example we can assume that New England will achieve a regional average of 30% source reduction. That is, the actual amount of material that enters the waste stream decreases by 30%. Given that the 30 million tons per year is what is being produced after current source reduction measures, I will assume that an additional 20% source reduction can be achieved for a total average source reduction for the region of 30%.[27] Thus the actual amount of waste that must be managed is now 24 million tons per year. Next the states will seek to reuse and recycle as much waste as possible. It is realistic to assume that a regional average recycling rate of 50% could be achieved, given sufficient program support and processing infrastructure, and continued strong markets for recyclable material.

The remaining quantity of waste is now only 12 million tons for the whole region. The recycling efforts should have removed the majority of the non-organic waste, meaning that the remaining waste should be almost entirely composed of organic material. I will assume 80% organic waste, material that is ideal for anaerobic digestion and composting. Thus, there should be a regional supply of 9.6 million tons of feedstock for anaerobic digestion facilities. One ton of organic waste provides around 100 cubic meters of biogas, which can be used to generate approximately 170kWh of net electricity capacity (Ostrem 2004). Given these conversion values, if all 9.6 million tons of organic waste from this example were anaerobically digested, the region could potentially be supplied with 209MW of net electrical capacity[28]. While not a substantial amount of

[27] I assume current source reduction for the region averages 10% of the waste stream, so an additional 20% will result in the 30% source reduction target for the region.
[28] The details of this calculation can be found in Appendix D.

megawatts, this is substantially more than the 13 MW of electricity currently available from anaerobic digestion in New England (ISO-NE 2008)[29].

Figure 3.3 Diversion Rate Impacts on Waste Fuel Supply[30]



The biogas produced by anaerobic digestion can be stored or transported for use at another time or location. Thus in this example New England would benefit from 203 – 209 MW of dispatchable electricity which could help offset existing fossil fuel-powered base load electricity recourses, or better yet, be available to replace dirty and expensive peaking systems that currently run on oil or diesel. This may be a more realistic option given the amount of available capacity, however, it is also important to recognize that these megawatts will be distributed throughout the region and not associated with a

[29] 209 MW represents 40% of the available energy. The remaining 60% of the energy exists as heat, and can be captured to provide heat to the anaerobic digestion process and to the facilities. Even after this, approximately $8x10^{12}$ btus of heat will be available for sale. Additionally, these facilities will be able to aerobically cure the residual from the process to create compost, which can also be sold to generate revenue.

[30] Note that in this example 90% of the original waste stream is diverted from landfills without using thermal treatment methods, and a significant amount of electricity is generated. This is not a substantial amount of net capacity, but organic diversion with anaerobic digestion is not merely a process for electricity generation; it is a piece of a process that co-optimizes energy development and waste management.

single, centralized unit. Therefore the facility parameters can be optimized for the specific capacity needs of a given area, perhaps supplying one or two megawatts per facility. The biogas could also be burned in existing natural gas power plants, thereby potentially mitigating price rising gas prices.[31]

The remaining 20% of the waste stream, or 1.61 million tons, will contain two types of material: combustibles and non-combustibles. The non-combustible material may be reusable for some purpose like construction aggregate, but it may also need to be landfilled. The combustible material can be used as fuel for thermal waste treatment with electricity generation, but does not have to be combusted. It may be that as little as half of the 1.61 million tons is combustible, giving the region only about 800,000 tons of waste for fuel. This is well below the current regional WTE capacity of over 6 million tons per year between Connecticut, Massachusetts, Maine, and New Hampshire.

Gasification technologies are not wholly proven, but for the sake of an example I will assume the numbers provided on the Ze-Gen website for its process are accurate. Ze-Gen claims its process will generate approximately 55 kW of net electrical capacity for every ton of waste input. If the yearly total of 800,000 tons of waste is divided into a daily average of 2192 tons, this will result in approximately 120 MW of net electrical capacity. This is less than half of the 333 MW of current claimed capability of the WTE facilities throughout New England. However, recall that the entire co-optimized ZWEG system includes 209 MW of capacity from anaerobic digestion, providing a total of 329 MW of net capacity for sale into the regional grid. This number is only 17 MW less than the current 346 MW of combined capacity for WTE and anaerobic digestion, and does

[31] In order to combust the biogas in standard natural gas turbines it would first have to be cleaned to remove contaminants that would otherwise damage the turbines. There are fewer contaminants in biogas than in the syngas produced by mixed MSW gasification.

not account for the potential to include sustainably harvested clean wood in the fuel mix. Doing so would very likely more than make up the 17 MW difference. A final important point regarding co-optimization is that this electricity is being generated behind substantial waste reduction and recycling achievements, and with only 5% of the waste stream directly landfilled.

A long-term supply contract that is designed to be consistent with the model waste management hierarchy should create incentives to supply organic material to digesters, with the goal of achieving the percentages described above. Contracts for substantial amounts of organic material will force entities that create waste, such as municipalities, to divert waste into anaerobic digestion or compost operations. Long-term supply contracts for this portion of the waste stream would create the right kind of incentives to help co-optimize waste management and electricity generation.

It may also be practical to create a second category of allowable long-term contract for the wood portion of construction and demolition debris. This type of contract would be most practical if the policy language stipulated that only certified or qualified construction and demolition processing and recycling facilities be allowed to contract to supply fuel to electricity generating facilities. This would create a requirement for material processing as a separate industry. This should, in theory, help to ensure that proper processing and recycling is a priority for the facility, and that only appropriate portions of the waste stream are subsequently passed along as fuel for electricity generation. If the electricity-generating facility were also the processing facility, it is more likely that sorting standards would be periodically ignored in the interest of maintaining optimal fuel inputs for the electricity-generating piece of the operation.

3.0.3 Integration

Section 3.0.2 introduced a variety of potential new incentive options that focus more on electricity generation than waste management. The existing incentive structure is designed to focus primarily on waste management with minimal consideration for waste management options that include electricity generation. Therefore, in order to integrate electricity generation into waste management more incentives for electricity generation will be necessary. A new incentive structure will not necessarily include all of the options discussed above, as some are potentially more useful and appropriate for creating incentives for waste management with electricity generation. It is important to understand and accept that good electricity incentives may not be good incentives for electricity generation that is also part of a waste management strategy. The next step is to determine the best combination of incentives to co-optimize waste management and electricity generation. I will provide these recommendations in Chapter 4.

3.1 Implementation and Coordination

Implementing and coordinating new policies that are designed to manage waste streams for maximum diversion and electricity generation across New England will require substantial increases in state interaction. In addition to more state-level coordination between environmental departments and energy departments, a new entity should be created that can provide regional oversight with the goal of achieving regional waste management and electricity generation benefits.

The states agencies responsible for waste management and energy development will also need to better coordinate their efforts. Better regional coordination could help New England deal more effectively with the interstate waste transport problems created by interstate commerce laws. This could be critical to regional success since it does not seem likely that Congress will pass new legislation designed to alleviate this problem anytime soon.

Additionally, agencies in the same state that are responsible for waste management and energy development respectively will need to better coordinate their state-level activities. Coordination may be more easily accomplished through the creation of an executive level office, and if such an office were created for each state, regional coordination may also be more easily accomplished.

3.1.1 A Regional Waste Management Organization

The New England regional electricity grid is monitored and managed by a quasi-public independent systems operator. The organization maintains supply and demand for electricity by managing the competitive electricity market for the region. In theory this allows the ISO to ensure a reasonable price for electricity by facilitating a bidding process that electricity generators must use to sell their electricity. Anticipated demand is closely monitored and predicted so that bids can be taken for a very specific amount of electricity. If electricity generators do not bid competitive prices they will not be able to sell their power in this system. However, the ISO has no regulatory authority to control the number or type of generation units. Regulation of the resources in the system is left to the states.

Waste management could benefit from a similar regional organization that could take a big picture view and better coordinate the market flow of waste to treatment and disposal facilities in the New England region.

A regional waste management organization (RWMO) would not take over the regulatory role of any existing state environmental departments, just as the ISO has not taken over regulatory responsibilities from state energy offices. The RWMO also would not take over waste management activities that are currently managed by private companies. The role of the RWMO would be similar to that of the ISO; it would ensure the efficient flow of waste streams between the myriad public and private actors. Additionally, unlike the ISO role in electricity markets, it could help to coordinate new waste management infrastructure and incentive programs to ensure regional benefits. In doing so, it would help to ensure the continuation of good economic, legal, and private sector management incentives while minimizing the negative impacts of technical failures and societal barriers.

ISO-NE is not a regulatory agency; it helps to ensure the proper function of private markets that operate within an electricity system that is controlled to some extent by the federal and state governments, but is operated primarily by private companies. Waste management is operated in a similar way, with some federal and state rules that guide the activities of private companies. For this reason it seems likely that the region could benefit from regional guidance and coordination by a single entity that is not entirely private, but also not a public regulatory body.

One of the goals of a waste management system that prioritizes electricity generation and adherence to principles of zero waste will be to expand capacity for the diversion and processing of organics, by either composting or anaerobic digestion or some combination of the two. An RWMO could coordinate this expansion with the New England state governments to co-optimize the two systems. Digesters could be constructed in distributed but centralized locations to maximize their benefit as disposal options, and to ensure they are located in proximity to existing electricity infrastructure or in regions that would benefit from additional installed capacity. Likewise, if it made sense to increase the capacity for organics processing in a location that was not well suited for electricity generation, the RWMO could facilitate the construction of compost facilities instead.

Section 3.0.2 questioned the availability of a sufficient supply of waste to fuel thermal waste treatment facilities that generate electricity. A regional management body could monitor and coordinate the flow of waste streams to maximize the benefit of a limited number of thermal treatment facilities, while also ensuring that the number of facilities is limited to what makes economic sense for the region based on fuel supply, waste management needs, and electricity demand. By consolidating remaining waste streams (what is left after reuse, recycling, and organics diversion) a smaller number of thermal treatment facilities could still benefit from economies of scale that are necessary for efficient facility operation. New England is a small enough region that it should be economical to transport waste that cannot otherwise be diverted to regional thermal treatment facilities. Waste streams are currently imported and exported between New England states, a process that is somewhat necessary to support existing combustion facilities. An RWMO would allow for better coordination of these flows, and could provide a more accurate means of monitoring these transactions to ensure compliance with state or regional waste bans.

Waste bans could also be enacted regionally rather than state-by-state, which would also help ensure that the banned materials do not end up in the landfills of nearby states. Regional waste bans would have to be implemented with regional financial incentives that support alternative treatment methods for the banned materials, but the RWMO would have the ability to make policy recommendations and provide guidance and financial incentives to ensure the development of new infrastructure. The actual implementation would have to be carried out state-by-state, which would likely prove difficult.

3.1.2 Increased Coordination between State-Level Regulatory Agencies

In addition to the RWMO, it will be necessary for state-level regulatory agencies to better coordinate their activities. This is not only necessary for better inter-state coordination, but will be most important for state environment departments to coordinate their waste management programs and incentives with those of the energy departments of the same state. The example of the goals of the Massachusetts solid waste master plan is a case in point. Activities around the goals of increasing diversion and processing of organic waste, and the landfill ban of construction and demolition debris should be coordinated with the state Division of Energy Resources. The two agencies could work together to pool resources and thereby more efficiently develop the necessary infrastructure to divert these waste streams and do so in a manner that provides fuel for electricity generation.

Not every waste management solution can or should include provisions for electricity generation, but by coordinating activities at the state level, agencies can design policies and incentives that consider all possible options. However, as stated previously in this thesis, this coordination will be broader than traditional integrated waste management. The energy office can provide input about which technologies and fuels will qualify for renewable energy financial incentives, or other energy-based financial incentives. The environmental department can then use its resources to provide support for desirable waste management options that may not be eligible for energy-based financial help.

The bottom line is that there is a lot of energy contained in the waste stream, and New England needs new sources of local energy generation. By coordinating regulatory activities for waste management and electricity generation waste can be managed in a way that is safe for humans and the environment, and also generates benefits in the form of electricity generation and soil amendments. Portions of the waste stream that are not appropriate for anaerobic digestion and cannot be recycled or reused can be consolidated for thermal treatment with electricity generation. Whether this is in the form of traditional combustion or newer technologies such as gasification may be a matter of technological feasibility, since combustion facilities are currently in use at a commercial scale while gasification is not really proven beyond smaller scale pilot projects.

Practical coordination

An important but confusing question is how this coordination will be accomplished in practice. Traditional WTE and landfill gas–to-energy projects are regulated and guided by the EPA via the Clean Air Act (CAA), Clean Water Act (CWA), and the Resource Conservation and Recovery Act (RCRA). The laws regulate environmental impact, not electricity generation.

Energy rules are the province of the Federal Energy Regulatory Commission (FERC) and the DOE. FERC is mostly concerned with issues around wholesale markets and transmission, and the DOE wields relatively little regulatory authority over electricity generation, leaving this responsibility to the states. In fact, the one major federal-level incentive for renewable electricity, the renewable electricity production tax credit, is the responsibility of the IRS.

Potentially the most problematic national rule is the interstate commerce clause of the constitution, which gives the management responsibility to Congress. The current system may benefit private waste management companies to some extent, but it certainly prevents states from controlling their own waste management destinies. States may be best served by working together to ensure the regional economics of waste management favor their goals.

There are more rules at the state level, since the states are tasked with implementing and managing federal-level rules and guidance. It therefore makes the most sense to increase waste management and electricity generation coordination at the state level, where general federal-level guidance can be incorporated but regulators are more knowledgeable of local and regional needs. Perhaps a new executive-level body would be appropriate, but it would have to be properly funded and staffed with people who are knowledgeable of historic, existing, and future goals of both the energy and environmental offices.

In order to facilitate the regional initiatives discussed in this thesis it will likely be necessary for each New England state to create a similar state-level coordinating body. These six offices of waste management and energy recovery could then coordinate regional goals, including infrastructure support and interstate waste stream transport. These offices could also work most closely with the RWMO to ensure the regional system functions properly and within the bounds of state and federal regulations.

Much of the waste management and electricity generation system is operated by private companies. The states, including any new executive-level offices and the RWMO would therefore not be responsible for daily management, but would rather need to concentrate resources on assisting private companies with the transition to a waste management system consistent with a zero waste–oriented waste management hierarchy. This should include financial incentives along with regulation, and should also include a substantial public information campaign to achieve buy-in from both residential and commercial waste producers (i.e., you and me, our favorite restaurants, the companies at which we're employed, and any other entity that generates and places waste into the system).

Dissemination of accurate and easy to interpret information will be critical to affecting systemic waste management changes, especially at the regional level. Currently most waste management changes are made at the local, city, or municipal level. It will certainly be more difficult to affect change at the regional level, but it should ultimately lead to a system of waste management more consistent with a waste management hierarchy that prioritizes diversion and incorporates well-designed and appropriate forms of waste management for electricity generation.

One potential platform on which to base this regional information campaign could be through additional state agency partnerships with the Northeast Waste Management Officials' Association. This existing non-profit organization provides regional waste management analysis and produces reports designed to increase regional coordination of regional waste management activities. It is not a regulatory body, nor is it an appropriate entity to take on the proposed responsibilities of a regional waste management organization. It is an existing clearinghouse of regional information that was created by the governors of the northeastern states (including New York and New Jersey) to assist with regional waste management coordination. State environmental agencies are members; however, there is no overlap with state energy agencies. This is understandable, but is also problematic for co-optimizing waste management and electricity generation.

3.2 Complementary Technologies to Encourage Waste Sorting

It will be important and necessary to determine how the waste stream will be sorted to fit within the purview of zero waste with electricity generation. This will be a substantial undertaking, and is unfortunately beyond the scope of this project.[32]

[32] A quick note on sorting: the goal of a ZWEG process is to create a strong economic incentive to generate electricity using sorted waste streams. If an electricity generator can make money selling electricity, it will pressure waste management entities to sort the waste steams. Waste management companies will also have

However, it is within the scope of this thesis to discuss why sorting the waste stream into various components is a good idea. Sorting requires a great deal of effort, and can incur a significant additional cost for waste management. Thus the reader may be wondering whether the benefits of sorting cover the costs, and why sorting is necessary in the first place.

The primary reason for sorting the waste stream is that the different components can then be used for various beneficial purposes. When the stream is all mixed together, it can generally either be combusted or landfilled. Landfill tipping fees are high in New England because there is a lack of available space and the tipping fee is the only source of revenue for the operation, unless the landfill has a landfill gas–to-energy process in place.

Alternatively, the processes described in this thesis result in the production of marketable products. Anaerobic digestion produces biogas and compost; gasification produces syngas; recycling conserves resources and reduces energy demands, and there is a market for recycled material. Because of these potential back-end revenue streams, the upfront tip fees can be much lower. However, these processes are most efficient and therefore most practical when the waste inputs are sorted. Simply put, anaerobic digestion is most efficient when the inputs are wet organics, and thermal processes such as gasification and combustion are most efficient with the inputs are dry organics or any non-organics.

---

an incentive to think about investing in electricity generation. The basic point is that I do not suggest mandatory sorting requirements because I think such requirements would be overly complex and ultimately unnecessary if the proper incentives are in place to create economic pressure for companies to work out sorting issues on their own, with their own resources.

Research done by the Energy Information Administration indicates that municipal solid waste combustors are able to generate more heat energy from the higher heat content of non-organic wastes like plastics (EIA 2007). In other words, combustion benefits from more non-organic waste, and anaerobic digestion benefits from all organic waste. Rather than viewing anaerobic digestion and MSW combustion as potentially competing energy generators, it appears the technologies are extremely compatible and in fact complementary.

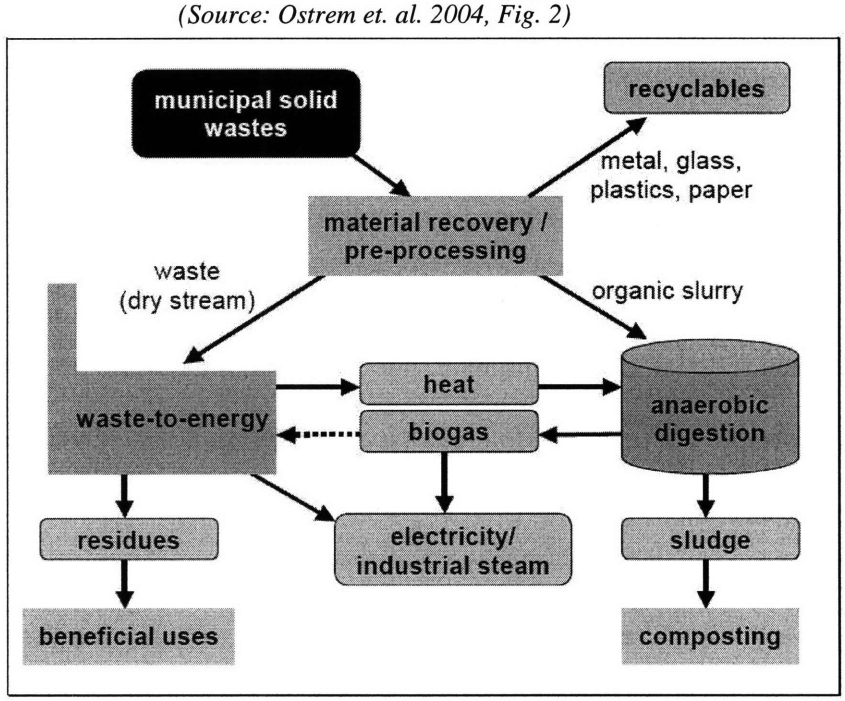
Additionally, non-waste biomass fuel resources may be used to supplement fuel supplies for existing combustion facilities, and will also be able to transition to a gasification fuel source. Older, cured biomass resources will be better suited for thermal processes, but in general biomass with a high lignin content is can be used more efficiently by thermal processes. The microorganisms associated with anaerobic digestion have a hard time digesting lignin. The high carbon content of this material makes it an excellent fuel for thermal processes, although it will combust or gasify less efficiently if it has a high moisture content. Essentially though, non-waste biomass resources such as forestry products could be used in conjunction with properly sorted waste streams to fuel thermal-based electricity resources.

The RWMO could work with the New England states to develop a network of biomass energy facilities that use forestry and other wood resources as fuel, and subsequently introduce properly sorted waste into the fuel mix as older combustion facilities shut down and the waste stream is significantly reduced and diverted via the above described process. This may prove to be a more practical strategy for the future of thermal waste management with electricity generation. After source reduction, reuse, recycling, and diversion to anaerobic digestion, the regional supply of waste for fuel will be much less than it is now. It can therefore comprise a lower percentage of the fuel, relative to amount of non-waste biomass in the mix.

While this could be viewed as polluting an otherwise clean biomass energy project, I prefer to view this idea as cleaning up a less-clean energy project that relies entirely on non-organic waste for fuel. Stringent emission control will still be in place, and if the conversion system is designed to use a variety of fuels and fuel mixes the facility will be less dependent upon a single input stream. This should lessen the potential for creating an electricity generating system that requires a continuous stream of waste. This in turn will make the process more in line with zero waste, and therefore more suited to the name zero waste with electricity generation.

Figure 3.3 Example Scheme for Complementary Technologies for Waste Treatment with Electricity Generation

(Source: Ostrem et. al. 2004, Fig. 2)



A final benefit of a mixed fuel system that uses properly sorted waste for a small percentage of the fuel is that it creates the potential for a sustainable forestry economy in New England. This region has historically supported forestry, but this economy has dwindled in recent decades. By adopting processes for zero waste with electricity generation, processes that co-optimize waste management and energy development, the development of a sustainable biomass energy industry in New England could be coordinated with the waste management proposals from this thesis. The biomass energy projects would benefit from the high thermal value of the sorted non-organic waste, but by prioritizing reduction and diversion to anaerobic digestion the co-optimized system would ensure the non-organic waste made up a small percentage of the fuel mix.

3.3 Coordination, Coordination, Coordination

Regardless of the recommendations made in this thesis, it will be extremely difficult to coordinate waste management and energy development activities at the national, regional, state, and local levels. The policies, programs, and incentives proposed in this chapter seek to begin the process of coordination, or to at least shed light on the current lack of coordination. The process for change will likely have to begin at the state level, with one state taking the initiative, but New England has the potential to develop a significantly improved regional strategy that co-optimizes waste management and electricity generation.

Chapter 4:

Policy Recommendations and Conclusions

4.0 Harmonization: Electricity Generation and Zero Waste

The goal of this thesis project has been to determine the extent to which renewable electricity incentives can be designed to incorporate appropriate waste-to-energy technologies, while being consistent with zero waste principles. Chapter 3 provided an account of possible policy and incentive structures based on several determinations:

- Maximum waste diversion should be the primary goal of waste management, thus electricity generation efforts should be consistent with this goal.
- Anaerobic digestion is the most consistent technology option, but thermal treatment with electricity generation should be considered to assist with diversion and additional electricity generation.
- Of the thermal options, gasification is most efficient at generating electricity and also allows for relatively better environmental pollution controls.
- There will likely always be some amount of waste that will require landfill disposal, but landfills should be a waste management option of last resort, and used to dispose of material that cannot be reused or recycled and contains no significant energy value.

Policy recommendations will need to balance the right regulations and the right economic incentives to maximize diversion while also maximizing electricity generation, thereby co-optimizing waste management and energy development.

4.1 Bringing it all together

What should a new policy structure look like, that is designed to encourage a shift in waste management to align practice with model waste management hierarchies, while simultaneously encouraging the integration of electricity generation as a waste management option at different levels of the hierarchy? It will be easiest to address this question by examining necessary regulations and incentives at different levels, moving from the national level through the regional level to the state and local levels.

National regulations and incentives

At the national level, the most important change needs to be legislation to modify the role Congress plays in the interstate transport of MSW. Solid waste is different than other commodities and states cannot properly plan for sustainable waste management without being able to have some control over waste flows. Giving states some ability to control flows will substantially improve waste management and make it more possible for states to create incentives that encourage a real shift toward a model waste management hierarchy. More state control will allow states to better plan for and manage their waste streams. Programs designed to promote environmentally friendly diversion methods will not result in the increased export of waste to other states, where traditional landfill disposal may be cheaper than in-state processing. Also, systems for processing diverted waste will not be overwhelmed by waste imports from other states.

The renewable electricity production tax credit (PTC) should be renewed and maintained. It should continue to include MSW combustion, but should include specific reference to anaerobic digestion. The PTC has a tiered system, with certain resources commanding more significant financial incentives. Anaerobic digestion should receive the higher incentives, just like closed-loop biomass. MSW combustion should continue to be a second-tier resource. A finer distinction should be made between closed-loop and open-loop biomass. Some open-loop biomass fuels are more desirable than others from the perspective of co-optimized waste management and electricity generation. Waste management goals should be considered and incorporated into the next PTC renewal, and reflected in modifications to which resources command a larger tax credit.

The federal government should use resources to support R&D that will contribute to recommendations for policy standards and regional infrastructure enhancements. Additional financial and educational resources to support research and development would assist municipalities as well as regional private companies. R&D should seek to improve both the specific waste management and electricity generating technologies at individual facilities, such as improved gasification techniques that include rigorous gas cleaning, as well as improve the planning and development of a regional infrastructure capable of processing and diverting waste streams for appropriate reuse, recycling, or electricity generation.

Federal level R&D and educational resources should be coordinated by a joint program between the EPA and the DOE. This program could be loosely modeled after the ENERGY STAR program which is also coordinated jointly by EPA and DOE. In other words, there is a precedent for collaboration between EPA and DOE when an issue is relevant to the work of both agencies. To the extent that waste management is regulated at the national level it is regulated by EPA, including waste management that involves energy recovery. R&D funding for technologies and processes that can co-optimize waste management and energy development should include support from DOE. The ENERGY STAR program provides both environmental and energy benefits; a co-optimized waste management and energy development program could do the same. The EPA and DOE regional offices could work closely with a New England regional waste management organization to adapt nationally relevant information into region-specific guidelines. The federal program would be a clearinghouse of information and should include a list of best management practices to co-optimize waste management and energy development. This material should include "decision maker guides" designed for state and local government officials, as well as more general "lifestyle" information designed for private citizens.

Regional regulations and incentives

New England states should create a regional waste management organization (RWMO) capable of coordinating waste management activities with electricity activities to ensure an appropriate and useful flow of waste streams for fuel. The RWMO will not own or operate any waste management or electricity generation resources. These facilities will continue to be owned and operated by public or private entities, as is currently the case. In fact the RWMO will not be a physical organization; rather it would be a virtual organization with a membership comprised of federal and state environmental and energy officials. Federal-level members would be from the coordinated EPA and DOE program, while state-level members should be from new executive-level offices in each state that coordinate state environmental and energy activities. The RWMO may best be seen as a kind of advisory board with financial resources to solicit research and development by private consultants. Waste flow coordination will be carried out between designated staff in the state-level executive offices.

The role of the RWMO would be limited to coordination and guidance to recommend facility and infrastructure locations and capacity expansions, as well as waste flow market facilitation. Actual site approvals would remain a power of local governments and environmental and energy regulations would still be enacted and enforced by state agencies. The RWMO would work closely with state governments and the Northeast Waste Management Officials' Association to produce and distribute information designed to facilitate the coordination of regional activities in support of waste management with electricity generation.

The RWMO would be responsible for recommending regional performance guidelines based on waste diversion potential, environmental impact, and electricity potential, rather than based on specific "proven" technologies. These standards would be agreed upon by the regional body, but it would be up to the individual states to implement the standards as actual enforceable policies that work in conjunction with RPS, AEPS, or FIT legislation.

One of the primary roles of the RWMO would be information distribution. While the Northeast Waste Management Officials' Association is already an excellent source of information for waste management officials, it does not provide information and educational material for private citizens. The RWMO, in cooperation with the member states and federal government, would produce educational materials for individuals as well as local municipalities. The goal of this material would be to overcome social stigmas associated with waste management and energy development to avoid NIMBY problems when trying to site and build local facilities. The federal and state supported educational campaign should include information about landfills and other garbage projects, the emissions impacts of energy development, visual impacts, and traffic and congestion impacts. The campaign should emphasize that an increase in organics diversion via zero waste with electricity generation will result in a decreased need for expanding existing landfills or siting new landfills, or burning fossil fuels.

Ultimately the regional entity will be restricted to providing information and guidance. The implementation and enforcement of standards and regulations will be overseen by the states.

WTE facilities operate most efficiently when they are combusting at or near their daily tonnage capacity. Given the regional waste supply discussion in Chapter 3, it would not make sense to keep all the existing WTE facilities. However, it may be economically feasible to transport waste to a few existing WTE facilities while closing others as their waste supply contracts expire or they reach the end of their operating lifetimes. The RWMO could coordinate these closures to ensure sufficient local processing and disposal capacity, much the way ISO-NE monitors electricity generation to ensure a sufficient supply.

Over the long term, approximately 20 years, it will likely begin to make better economic and environmental sense to close all existing WTE facilities and replace the waste treatment capacity with gasification facilities. Gasification processes are more efficient at generating electricity using smaller amounts of waste inputs. A distributed network of gasification facilities could therefore more efficiently treat the 800,000 tons of waste that may remain, based on the diversion example from Chapter 3. The RWMO could be responsible for ensuring that this network of gasification facilities is sufficient to process the remaining waste stream, while also preventing an overbuild of capacity that could indirectly harm diversion efforts. Rather than regulating site assignments, the RWMO would use its regional vision to recommend site locations to state and local governments. It would be up to the local governments to actually site gasification resources. The RWMO could help facilitate the siting process by providing contract guidance and assisting local governments in negotiations with private companies.

Site assignment and capacity coordination will be an important responsibility of the RWMO. The market for waste management and energy development could support a major expansion of ZWEG facilities. However, a priority of ZWEG is waste reduction and it will be important to ensure that only an appropriate amount of ZWEG capacity is built, to support the treatment of the amount of waste that incentives and regulations should allow. An example will help clarify this point.

Suppose there is 100,000 tons of waste in a system, after source reduction measures have been used. We will want to recycle and reuse 50% of this volume, leaving us with 50,000 tons. Of the remaining volume, 80% can be diverted to anaerobic digestion (40% of the original 100,000 tons). This means the RWMO should ensure there is sufficient AD capacity to process 40,000 tons of waste. This leaves 10,000 tons that can be processed via gasification or combustion. The RWMO will need to ensure there is sufficient capacity to process these 10,000 tons, but not additional capacity. If there is more capacity, there will be an incentive to disregard reduction and other diversion priorities to maximize the conversion efficiencies of the thermal treatment facilities. Thus the RWMO will need to manage waste management priorities for reduction and diversion in the potential face of market pressures to expand thermal treatment capacity.

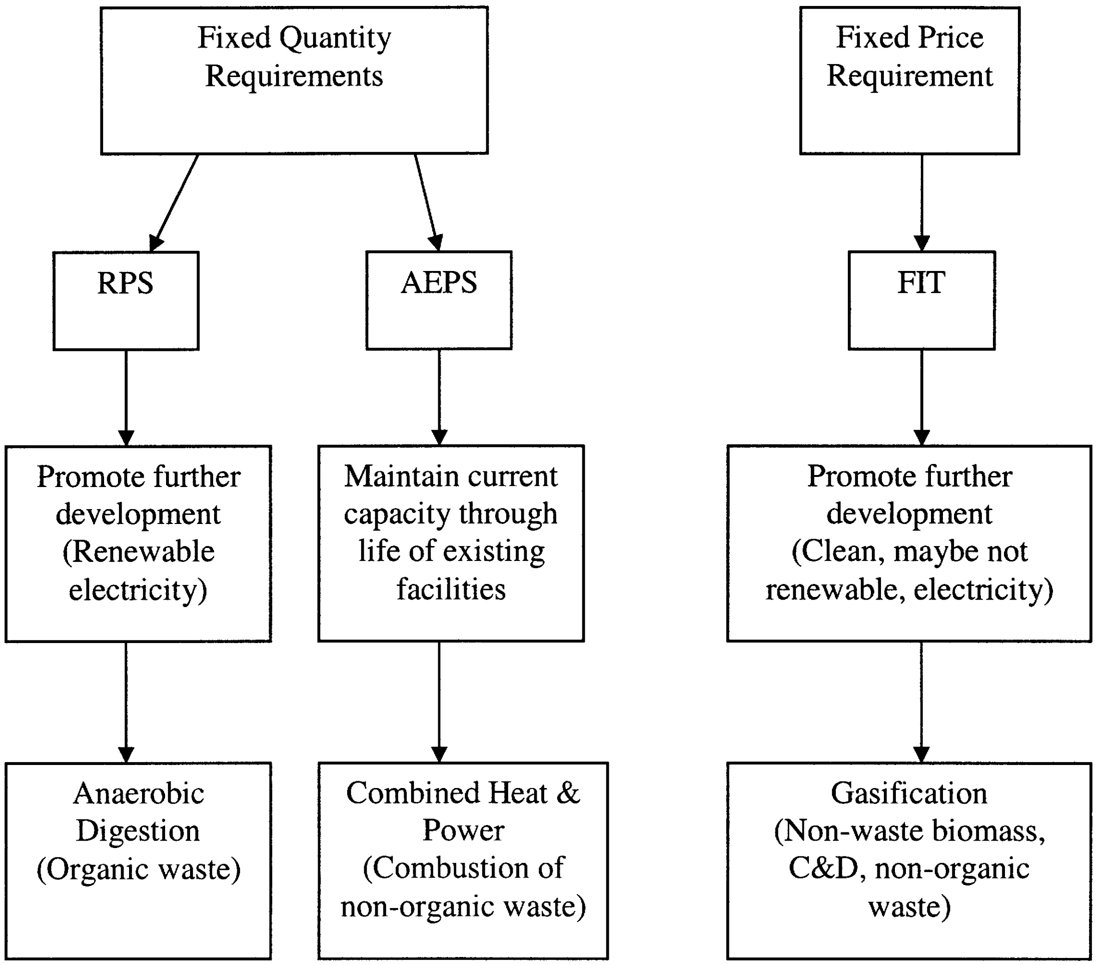
State regulations and incentives

State environmental and energy agencies need to better coordinate activities around waste management and energy development, and this will best be accomplished through the creation of a new executive-level office in each state. The Office of Waste Management and Energy Development (OWMED) will coordinate the relevant activities of state agencies responsible for waste management and energy development. Individuals from these state offices will comprise the state-based membership of the RWMO to ensure proper coordination of state activities within the region. The OWMED will also provide guidance to the state environmental and energy agencies concerning how to best distribute funds and other resources to create necessary incentives. The funding for the OWMED should come in part from the state environmental and energy agency resources; however, the state environmental and energy agencies will continue to control financial and regulatory resources associated with waste management and energy development within each state. The RWMO and OWMED will provide guidance only and facilitate regional and inter-agency coordination.

Alternatively, these responsibilities could be adopted by appropriate existing administrative offices. For example, the Massachusetts Executive Office of Environmental Affairs was recently reorganized and changed to the Executive Office of Energy and Environmental Affairs. The previous incarnation of this executive-level office was responsible for oversight of the Department of Environmental Protection, but the reorganization moved both the Division of Energy Resources and the Public Utilities Commission under the EOEEA. Thus Massachusetts has essentially already created an executive-level office to coordinate waste management and energy development activities and goals. It would therefore be redundant to create an OWMED. However, if there is no existing state executive capacity for high-level coordination of waste management and energy development an OWMED should be created.

States should implement waste bans for organic wastes that are inputs for anaerobic digestion, and should require five-year supply contracts between waste haulers and anaerobic digestion facility operators. The combination of guaranteed supply, tipping fees, and revenues from electricity sales should help make anaerobic digestion more economical. Given appropriate inputs, meaning separated organic wastes, the anaerobic digestion process results in a residual sludge that can be aerobically cured to produce compost. Although a somewhat tangential issue, compost is another marketable product, and therefore could provide another source of revenue to help make anaerobic digestion economically viable. While electricity will be sold to the competitive market, the state could establish a mandatory state agency purchasing program for the compost from these facilities to be used for landscape activities on state-owned property. Any activities that expand the market for compost should provide an additional economic incentive to support the development of anaerobic digestion facilities.

Figure 4.1 State-level Energy Standards Tailored to ZWEG



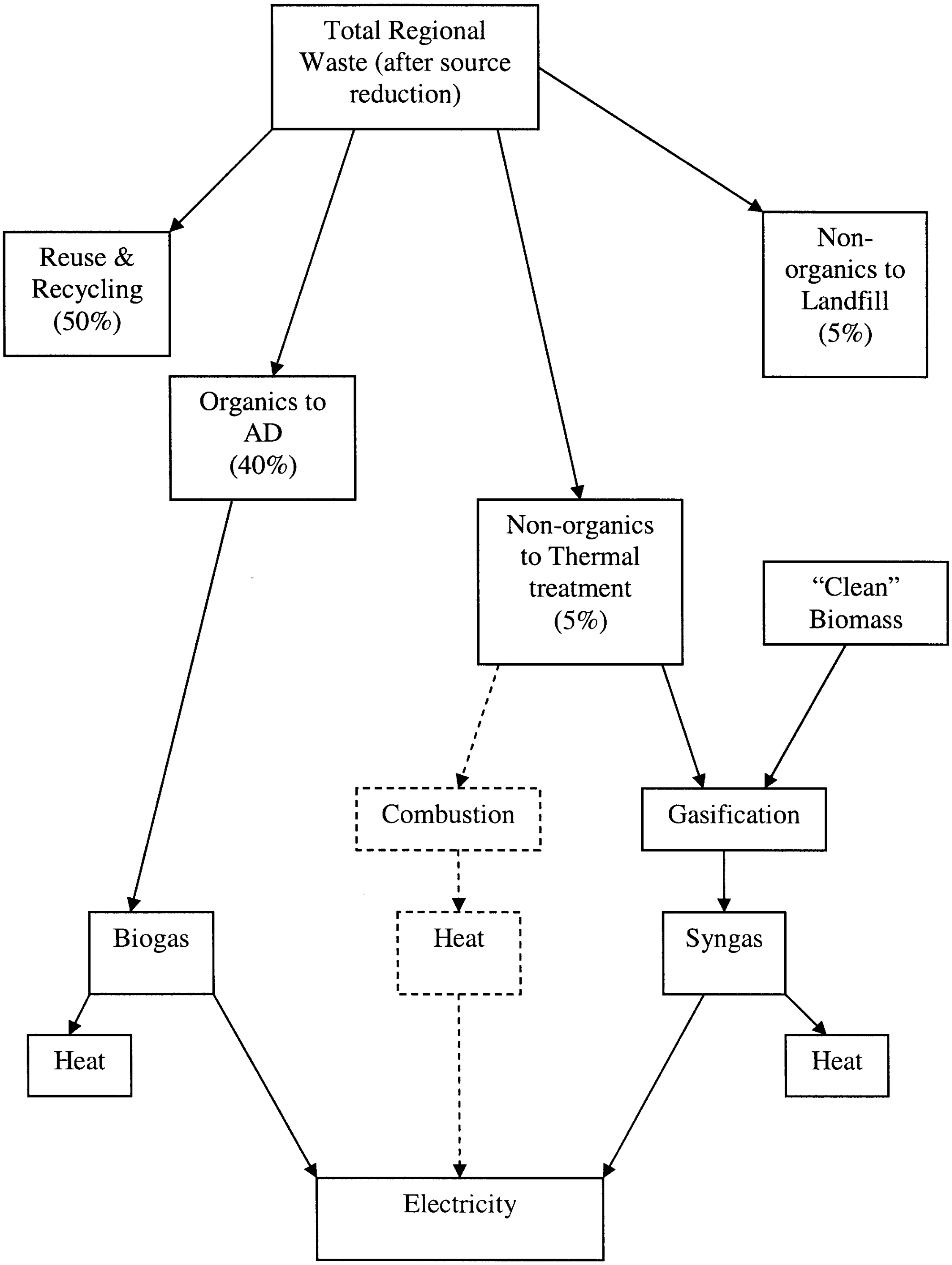
State renewable portfolio standards should be modified to create greater incentives for anaerobic digestion, such as making specific electricity percentage requirements for this technology. This would essentially mimic a tiered RPS structure, with anaerobic digestion commanding a separate tier. The RPS language should also reference the role of anaerobic digestion as a beneficial waste management option that is consistent with state waste management goals. The incentive for anaerobic digestion, in the form of an increased required percentage of electricity, will need to be sufficient to ensure that it encourages maximum diversion of eligible feedstocks. Increasing the percentage requirement for anaerobic digestion in the RPS should compliment an organic waste ban by providing an economical means by which this material can be diverted from the landfill. Through the combination of the waste ban and the RPS percentage adjustment, there should be sufficient incentive created to spur private investment in the expansion of anaerobic digestion capacity.

State regulations should also include an alternative energy portfolio standard for combined heat and power units that are fueled by waste streams that remain after maximum diversion has been achieved. The AEPS should be based on performance standards rather than specific technologies to allow the options that best achieve zero waste with electricity generation to obtain the benefits associated with the AEPS. It will likely be difficult to ensure compliance with rules for maximum diversion unless the AEPS includes performance standards based on this goal. The AEPS performance standards and percentage requirements should be designed to maintain the current capacity of combustion waste management facilities; to the extent such facilities are consistent with RWMO and state OWMED recommendations.

The important distinction between performance-based standards and standards based on accepted technologies is that the standards based on performance allow for the entry of new technologies. This is a critically important allowance if waste management and energy development are going to ever truly be co-optimized. There is also a variety of emerging pilot projects for technologies that generate electricity while treating waste streams. Current policies support technologies that are more or less good at either managing waste or generating electricity. Performance standards that are based on both waste management and energy development goals should create an incentive for private companies to continue to invest in the research and development of new technologies and processes.

Finally, each state should seek to create a form of FIT to support the regional development of a gasification industry that incorporates both the remaining non-organic portion of the sorted, diverted waste stream and non-waste biomass inputs from sustainably harvested forestry resources. Gasification facilities are capital intensive, and have relatively high operation and maintenance costs. The facilities will also have to purchase the non-waste portion of their fuel. However, by incorporating non-waste biomass into the fuel mix, the facilities will not become dependent on a waste stream for fuel, and will also help revitalize the regional forestry economy. The FIT will be the most appropriate incentive tool for this job because it will allow facility owners to secure sufficient investment based on the known revenue from electricity sales. The FIT eligibility requirements should be designed to strictly limit the percentage of the fuel that can be waste, and should qualify the types of waste that are acceptable. This will help to further promote waste reduction and sorting, which will benefit the anaerobic digestion processes supported by the RPS.

Figure 4.2 Waste Flow Supported by State Incentive Package



Local regulations and incentives

Site permitting processes should be streamlined, to some extent, for proposed projects that seek to co-optimize good waste management with electricity generation, and which are being proposed in locations recommended by the RWMO and the state OWMED. In other words, preference should be given to anaerobic digestion and permits should be easier to obtain. Environmental and human health and safety should still be carefully considered, but there should be alternative permitting procedures in place that allow for this consideration to be fast-tracked. This will make anaerobic projects more enticing to developers, since there will be less likelihood of costly construction delays. Permitting adjustments and easements should be based on guidance from the RWMO. The RWMO should specifically design educational packages that provide guidance and information to municipal planning offices and local health boards that will facilitate revised, streamlined permitting processes. The information package should also include fact sheets that can be distributed to municipal residents to help allay concerns associated with perceived negative environmental and human health and safety impacts.

Permit adjustments should also be considered for thermal waste management with electricity generation, as long as the facility is consistent with zero waste with electricity generation processes and technologies, and part of an RWMO and state OWMED recommendation. Thermal waste management with electricity generation should be considered ahead of the landfill option, but the potential environmental and human health and safety impacts should be carefully evaluated.

Additional local incentives could include tax breaks and other standard incentives historically associated with new development projects since increasing the regional capacity for waste diversion and electricity generation will involve significant development.

4.1.1 Why these technologies with these incentives?

Over the course of this document I have tried to stress the point that ZWEG should co-optimize waste management and energy development. Thus, simply put, I believe the technologies and incentives described above accomplish this goal. Anaerobic digestion is an efficient and relatively cheap option. The quantity requirements associated with RPS eligibility should be a sufficient incentive to promote continued expansion, especially when paired with a strictly organic fuel supply. Biomass gasification is more capital intensive, and the economics are not fully proven. If a portion of the fuel must be purchased, facilities will face an additional cost. For this reason, and because I have advocated for a fuel mixture that is arguably not renewable, I believe the FIT is a more appropriate incentive.

Additionally, infrastructure considerations support prioritization of anaerobic digestion (AD) followed by gasification. New England already has an extensive network for natural gas distribution and utilization. AD and gasification both produce gas which can be used in standard gas turbines once contaminants are removed. Thus the biogas from AD and the syngas from gasification should slip somewhat seamlessly into the existing regional natural gas infrastructure. In addition to providing for the diversion of the organic portion of the waste stream, the biogas from AD has a higher thermal value than syngas, providing further support for the prioritization of this ZWEG process.

Table 4.1 Calorific Value Comparison (Williams 2005)

Technology	MJ/m^3	Btus[33]
Natural Gas	37	35,076
Gasification (air)	4-6	3,792 – 5,688
Gasification (oxygen)	10-15	9,480 – 14,220
Anaerobic Digestion	20-25	18,960 – 23,700

But ultimately the point is that the costs and benefits of these technologies and fuels cannot be thought of in historical terms. Biomass energy and anaerobic digestion are not just electricity resources; they are also waste management options that have the potential to dramatically improve our waste management practices. Thus the economics and efficiencies cannot simply be thought of, or compared to, historical electricity resources *or* historical waste management options. The benefits of implementing ZWEG processes will be realized at multiple levels, and new metrics will have to be developed to measure their success.

I have not created these metrics, nor have I attempted quantitative comparisons. However, the anecdotal evidence presented via examples in previous chapters suggests that these technologies are complementary based on their optimal fuel input requirements, and as such will efficiently and cost-effectively co-optimize waste management and energy development.

[33] Tester et al. (2005) state that 1 Joule = 9.48×10^{-4} Btu.

Reflections on cost implications

Table 4.2 displays a comparative list of some of the technology and fuel combinations discussed in this thesis. The cost per kilowatt hour for food-based anaerobic digestion is already relatively low. New metrics, based on the co-optimization of waste management and energy development, should result in an even lower relative cost. Conversely, the cost per kWh for landfill gas-to-energy (LFG) is currently very low. Given that landfills are not an optimal means of waste management, metrics for co-optimization should cause a relative cost increase, thereby making other forms of biomass energy more cost-competitive. Table 4.2 also demonstrates the higher costs of electricity generation associated with technologies that use biomass as fuel, further supporting the use of a FIT to provide a more direct economic incentive for projects that employ these technologies.

Table 4.2 Levelized Costs of Electricity Generation

(Source: California Energy Commission, Electricity Analysis Office http://www.energy.ca.gov/electricity/levelized_costs.html)

Electricity Resource	MW	Dollars Per MWh	Cents Per kWh
Conventional Combined Cycle (CC)	500	102.19	10.22
Advanced Combined Cycle	800	96.36	9.64
Integrated Gasification Combined Cycle (IGCC)	575	126.51	12.65
Biomass - AD Dairy	0.25	143.61	14.36
Biomass - AD Food	2	70.05	7
Biomass Combustion - Fluidized Bed Boiler	25	118.72	11.87
Biomass Combustion - Stoker Boiler	25	111.15	11.12
Biomass - IGCC	21.25	123.66	12.37
Biomass - LFG	2	56.11	5.61
Solar - Concentrating PV	15	424.84	42.48
Solar - Parabolic Trough	63.5	277.3	27.73
Solar - Photovoltaic (Single Axis)	1	704.98	70.5
Solar - Stirling Dish	15	518.89	51.89
Wind - Class 5	50	84.24	8.42

4.2 The Potential Incompatibility of ZWEG and Zero Waste

Zero waste with electricity generation attempts to co-optimize waste management and energy development while remaining as consistent as possible to zero waste principles. However, zero waste is more than diversion and energy recovery, and generally doesn't consider energy recovery to be part of the design due to the potential to create a perverse incentive for a waste stream to fuel electricity generation. I believe that the primary emphasis on reduction with a secondary emphasis on organics diversion to anaerobic digestion does at least partially address these concerns, as does the development of a system to produce and market compost using the residual from the digestion process. I believe concerns for perverse incentives can be further addressed by designing the system to incorporate sustainably harvested non-waste biomass.

My recommendations are not intended to preclude the adoption of more stringent zero waste policies. I have attempted to leave the door open for additional policies that will truly disrupt the linear production process. I don't believe any of the ZWEG processes I have proposed will suffer from additional waste reduction measures. We will presumably always have a flow of organic material that is not fit for consumption or other reuse that we can use as feedstock for anaerobic digestion, and by coordinating remaining thermal processes with the development of a FIT-supported biomass energy industry, there should be no productivity losses due to an ever decreasing supply of non-organic waste.

Ultimately I recognize that this proposal is not completely consistent with zero waste, and certainly does not address some significant zero waste concerns related to a closed-loop production cycle. However, it is also not wholly inconsistent, and should allow room for stricter adoption of zero waste in future plan iterations. I do believe the policies and incentives I have recommended are close to ideal in terms of co-optimizing waste management and energy development. Unfortunately this may actually preclude the adoption of strict zero waste policies. Although successful implementation will require everyone to reconsider how they think about waste, which should at least point our society toward the trailhead for zero waste, if it doesn't actually start us walking down the path.

4.3 Conclusions

Waste management and energy development are generally still viewed as very different issues. To the extent that electricity generation using waste is dealt with, it is dealt with by environmental organizations concerned primarily with environmental and waste management goals. The electricity produced is essentially a secondary consideration and therefore not well incorporated with other energy development initiatives being pursued by state energy agencies. Thus electricity generation from waste is not optimized for either waste management or energy development, and suffers criticisms from both camps.

Waste management and energy development activities need to be coordinated at different levels. Ideally this would involve the creation of a joint program administered by the US EPA and US DOE, the creation of a regional waste management organization for New England, and the creation of a new executive-level office within each state to coordinate intra-state activities. Working together, these entities could contribute to significant improvements in technologies and process management that will allow New England to increase installed electrical generating capacity while simultaneously decreasing regional reliance on landfills.

Creating new organizations will not be easy, and may in fact prove to be too difficult. Regardless of whether or not new agencies are created, the key to successful co-optimization of waste management and energy development will be better coordination between the agencies responsible for regulating waste management and energy development. As our society becomes more aware of sustainability concerns, and as virgin resources become more scarce and more expensive to extract, it will be critically important to look for ways to "close the loop" of the currently linear production cycle. Reusing and recycling materials between different industrial and manufacturing processes will be a substantial part of this, but waste streams will likely continue to flow from consumer activities. Processes designed around the idea of zero waste with electricity generation will allow us to at least recover energy from our waste, and will hopefully force society to deal more openly and directly with its waste. I am not advocating for zero waste with electricity generation as the permanent solution to the larger sustainability problem. I do believe ZWEG will co-optimize waste management and energy development, thereby contributing to sustainability efforts through improved waste management that does not rely on landfill disposal, and by establishing a regional network of distributed, dispatchable electricity generators that do not rely on fossil fuels.

Appendices:

A - New England State Renewable Energy Standards – General Targets and Applicability to Source of Electricity from Waste Streams

B - Waste-to-Energy Technology Review

C - WTE vs. Fossil Electricity vs. Renewable Electricity vs. Landfills vs. Recycling

D - Electricity Conversion Calculations

Appendix A:

New England State Renewable Energy Standards – General Targets and Applicability to Source of Electricity from Waste Streams[34]

Connecticut

Technologies covered by the Connecticut Renewable Portfolio Standard include landfill gas, biomass, MSW, and CHP/cogeneration. Connecticut uses a tiered RPS with three classes. Class I resources include landfill gas and "new sustainable" biomass. Air emission limits apply to the biomass facilities. Class II resources include MSW and biomass not covered by Class I. Class III includes combined heat and power (CHP) and cogeneration. The RPS targets are based on this class system in the following way: by 2020 the state should get 27% of its power from renewable sources, with 20% coming from Class I, 3% from Class I or II, and 4% from Class III by 2010.

Maine

Technologies covered by the Maine Renewable Portfolio Standard include landfill gas, biomass, and MSW. The Maine RPS was set high at 30%, but the state was already producing more than 30%. A more recent goal was established under the RPS to achieve 10% of new energy through renewable generation. The 10% is not part of the original 30%, and does not include MSW.

[34] *Source: Database for State Incentives for Renewables & Efficiency (DSIRE)*

Massachusetts

Technologies covered by the Massachusetts Renewable Portfolio Standard include landfill gas and biomass. The nature of eligible biomass fuels is a current policy issue within Massachusetts. The DOER recently (November 2007) released a final summary of proposed revisions to the RPS. The revisions were supposed to clarify and expand the definitions associated with biomass energy; however certain topics were too controversial and therefore were left out of this final proposal. Issues pushed off include whether C&D wood waste is an eligible fuel.

Current Massachusetts eligible biomass fuels include "brush, stumps, lumber ends and trimmings, wood pallets, bark, wood chips, shavings, slash and other clean wood that are not mixed with other solid wastes; agricultural waste, food material and vegetative material as those terms are defined, or may subsequently be defined, by the Department of Environmental Protection at 310 CMR 16.02; energy crops; biogas; organic refuse-derived fuel that is collected and managed separately from municipal solid waste; or neat biodiesel and other neat liquid fuels that are derived from such fuel sources." (225 CMR 14.02)

New Hampshire

Technologies and fuels covered by the New Hampshire Renewable Portfolio Standard include landfill gas, biomass, and anaerobic digestion. The New Hampshire RPS is also a tiered system. Class I includes landfill gas, new biomass that meets air quality standards, and new biomass production from existing facilities that exceeds historic baseline production. Class III includes existing biomass and methane, presumably operating within a historic baseline.

The goal is to achieve 23.8% by 2025 with the following class percentages: 16% Class I, 0.3% Class II, 6.5 % Class III, and 1% Class IV.

Rhode Island

Technologies and fuels covered by the Rhode Island Renewable Portfolio Standard include landfill gas, biomass, and anaerobic digestion. To be eligible, biomass facilities must use eligible fuels and meet air emissions standards. Eligible fuel can be co-fired with fossil fuels, but only the portion of energy generated by the eligible biomass fuels will qualify as renewable energy. The Rhode Island target is 16% renewable energy by 2020.

Eligible biomass in Rhode Island "means fuel sources including brush, stumps, lumber ends and trimmings, wood pallets, bark, wood chips, shavings, slash and other clean wood that is not mixed with other solid wastes; agricultural waste, food and vegetative material; energy crops; landfill methane; biogas; or neat bio-diesel and other neat liquid fuels that are derived from such fuel sources" (RI RPS Leg. 2).

Vermont

Vermont has a Renewable Portfolio Goal which includes landfill gas, biomass, and anaerobic digestion. This is not a RPS, and differs in the following way: Vermont retail electricity providers are encouraged to meet future electricity demand (demand growth) by establishing long term contracts with renewable energy generators. The generators can sell the associated renewable energy credits into other markets outside Vermont since the Vermont goal is not based on the credit system. If the goal of total growth, or a 10% cap, is not met by 2012, the goal will become a RPS in 2013. Essentially, Vermont energy suppliers are currently encouraged to increase the share of renewable energy rather than being required to do so.

However, Vermont does have a form of FIT to provide an economic incentive for "cow power," (anaerobic digestion that uses cow manure as a feedstock). Farms that participate are given fixed price electricity purchase agreements by the sponsoring utility for a period of five years, with the option to renew for another five years.

The Vermont definition of renewable energy is, "energy produced using a technology that relies on a resource that is being consumed at a harvest rate at or below its natural regeneration rate." (DSIRE Web site) This specifically includes methane from landfills, anaerobic digesters, and sewage treatment plants.

Appendix B:

Waste-to-Energy Technology Review

Combustion

Combustion is the original WTE technology, and WTE still generally refers to combustion. There are different methods of combustion that use different feeding systems, boilers, and flue gas systems. However, the processes all essentially involve feeding the fuel supply into a combustion chamber where air is added at a sufficient rate to attempt as efficient a combustion process as possible. Efficient combustion means that as much of the fuel is combusted as possible, thereby "converting" it into heat rather than ash. Ash is the non-combusted portion of the fuel. Ash is one residual of combustion, as is the melted remains of non-combustible material that may have been left in the waste stream. There are two types of ash, bottom ash and fly ash. Bottom ash is what is left in the boiler after combustion. Fly ash is the portion of the ash that remains in the flue gas and must be removed using emissions control technologies. Fly ash is generally much more toxic than bottom ash (Tammemagi 1999).

Bottom ash can be processed for use as construction aggregate. However, it must first be tested for toxicity. Fly ash must currently be treated as a toxic waste due to the make up of the waste stream. That is, everything that comes out of combustion is a reflection of what went in. If there are fewer toxics in the waste stream, there will be fewer toxics in the emissions (Denison and Ruston 1996; Williams 2005).

The WTE industry claims that recycling rates increase when waste is incinerated (Kiser 2003). This is because metals that would have been placed in a landfill can be recovered after combustion.

Combustion WTE involves combusting the waste as a fuel in a boiler. This produces heat in the form of hot flue gas. The gas is passed through chambers that are lined with water in order to heat the water into steam. The steam is then either used as a heat source for district heating, or put through steam turbines to generate electricity. Using the steam for heat is the most efficient use, since the energy does not have to be converted into another form. However, the market for steam and heat fluctuates by time of day and year, and the customer must be in close proximity to the WTE facility. On the other hand, converting the steam into electricity results in some energy efficiency losses, but provides a more marketable product. Electricity is required at a relatively constant rate, compared to steam heat, and can be sold into the general electricity market that exists in New England. Regardless of whether the WTE facility sells heat or steam, or both via a combined heat and power system, the economics of the plant will likely be dependent on long-term purchasing contracts for the heat and/or electricity products (Williams 2005).

Pyrolysis and Gasification

Pyrolysis and gasification are often used in combination with pryolysis preceding gasification. Pyrolysis uses no oxygen and results in some syngas and char, as well as oils and chemicals that can be used as industrial inputs. Char is essentially like charcoal, and pyrolysis techniques have been used for centuries to produce charcoal. The second phase of gasification uses some oxygen to combust the remaining carbon to release all the syngas. The result of this process is a more complete conversion of the waste into syngas; more of the carbon is extracted from the carbon based waste. It should also be noted that gasification has been used for many years as well. Its most infamous application may be when it was used to produce synthetic diesel fuel for the German war machine in WWII. Cut off from oil, the Germans were forced to develop the process of gasifying coal, and converting the resulting syngas into liquid fuel via a process they developed called Fischer-Tropsch. This process has been used more recently by South Africa, which was cut off from oil during apartheid. Converting coal into liquid fuel is not economical when one has access to oil. Gasification as a waste treatment and energy recovery method is more economical and should become more so as fossil energy prices continue to rise.

Gasification involves the active creation of syngas, which is a methane-based gas. The gas can be purified and used to generate electricity in the same manner as natural gas, which is comprised almost entirely of methane. It can also be used in an unpurified form, in which case it is less efficient at creating electricity due to the diluted methane content. Fuels for biomass gasification can include any organic waste materials. Gasification uses hot temperatures and little oxygen to break up the chemical composition of the fuel and turn the material into gas. Gasification technologies are capable of gasifying construction and demolition wastes as well and there are current efforts to improve the economic efficiency of gasifying unsorted municipal solid waste.

Gasification takes place in an oxygen starved environment, just as in anaerobic digestion. The lack of oxygen, in combination with high temperatures, results in greatly reduced emissions. This is in part because very little actual combustion takes place. The carboniferous material in the waste inputs is instantaneously gasified, while impurities are destroyed or melted into slag. The resulting slag, which is similar to melted bottom ash from a combustion facility, is generally inert. Any persistent toxins become trapped in a non-leachable state and can be used as construction aggregate or dumped in unlined landfills.

Gasification is still an emerging technology. While various forms of gasification have been developed and used for a long time, gasification of waste stream material is embryonic. Facilities are often not economically viable due to the costs associated with new technology deployment (lack of investor confidence and risk acceptance). They are also not necessarily capable of producing a net quantity of heat energy due to the temperature input requirements of gasification. However, gasification systems are more efficient at producing electricity via the product syngas, and are more efficient than combustion at smaller scales.

Anaerobic Digestion

Anaerobic digestion is a process that creates biogas, which is largely comprised of methane. The gas can be purified and used to generate electricity in the same manner as natural gas, which is comprised almost entirely of methane. It can also be used in an unpurified form, in which case it is less efficient at creating electricity due to the diluted methane content. Fuels for anaerobic digestion can include any organic waste materials. Anaerobic digestion controls the decomposition environment of organic matter to maximize the efficiency of decay and the production of biogas (methane). Methane is released by the anaerobic decomposition of organic matter. Methane releases are problematic for poorly managed composting operations, and also present emission problems for landfills.[35] In other words, open-air, uncontrolled anaerobic digestion is not

[35] All landfills are required by the EPA to manage their methane emissions. Many now capture the methane produced by the decaying MSW so it can be combusted to generate electricity. Others simply capture the

desirable, but controlled processes that capture the methane for electricity production are beneficial.

Anaerobic digesters essentially speed up the decomposition processes that naturally occur in solid waste landfills. The organic waste is placed in the digester to decompose in an oxygen deprived state. This process generates methane which can be captured and used to power gas-fired generators. Digesters simply control what would be a natural process of decay. A digester can optimize the environment for the bacteria that breakdown the waste, most importantly by maintaining a relatively constant temperature. The digestion process can reduce waste volumes by more than 70% (Denison 1990) while stabilizing the waste.[36]

Digesters have to use organic waste, since non-organic waste will not break down using this process. Organic wastes contribute to the majority of methane emissions from the waste stream, which is why they work so well for anaerobic digestion. By removing the organics from the rest of the waste stream, or not placing them into the waste stream to begin with, a significant reduction in landfill methane emissions can be achieved. Some of the methane could be captured at the landfill, but as a closed system the anaerobic digestion process is able to more easily capture all the gas.

Anaerobic digesters are also used to capture methane from farm animal waste. In general, these types of projects are an excellent way to manage and control odors, with

---

gas and flare it off (converting it into the less potent GHG carbon dioxide). Regardless of how methane is managed at landfills, only around 50% of the gas is actually captured.

[36] Stabilization refers to the process by which waste decays and releases gases. Organic waste that is placed in a landfill does this slowly over time, and releases emissions into the atmosphere unless the landfill has the technology to capture these gases. Processes that generate electricity from waste do so by using the energy stored in the waste, which is the same material that generates landfill emissions. Thus waste that is landfilled after energy recovery is relatively inert in terms of its potential to release harmful emissions. Although ash from combustion processes is generally a hazardous material that must be disposed of carefully.

the added benefit of producing electricity. Farm-based anaerobic digesters are often primarily used as a waste management tool, rather than as a means to generate electricity. Electricity generation can be a nice side benefit if the farm has a sufficient supply of waste to fuel the digester. Often farm-based digesters choose to simply flare off the captured methane.

Anaerobic digestion does produce a waste product of its own, referred to as sludge. The sludge is what remains after the material fully decays. It is rich in nutrients and can be used as a soil conditioner. It may also be used as feed for livestock. However, any toxins in the original mix of biomass can be concentrated in the sludge. The sludge should therefore be tested before being put to another use.

Appendix C:

WTE vs. Fossil Electricity vs. Renewable Electricity vs. Landfills vs. Recycling

Waste-to-energy systems seem to fall somewhere between fossil energy and renewable energy in terms of perceived environmental impact associated with electricity production. Environmental impacts must be accounted for both before and after the actual production of electricity, to account for fuel extraction and transportation and the disposal of any conversion process residuals. Waste-to-energy is also a method of waste management, thus this section also briefly examines the alternative practices of landfilling and recycling.

Fossil Electricity

Electricity generated using fossil fuels almost always consists of combustion. Coal and oil are combusted in boilers while natural gas is combusted in gas turbines. In all cases, the fossil fuel must be extracted from the earth and then transported to the location of the generation facility. Extraction is generally environmentally destructive, or at least highly disruptive. The fuel is often located far from the generation facility, be it the Rocky Mountain West, the North Slope of Alaska, or the Middle East. The fuel must be transported great distances, using substantial amounts of energy.

Once the fuel reaches the generation facility it is combusted, perhaps preceded by some form of processing to facilitate efficient combustion. Combustion results in emissions in the form of fly ash and gases, much of which is captured and controlled via various technologies. However, some solids are trapped by the emissions controls, and bottom ash is also a product of combustion. These must be disposed of, and are generally toxic.

After the electricity is generated it must be transmitted through the electrical grid. Fossil fuel-powered generation facilities can be sited more or less anywhere, so connectivity tends to not be an issue. The electricity is also dispatchable, meaning it can be generated on demand. Fossil fuel–powered power plants can also generate electricity constantly, and can therefore supply the grid with base load power. Base load refers to the amount of power that is always required to keep modern society functioning twenty-four hours a day, seven days a week, three hundred sixty-five days a year.

Fossil fuel–powered facilities require complex technologies and significant material resources. This results in high capital costs and high operation and maintenance costs. However, in the long run fossil fuel–powered facilities can be de-powered, remediated, and the land put to another beneficial use.

Renewable Electricity

Electricity generated from renewable sources such as wind and solar does not require fuel. Thus there is no environmental impact associated with fuel extraction and transportation. In the case of wind there are environmental concerns around turbine impacts on flora and fauna. Both solar and wind electricity facilities must be sited in an area with strong solar or wind resources respectively. Additionally, large-scale facilities take up a lot of land area. This can result in a significant environmental impact in the form of land use. The large land requirement can also mean that facilities are sited great distances from electricity customers. Even if the facility is located in close proximity to sufficient existing transmission infrastructure, line losses will occur. If sufficient transmission does not exist, new transmission infrastructure will have to be built and will have an environmental impact.

Renewable electricity facilities are material-intensive construction projects that require substantial amounts of metal, concrete, and electronics, just like other modern power plants. The facilities thus face high capital costs. Operation and maintenance costs are also not cheap, although renewable facilities do not have to maintain expensive emission controls, or purchase fuel.

Finally, and perhaps most importantly, renewable electricity from wind and solar is not dispatchable. It cannot be turned on and off when it is needed or not, and the "fuel" source is not always available to generate electricity. Thus wind and solar cannot contribute to base load or peaking power need reliably.[37] Generally electricity demand is higher during the day, when wind and solar are also most productive, but there is no way to guarantee electricity production. Renewable electricity resources must currently contribute to the grid when they can. This intermittency is a major obstacle to the expanded development of renewable electricity resources.

One potential solution to the dispatchability problem is electricity storage technologies. However, no technologies exist that can be deployed at a useful scale, and any technologies that are developed would have an environmental footprint of their own that would have to be included in the comparison.

[37] Peaking plants are designed to provide excess capacity on short notice as necessary, when electricity demand peaks and exceeds the supply capacity of base load resources. There are a significant negative environmental impacts associated with fossil fuel-powered peaking plants. Thus to the extent that renewable resources can displace tradition peaking plants they may provide cleaner peaking capacity.

Clean wood biomass is considered to be a renewable resource in many states, including all six New England states. Whether the electricity is generated via combustion or gasification it will be dispatchable. Thus biomass renewable electricity resources are capable of circumnavigating the dispatchability problem.

Waste-to-Energy

Waste-to-energy in this thesis includes the use of waste biomass as a fuel source, which can include biomass that is also considered fuel for renewable electricity resources. However, for the purposes of this comparison WTE will refer to standard MSW combustion. Using waste as a fuel means the fuel supply will be very heterogeneous and potentially made up of material originally gathered via environmentally harmful practices. However, it is also waste, and if it is disposed of improperly the result will be another harmful environmental impact.

For the purposes of this basic comparison, waste is generated locally, and therefore if it is used as an electricity producing fuel locally it will not have to be transported a great distance. Just like fossil fuel–power facilities, WTE facilities can be sited in close proximity to electricity customers. This has the additional benefit of also being in close proximity to the fuel source, since the electricity customers and fuel generators are the same group. As a fuel source, it therefore has fewer environmental impacts associated with transportation than fossil fuels, and may require less transportation than hauling to the nearest landfill.

Waste-to-energy facilities are similar to fossil fuel–powered facilities and therefore have high capital costs and high operation and maintenance costs. However, because they are also waste management facilities they collect tipping fees for accepting waste and are thereby able to help offset costs. In other words, a WTE facility is paid for the fuel it uses, rather than having to pay for the fuel it uses.

And finally, just like fossil fuel-powered facilities, WTE facilities are dispatchable and can therefore contribute to base load supply. An important consideration on this point is that WTE is also a waste management process, and therefore it essentially has to be a base load power source since waste management generally needs to continue non-stop. Thus, unlike renewables and some fossil fuel-powered facilities, WTE is not really suited to serve as a peaking facility.

Landfills

Landfills are an unfortunate but necessary component of the waste management system. Some have crossed into the energy generation arena through landfill gas capture and combustion, but the basic design of the landfill is the same. Landfills do not have a "fuel," but waste must be transported to the landfill site for disposal. As populations increase we generate more waste and have less land available for disposal. Thus open landfills are harder to find and generally far away from the sources of waste. Thus more and more energy is being spent to ship waste further and further. This is also a growing expense as transportation fuel costs rise.

Landfills themselves are little more than large holes that hold a variety of wastes. Modern landfills are strictly regulated to mitigate environmental harms, but leaks into the ground and emissions into the air are hard to control with such a heterogeneous waste stream. As organic matter decomposes it releases methane and other gases such as hydrogen sulfide. Methane must be controlled because it is a highly potent greenhouse gas, but control can consists of capturing as much of the gas as possible and flaring it off to convert it into less potent carbon dioxide. Either way carbon is emitted and it is not possible to capture all the methane generated by a landfill.

More and more, landfill operators are installing gas capture technologies that are designed to combust the gas and generate electricity. However, similar to the siting problems for large-scale wind and solar, landfill gas-to-energy projects may have trouble connecting to existing transmission lines, and may be located great distances from electricity customers. This is especially true for newer landfills, since there is no land available close to inhabited areas, and people don't want landfills sited near their homes.

Historically, the largest perceived benefit of landfills was their low capital costs and low operation and maintenance costs. However, this is beginning to change. Capital costs may still be low compared to WTE facilities, but they are higher now that there are more environmental regulations. These regulations also require long-term site monitoring, which means that maintenance costs may actually continue indefinitely, well after the landfill is closed and is no longer collecting tipping fees. The heterogeneous makeup of the waste and the slow, uneven decomposition result in highly unstable land. It is therefore very difficult to remediate and reuse land that was used as a landfill. Remediation may be difficult on land used for a fossil or WTE facility, but options are more promising.

In addition to taking up substantial physical space, landfills potentially leak toxic pollutants into surrounding areas and release methane gas--a greenhouse gas that is 21 times more potent than carbon dioxide--into the atmosphere, thereby contributing to climate change. Despite modern controls and regulations for landfills, landfills remain essentially large containers for a very heterogeneous waste stream. These various wastes decay and decompose and release harmful, toxic emissions such as hydrogen sulfide.

Landfill operators are required to manage methane gas. While many simply capture the gas and flare it off, thereby converting the methane into less potent carbon dioxide, some landfill operators employ gas capture techniques that allow the methane to be burned in engines or turbines that generate electricity. While this process does provide some electricity generation, it does not solve the landfill problems associated with land use and environmental contamination and does not provide for the management and capture of all the landfill-generated methane or other problematic gases. A significant portion of landfill gas emissions, as much as 50%, are released directly into the atmosphere even when gas capture and control technologies are employed (Williams 2005).

Recycling

Recycling is a form of waste management that is also very relevant to energy. Recycling and reusing materials such as plastics and metals can result in real energy/electricity savings associated with decreased virgin resource extraction and cheaper production processes. Recycling centers are handling a part of the waste stream, so there are environmental concerns due to the toxicity of some recyclable materials and processes used to recycle materials. Ultimately however, this has to be compared with the environmental benefits of less extraction, less energy and electricity use, and less waste being hauled to and dumped into a landfill. Capital costs, as well as operation and maintenance costs are also much lower for recycling than for electricity generation facilities. It is not exactly a fair comparison, but I feel that the energy savings realized by recycling have the potential to be quantified as carbon offsets and thereby play a role in the overall energy and waste management policy goals of this thesis.

It will be very difficult to accurately quantify the emissions savings associated with recycling however, which would make it unlikely to be a viable offset. It is possible to show that recycling contributes to GHG emission reductions, and to decreased energy consumption associated with production. Therefore, a policy based more on the qualitative benefits of recycling may be more reasonable, but it can be based on the unquantifiable, but known, quantitative benefits (Kaplan, Reid, Vale interview).

Appendix D:

Electricity Conversion Calculations

Assumptions:

Ostrem 2004
1 ton organic waste = 100 m^3 biogas = 170kWh net electrical capacity

Williams 2005
Biogas calorific value = 20MJ/m^3

Tester et al. 2005
1kWh = 3.6 MJ
1kWh = 3414 Btus

Author
Capacity factor = 90%
7890 hours/year of operation at 90% capacity factor
Regional volume of waste = 9.6 million tons

Conversions:

Electricity

Williams and Ostrem	Ostrem only
9.6 * 100m^3 = 960 million cubic meters biogas 960 million * 20MJ/m^3 = 19.2 billion MJ 19.2 billion MJ / 3.6 = 5.3 billion kWh / 1000 = 5.3 million MWH 5.3MWH / 7890 hrs/yr = 676MW gross capacity (combined heat and power) 40% of 676 = 270 25% of 270 = 67 270 – 67 = **203MW (approximate net electrical capacity)**	9.6 million tons * 170kWh = 1,632,000,000 kWh 1,632,000,000 / 1000 = 1,632,000 MWH 1,632,000 / 7890 **= 209 MW (approximate net electrical capacity)**

Heat

60% of 676 = 406
27% of 406 = 110
406 – 110 = 296 MW (approximate net heat energy)

296 * 1000 = 296,000kW * 7890 = 2,335,440,000kWh
2,335,440,000 * 3414 Btus = **$8x10^{12}$ Btus**

References and Works Consulted

Alternative Resources, Inc. “Los Angeles County Conversion Technology Evaluation Report: Phase II – Assessment.” April 2007. The Southern California Conversion Technology Demonstration Project. February 24, 2008 <http://www.socalconversion.org/pdfs/LACo_Conversion_PII_Report.pdf>.

Asami, N. et al. (2002). “Development of high-efficient waste power generation technologies: feasibility study on the high-efficient waste gasification process.” Waste management and the Environment. Ed. Almorza, D. Boston: WIT Press, 41–52.

Ashford, N. A., Ayers, C. and Stone, R F. (1985) "Using Regulation to Change the Market for Innovation," Harvard Environmental Law Review 9(2), 419-466.

The Associated Press. “Other fuels in greater demand.” February 25, 2008. Portland Press Herald/Maine Sunday Telegram. February 29, 2008 <http://pressherald.mainetoday.com/story.php?id=171865&ac=PHnws>.

Banks, C.J., and E.I. Stentiford. (2007). “Biodegradable Municipal Solid Waste: biotreatment options.” Waste and Resource Management 160, 11–18.

Barlaz, Morton A., and Keith A. Weitz. (1995). Life-Cycle Study of Municipal Solid Waste Management: System Description. Washington: US EPA.

Barmann, Timothy C. “Renewable-energy bills seen aiding the economy.” March 7, 2008. Providence Journal. March 7, 2008 <http://www.projo.com/news/content/bz_senate_energy07_03-07-08_9P99IGT_v13.7f17f.html#>.

Blue Ridge Environmental Defense League. “Incineration and Gasification: A Toxic Comparison.” April 12, 2002. Global Alliance for Incinerator Alternatives. February 24, 2008 <http://www.no-burn.org/resources/library/incingafcomp.pdf>.

- - . “Waste Gasification: Impacts on the Environment and Public Health.” April 2002. Blue Ridge Environmental Defense League. February 24, 2008 <http://www.bredl.org/pdf/wastegasification.pdf>.

Bowles, Ian. “Want to buy some pollution?” March 15, 2008. New York Times online. March 17, 2008 <http://www.nytimes.com/2008/03/15/opinion/15bowles.html?_r=1&oref=slogin>.

Box, N. (2007). “Rotary in-vessel advanced anaerobic composting.” Waste and Resource Management 160, 33-38.

Breger, Dwayne. Massachusetts Division of Energy Resources. Telephone interview. March 18, 2008.

Brown, A. et al., ed. (1998). Seminar on Recovery of Energy from Municipal and Industrial Waste through Combustion: Energy recovery through waste combustion. New York: Elsevier Applied Science.

Brunner, Calvin R. (1996). Incineration Systems Handbook. Reston: Incinerator Consultants Inc.

California Green Chemistry Initiative. April to December 2007. CA Dept. of Toxic Substances Control. February 26, 2008 <http://www.dtsc.ca.gov/PollutionPrevention/GreenChemistryInitiative/index.cfm>.

California Public Utilities Commission. "Energy Division Resolution E-4137." February 14, 2008. California Public Utilities Commission. April 6, 2008 <http://docs.cpuc.ca.gov/Published/Agenda_resolution/78711.htm>.

Carpenter, T.G., ed. (2001). Environment, construction and sustainable development. Vol. 2. New York: Wiley.

Cheremisinoff, Nicholas P. (2003). Handbook of solid waste management and waste minimization technologies. Boston: Butterworth-Heinemann.

Colman, James C. "Memorandum: BACT Guidance for Biomass Projects." April 2007. MA DEP. February 24, 2008 <http://www.mass.gov/dep/air/laws/biombact.pdf>.

Conaboy, Chelsea. "New recycling center could save trash fees: Co-op mulls option to offset expenses." January 18, 2008. Concord Monitor. January 18, 2008 <http://www.concordmonitor.com/apps/pbcs.dll/article?AID=/20080118/FRONTPAGE/801180361>.

Concerned Citizens of Russell. "Final Comments on Proposed Revisions to the Regulations for the Massachusetts Renewable Energy Portfolio Standard, 225 CMR 14.00." July 17, 2006. MA DOER. February 24, 2008 <http://www.mass.gov/doer/rps/rps_regev_fcomments_jc.pdf>.

US Congress (House). "H.R. 274 Solid Waste Interstate Transportation Act of 2007." January 5, 2007. Thomas: Library of Congress. March 30, 2008 <http://thomas.loc.gov/cgi-bin/query/z?c110:H.R.274:>.

State of Connecticut Department of Environmental Protection. (2006). State Solid Waste Management Plan. State of Connecticut.

Daniels, Tom, and Katherine Daniels. (2003). The Environmental Planning Handbook: for Sustainable Communities and Regions. Washington: APA.

Davis, Bill. President, Ze-Gen. Telephone interview. March 14, 2008.

Denison, Richard. (1996). "Environmental Life-cycle comparison of recycling, landfilling, and incineration: A review of recent studies." Annu. Rev. Energy Environ. 21, 191–237.

Denison, Richard A., and John Ruston. (1990). Recycling and Incineration: Evaluating the Choices. Washington: Island Press.

Deriziotis, Panagiotis G. "Substance and Perceptions of Environmental Impacts of Dioxin Emissions." Masters Thesis. Columbia University. 2004. Waste-to-Energy Research and Technology Council. February 27, 2008 <http://www.seas.columbia.edu/earth/wtert/sofos/Deriziotis_thesis_final.pdf>.

Dryzek, John S. (1997). The Politics of the Earth: Environmental Discourses. New York: Oxford.

Dubester, Laura. Co-director, Center for Ecological Technology. Telephone interview. March, 18. 2008.

Ehrlich, David. "Waste to energy shows potential." October 19, 2007. Cleantech.com. April 6, 2008 <http://media.cleantech.com/1953/waste-to-energy-comes-of-age>.

- - - . "Who's lining up for California's feed-in tariffs?" February 20, 2008. Cleantech.com. April 6, 2008 <http://media.cleantech.com/2483/whos-lining-up-for-californias-feed-in-tariffs>.

Eleftheriou, Polyvios. (2007). "Energy from waste: a possible alternative energy source for large size municipalities." Waste Management Research 25, 483–486.

Energy Information Administration. Methodology for Allocating Municipal Solid Waste to Biogenic and Non-biogenic Energy. May 2007. Energy Information Administration February. 24, 2008 <http://www.eia.doe.gov/cneaf/solar.renewables/page/mswaste/msw.pdf>.

Dept. for Environment, Food, and Rural Affairs. "Waste Strategy for England 2007." May 2007. Dept. for Environment, Food, and Rural Affairs. February 24, 2008 < http://www.defra.gov.uk/ENVIRONMENT/waste/strategy/strategy07/pdf/waste07-strategy.pdf>.

U.S. Environmental Protection Agency. (2006). Clean Energy-Environment Guide to Action: Policies, Best Practices, and Action Steps for States. US EPA.

- - - . "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2005." October 2006. U.S. EPA. February 24, 2008 <http://www.epa.gov/epaoswer/osw/conserve/resources/msw-2005.pdf>.

- - - . Solid Waste Management and Greenhouse Gases. September 2006. US EPA. February 24, 2008 <http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html >.

Fickes, Michael. (2007, August). "Power Up: The movement to reduce dependence on fossil fuels may put a charge in the waste-to-energy industry." Waste Age. 28–33.

- - - . "Still Plugged In." (2005, March). Waste Age. 36–41.

Jackson, Danielle. (2002, August). "MACT Regulations Help Cleanup WTE." Waste Age: 8+.

Fischer, John. Massachusetts Department of Environmental Protection. Telephone interview. March 21, 2008.

Friedemann, Alice. "Peak Soil: Why cellulosic ethanol, biofuels are unsustainable and a threat to America." April 10, 2007. Culture Change. February 24, 2008 <http://www.culturechange.org/cms/index.php?option=com_content&task=view&id=107&Itemid=1>.

Friends of the Earth. "Pyrolysis and Gasification." October 2002. Friends of the Earth. February 24, 2008 <http://www.foe.co.uk/resource/briefings/gasification_pyrolysis.pdf>.

- - - . "Anaerobic Digestion." September 2007. Friends of the Earth. April 16, 2008 <http://www.foe.co.uk/resource/briefings/anaerobic_digestion.pdf>.

Garcia, Natalie. "Recycling facility can handle more material." February 27, 2008. Providence Journal. February 29, 2008 <http://www.projo.com/news/content/senate_dump_tour_02-27-08_PM95D61_v14.3724bb0.html#>.

Geiselman, Bruce. (2007, October). "Peak Demand: Climate Worries, Economics Drive WTE Plant Expansions." Waste News. 1+.

Global Alliance for Incinerator Alternatives. "Gasification, Pyrolysis, and Plasma Incineration." April 2006. Global Alliance for Incinerator Alternatives. February 24, 2008 <http://www.no-burn.org/resources/library/Factsheet_IncinInDisguise_Apr2006.pdf>.

Gohlke, Oliver, and Johannes Martin. (2007). "Drivers for innovation in waste-to-energy technology." Waste Management Research 25, 214–219.

Greenaction for Health and Environmental Justice, and Global Alliance for Incinerator Alternatives. "Incinerators in Disguise." April 2006. Global Alliance for Incinerator Alternatives. February 24, 2008 <http://www.no-burn.org/resources/library/Incinerators_In_Disguise_CaseStudies.pdf>.

Healthcare without Harm. "Update on Pyrolysis – A Non-traditional Thermal Treatment Technology." Healthcare without Harm. February 24, 2008 <http://www.noharm.org/library/docs/Update_on_Pyrolysis.pdf>.

Horinko, Marianne Lamont, and Jeffery R. Holmstead. "EPA Letter to IWSA President." February 14, 2003. Integrated Waste Services Association. February 24, 2008 <http://www.wte.org/docs/epaletter.pdf>.

Hughes v. Alexandria Scrap. (1976). 426 U.S. 794.

Institute for Local Self Reliance. February 8, 1991. "Trashing Transport: Strategies to Ban Imported Garbage." Institute for Local Self Reliance. May 2, 2008 <http://www.ilsr.org/recycling/FTAO_17-TrashingTransport.pdf>.

Integrated Waste Services Association. "Fact Sheet: Waste-to-Energy: A Renewable Energy Source." Integrated Waste Services Association. February 24, 2008 <http://www.wte.org/docs/FactSheetRenew.pdf>.

- - - . "Fact Sheet: Waste-to-Energy and the Production Tax Credit." Integrated Waste Services Association. February 24, 2008 <http://www.wte.org/docs/FactSheetPTC.pdf>.

Internal Revenue Service. "Revenue Notice 2006-88." October 16, 2006. Internal Revenue Service. February 24, 2008. <http://www.irs.gov/irb/2006-42_IRB/ar07.html>.

- - - . "Revenue Procedure 2007-65." October 19, 2007. Internal Revenue Service. February 24, 2008 <http://www.irs.gov/pub/irs-drop/rp-07-65.pdf>.

ISO NE. "New England Electricity Scenario Analysis." August 2, 2007. ISO NE. April 19, 2008 <http://www.iso-ne.com/committees/comm_wkgrps/othr/sas/mtrls/elec_report/scenario_analysis_final.pdf>.

- - - . "2008 CELT Report Workbook." April 28, 2008. ISO NE. May 6, 2008 <http://www.iso-ne.com/trans/celt/report/index.html>.

Jeffery, Patrick. Public Affairs Manager, Wheelabrator Technologies, Inc. Telephone interview. March 5, 2008.

Kaplan, Seth, Susan Reid, and Shanna Vale. Attorneys, Conservation Law Foundation. Personal interview. March 3, 2008.

Kelleher, Maria. "Anaerobic Digestion Outlook for MSW Streams." August 2007. BioCycle. April 8, 2008 <http://www.jgpress.com/archives/_free/001406.html>.

Kingsley, Eric. Vice President, Innovative Natural Resource Solutions. Telephone interview. March 5, 2008.

Kiser, Jonathan V.L. "Recycling and WTE." May/June 2003. MSW Management. February 24, 2008 <http://www.erosioncontrol.com/mw_0305_recycling.html>.

Klein, Alexander. "Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes." Masters Thesis. Columbia University. 2002. Waste-to-Energy Research and Technology Council. February 27, 2008 <http://www.seas.columbia.edu/earth/wtert/sofos/klein_thesis.pdf>.

Kolaitis, D. et al. (2004). "Development of a Decision Support Tool for Sustainability Assessment of Energy Recovery Systems using RDF." New and renewable energy technologies for sustainable development: proceedings of the Conference on New and Renewable Energy Technologies for Sustainable Development, 24–26 June 2002, Ponta Delgada, Azores, Portugal. Ed. Afgan, Naim Hamdia, and Maria da Graça Carvalho. Exton: A.A. Balkema, 55–65.

Landy, Michael P. (1998). "Options for the Recovery of Energy in Municipal Solid Waste." Seminar on Recovery of Energy from Municipal and Industrial Waste through Combustion: Energy recovery through waste combustion. Ed. Brown, A. et al. New York: Elsevier Applied Science, 194–203.

Last, Steve. "The Magic of Combined Anaerobic Digestion with Composting of Municipal Solid Waste." 2006. Guilford Anti-Incinerator Network (GAIN). April 8, 2008 <http://www.no-incinerator.org.uk/Advantages_of_Combined_Digestion_and_Composting.pdf>.

LeFrancois v. Rhode Island. (D.R.I. 1987). 699 F. Supp. 1217.

Longdena, David, et al. (2007). "Distributed or centralised energy-from-waste policy? Implications of technology and scale at municipal level." Energy Policy 35, 2622–2634.

Maine State Planning Office. (2007, March). Solid Waste Disposal Capacity Report. Executive Office, State Planning Office.

Makhijani, Arjun. (2007). Carbon-free and Nuclear-free: A Roadmap for U.S. Energy Policy. IEER Press, Tacoma Park: IEER Press; Muskegon: RDR Books.

Massachusetts DEP. (2000, December). Beyond 2000 Solid Waste Master Plan – A Policy Framework. Executive Office of Environmental Affairs.

- - - . Solid Waste Master Plan: 2006 Revision. (2006, June). Executive Office of Environmental Affairs.

- - - . "Active Combustion Facilities." September 2007. MA DEP. April 19, 2008 <http://www.mass.gov/dep/recycle/actcf.pdf>.

McCarthy, James E. "RS20106: Interstate Waste Transport: Legislative Issues." June 16, 1999. National Council for Science and the Environment. March 30, 2008 <http://www.ncseonline.org/nle/crsreports/waste/waste-29.cfm>.

McLean, Dan. "Nonprofit to turn gas into energy." April 13, 2008. Burlington Free Press. April 14, 2008 <http://www.burlingtonfreepress.com/apps/pbcs.dll/article?AID=/20080413/BUSINESS/804130301/1003/NEWS05>.

Melosi, Martin V. (2005). Garbage in the Cities: Refuse, Reform, and the Environment. Rev. Ed. Pittsburg: University of Pitt. Press.

Mickey, David. "Green-e Renewable Energy Certification Program, 2nd Electronic Ballot Program, Blue Ridge Environmental Defense League Comments." October 2005. Blue Ridge Environmental Defense League. February 24, 2008 <http://www.bredl.org/pdf/BREDL_Green-e_Ballot101905.pdf>.

Miranda, Marie Lynn, and Brack Hale. (1997). "Waste not, want not: the private and social costs of waste-to-energy production." Energy Policy 25.6, 587–600.

Moy, Pearl. "A Health Risk Comparison of Landfill Disposal and Waste-to-Energy (WTE) Treatment of Municipal Solid Wastes in New York City (NYC)." Masters Thesis. Columbia University. 2005. Waste-to-Energy Research and Technology Council. February 27, 2008 <http://www.seas.columbia.edu/earth/wtert/sofos/Moy_ms_thesis.pdf>.

New Hampshire Dept. Environmental Services. (2006, September). Solid Waste Report to the Legislature 2005. New Hampshire Department of Environmental Services.

NEWMOA. "Interstate Coordination and Cooperation – A Formula for Success: NEWMOA 2005 Annual Report." 2005. Northeast Waste Management Officials' Association. March 30, 2008 <http://www.newmoa.org/publications/Annual05.pdf>.

Niessen, Walter R. (2002). Combustion and incineration processes. 3rd ed. New York: Marcel Dekker.

Nickolas J. Thermelis, Young Hwan Kim and Mark H. Brady. (2002). "Energy recovery from New York City municipal solid wastes." Waste Management Research 20, 223–233.

NYC EDC and Dept. of Sanitation. "Evaluation of New and Emerging Solid Waste Management Technologies." September 16, 2004. NYC.gov. February 24, 2008 <http://www.nyc.gov/html/dsny/downloads/pdf/pubnrpts/swmp-4oct/appendix-f.pdf>.

O'Connell, Kim. (2003, January). "Getting a Grip: It's a Grab Bag of Issues in 2003." Waste Age. 34–37.

Ostrem, Karena. "Greening Waste: Anaerobic Digestion for Treating the Organic Fraction of Municipal Solid Wastes." Masters Thesis. Columbia University. 2004. Waste-to-Energy Research and Technology Council. February 27, 2008 <http://www.seas.columbia.edu/earth/wtert/sofos/Ostrem_Thesis_final.pdf>.

Ostrem, Karena M., et al. "Combining Anaerobic Digestion and Waste-To-Energy." 2004. Waste-to-Energy Research and Technology Council. April 8, 2008 <http://www.seas.columbia.edu/earth/wtert/sofos/ostrem-millrath-themelis_nawtec12_2004.pdf>.

Palmer, Paul. "The Death of Recycling." Rachel's Democracy & Health News. 90 (2007). February 24, 2008 <http://www.precaution.org/lib/07/ht070329.htm#The_Death_of_Recycling>.

Petts, J. (1994). "Incineration as a waste management option." Waste Incineration and the Environment. Ed. Hester, R.E. and R.M. Harrison. Royal Society of Chemistry, 1–25.

Pichtel, John. (2005). Waste Management Practices: Municipal, Hazardous, and Industrial. Boca Raton: CRC Press.

Page, Candace. "Reprieve for composting in Chittenden County." March 14, 2008. Burlington Free Press. March 14, 2008 <http://www.burlingtonfreepress.com/apps/pbcs.dll/article?AID=/20080314/NEWS01/803140311/1009>.

Platt, Brenda. "Resources up in Flames." April 2004. Global Alliance for Incinerator Alternatives. February 24, 2008 <http://www.no-burn.org/resources/library/RuiF.pdf>.

Porter, Louis. "Commercial composting? It's a hot topic for lawmakers to figure out." Feb 27, 2008. Times Argus. February 29, 2008 <http://www.timesargus.com/apps/pbcs.dll/article?AID=/20080227/NEWS/353810657/1002/NEWS01>.

Porteous, A. (2000). "MSW Energy Recovery – A Comparison between Mass Burn Incineration and Gasification Options." Power generation by renewables: organized by the Energy Transfer and Thermofluid Mechanics Group of The Institution of Mechanical Engineers (IMechE); co-sponsored by the Power Industry Division. Bury St. Edmunds: Professional Engineering Pub., 113–130.

Prosper, Terrie. "CPUC Approves Feed-in Tariffs to Support Development of Onsite Renewable Generation." February 14, 2008. California Public Utilities Commission. April 6, 2008 <http://docs.cpuc.ca.gov/PUBLISHED/NEWS_RELEASE/78824.htm>.

Rhode Island Department of Environmental Management. (2005, May). Rhode Island Comprehensive Solid Waste Management Plan (DRAFT). RI Dept. of Environmental Management.

Rickerson, Wilson, and Robert Grace. "The Debate over Fixed Price Incentives for Renewable Electricity in Europe and the United States: Fallout and Future Directions." February 2007. Heinrich Boll Foundation. February 24, 2008 <http://www.boell.org/docs/Rickerson_Grace_FINAL.pdf>.

Ring, Dan. "Trash turns to cash for communities." March 2, 2008. Masslive.com. March 3, 2008 <http://www.masslive.com/news/index.ssf/2008/03/trash_turns_to_cash_for_commun.html>.

Ryan, Andrew. "Urban decay, redefined: City hopes to turn yard clippings and food scraps into heat, electricity." February 26, 2008. Boston.com. February 26, 2008 <http://www.boston.com/news/local/articles/2008/02/26/urban_decay_redefined>.

Schlissel, David. "The Risks of Participating in the AMPGS Coal Plant." February 13, 2008. National Resources Defense Council. February 26, 2008 <http://docs.nrdc.org/globalwarming/glo_08021401A.pdf>.

Schubert, Jim. "Gasification/Cogeneration Using MSW Residuals and Biomass." April 2006. SWANA BC Pacific Chapter. February 24, 2008 <http://www.swanabc.org/PDF/Library/2006%20Northwest%20Symposium/Gasification-Cogeneration%20Using%20MSW%20Residuals%20and%20Biomass.doc>.

Schuren, Alyssa. Executive Director, Toxics Action Center. Telephone interview. March 21, 2008.

Shanoff, Barry S. “Commerce ‘Claws’ Grips Government.” 2001. MSW Management. March 30, 2008 <http://www.gradingandexcavation.com/msw_0011_commerce.html>.

Siemons, Roland V. (2002). “Viewpoint: How European waste will contribute to renewable energy.” Energy Policy 30, 471–475.

Skala, Z. et al. (2004). “Biomass and Waste Gasification in AFB Reactor.” New and renewable energy technologies for sustainable development: proceedings of the Conference on New and Renewable Energy Technologies for Sustainable Development, 24–26 June 2002, Ponta Delgada, Azores, Portugal. Ed. Afgan, Naim Hamdia, and Maria da Graça Carvalho. Exton: A.A. Balkema, 229–241.

Solid Waste Association of North America. “Pushing the Envelope on Waste Reduction and Recovery.” January 30, 2003. The Solid Waste Association of North America. February 24, 2008 <http://www.swana.org/pdf/swana_pdf_224.pdf>.

- - - . “SWANA’s Position on Municipal Solid Waste as Renewable Energy.” May 18, 2007. Association of Indiana Solid Waste Management Districts, Inc. February 24, 2008 <http://www.aiswmd.org/SWANA%20Policy%20on%20Renewable%20Energy%20from%20MSW.pdf>.

Stateside Associates. “Interstate Shipment of Municipal Solid Waste.” July 30, 1999. Stateside Associates Issue Management Services. March 30, 2008 <http://www.stateside.com/management/specialty/ehsarticles/interstate.shtml>.

Steverson, E.M. (1994). “The US approach to incinerator regulation.” Waste Incineration and the Environment. Ed. Hester, R.E. and R.M. Harrison. Royal Society of Chemistry, 113–135.

Tammemagi, Hans. (1999). The Waste Crisis: Landfills, Incinerators, and the Search for a Sustainable Future. New York: Oxford University Press.

Tester, Jefferson W. et al. (2005). Sustainable Energy: Choosing Among Options. Cambridge: MIT Press.

Tchobanoglous, George, and Frank Kreith. (2002). Handbook of Solid Waste Management, 2nd ed. New York: McGraw-Hill.

Union of Concerned Scientists. Principles for Bioenergy Development. April 23, 2007. Union of Concerned Scientists February 24, 2008 <http://www.ucsusa.org/assets/documents/clean_energy/UCS-Bioenergy-Principles.pdf>.

Ursery, Stephen. (2005, September). “Extension Granted.” Waste Age. 4+.

Vermont Dept. of Environmental Conservation. (2006, October). Revised Solid Waste Management Plan. Agency of Natural Resource, VT DEC.

Williams, John F. "WTE 25 Years Later." September/October 2004. MSW Management. February 24, 2008 <http://www.mswmanagement.com/mw_0409_wte.html>.

Williams, Paul T. Waste Treatment and Disposal. (2005). 2nd Ed. West Sussex, England: Wiley.

Wynar, Michael. "Time running out at Wayland's landfill." March 2, 2008. The MetroWest Daily News. March 3, 2008 <http://www.metrowestdailynews.com/news/x1036310471>.

Websites Consulted

- Blue Ridge Environmental Defense League (BREDL) http://www.bredl.org/
- Concord Steam http://www.concordsteam.com/index.html
- Deer Island Sewage Treatment Plant http://www.mwra.state.ma.us/03sewer/html/sewditp.htm
- Eco-Cycle http://www.ecocycle.org/
- Energy Information Administration http://www.eia.doe.gov/
- EPA Landfill Methane Outreach Program http://www.epa.gov/lmop/proj/index.htm
- EPA Municipal Solid Waste http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm
- Database of State Incentives for Renewables and Efficiency http://www.dsireusa.org/index.cfm?EE=0&RE=1
- Global Alliance for Incinerator Alternatives (GAIA) http://www.no-burn.org/
- Grassroots Recycling Network (GNNR) http://www.grrn.org/
- Integrated Waste Services Association http://www.wte.org/environment/
- MA DOER: MA RPS Rulemaking Final Comments Page http://www.mass.gov/doer/rps/rps_regrev_final_comments.htm
- MTC Bioenergy Technologies http://www.masstech.org/cleanenergy/biomass/technology.htm
- MTC Waste-to-energy Grant Program http://www.mtpc.org/renewableenergy/wtoe.htm
- Northeast Regional Biomass Program http://www.nrbp.org/
- NREL Biomass Energy Basics http://www.nrel.gov/learning/re_biomass.html
- NREL Renewable Energy for Farmers and Ranchers http://www.nrel.gov/learning/farmers_ranchers.html

- Solid Waste Association of North America http://www.swana.org/www/default.aspx

- Toxics Action Center http://www.toxicsaction.org

- Waste-to-Energy Research and Technology Council http://www.seas.columbia.edu/earth/wtert/

- Ze-Gen http://www.ze-gen.com/index.htm