THE FINANCIAL FEASIBILITY ANALYSIS OF MUNICIPAL SOLID WASTE TO ETHANOL CONVERSION

By

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ABSTRACT

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Lignocellulosic portion of municipal solid waste (MSW) is considered a potential feedstock for fuel ethanol production. I review the trends in MSW generation, composition and disposal practices, and evaluate the aggregate and regional potential of MSW as a feedstock. I present an overview of the current technology of MSW to ethanol conversion. An attractive feature of MSW-ethanol conversion is that the feedstock is available at a negative cost; i.e. disposal facilities charge tipping fees ranging from $15-$100/ton to accept MSW. I assess the financial feasibility of a typical MSW-ethanol plant with a capacity of 500 tons per day under a number of scenarios with respect to tipping fees, ethanol prices, capital costs, byproduct prices and ethanol tax incentives. I find the profitability to be robust across scenarios. I then discuss technical, economic, environmental and social barriers that inhibit commercialization.

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ABBRIVIATION

ADM (Archer Daniels Midland)
AEO2000 (Annual Energy Outlook 2000)
ARI (Alternative Resource, Inc.)
BDT (Bone-dry ton)
BGY (Billion gallons per year)
CAAA90 (The Clean Air Act Amendments of 1990)
CFDC (Clean Fuel Development Coalition)
CG (Conventional gasoline)
CNG (Compressed natural gas)
CO (Carbon monoxide)
CO_2 (Carbon dioxide)
Cu.Yd. (Cubic yard)
C/D (Construction and Demolition)
DAI (Downstream Alternative, Inc.)
DOE (Department of Energy)
EBITDA (earning before interest, tax, depreciation and amortization)
EIA (Energy Information Administration)
EPA (Environmental Protection Agency)
GAO (General Accounting Office)
GPV (Gravity Pressure Vessel)
GSA (General Service Administration)
IRR (Internal rate of return)
LNG (Liquefied natural gas)
LPG (Liquefied petroleum Gases)
MGY (Million gallons per year)
MRF (Material recovery facility)
MSW (Municipal solid Waste)
MT (Metric ton)
MTBE (Methyl tertiary butyl ether)
NAAQS (the National Ambient Air Quality Standard)
NESCAUM (Northeastern States for Coordinated Air Use Management)
NOx (Nitrogen oxide)
NPV (Net present value)
NREL (National Renewable Energy Laboratory)
N/A (No data is available)
OLS (Ordinary least square)
PADD (Petroleum Administration of Defense District)
PMO (Pencor-Masada OxyNol)
PPI (Producer Price Index)
RCRA (Resource Recovery Act)

RFA (Renewable Fuel Association)
RFG (Reformulated gasoline)
SSCF (Simultaneous saccharification and co-fermentation)
SWM (Solid waste management)
TS (Transfer station)
TPD (Tons per day)
TVA (Tennessee Valley Authority)
USDA (U.S. Department of Agriculture)
WRBEP (Western Regional Biomass Energy Program)
WTE (Waste-to-energy facility)

CHAPTER I

INTRODUCTION

1.1 Problem Statement

Ethanol blended gasoline is currently used as a cleaner burning automobile fuel in the United States. The Clean Air Act Amendments of 1990 (CAA90) mandated the use of reformulated or oxygenated gasoline in many urban areas in the United States. While ethanol and methyl tertiary butyl ether (MTBE) have been the two most common oxygenates, MTBE is more widely used due to relatively lower production cost. Moreover, ethanol is mostly produced in the Corn Belt Area of the Midwest, far from the major gasoline consumption urban centers. The critical shortcoming of ethanol is that it cannot be transported through pipelines. Hence, high transportation costs prevent increasing consumption of ethanol on the East and West coasts.

In a recent turn, however, MTBE is now seen as a suspected carcinogen that moves quickly through bedrock into underground water supply, giving it taints the water and has a distinct odor (Broder *et al*. 2001; U.S. EPA 2004a). For this reason, 14 States have banned the use of MTBE in transportation fuels. MTBE was to be phased out in California beginning in 2003 (Dipardo 2002; RFA 2001a; GAO 2002). However, the state government announced the decision to delay the ban until 2004, in part to keep California's consumer gasoline prices from skyrocketing, and also to protect the state from facing another energy crisis. This phase out leaves ethanol as the leading candidate to replace MTBE. Taking the issues associated with national security and the balance of trade deficit of oil from the Middle East into consideration, demand is projected to increase steadily over the next two decades (EIA 2004a; California Energy Commission 2001a; Hutzler 2003).

Most of the projected increase in ethanol demand in the short run is likely to be met by corn-based ethanol, produced in the Midwest. However, current technology allows cellulose contained in various kinds of biomass to be converted to ethanol. Significant amounts of cellulosic biomass, in the form of paper and paper products, is currently disposed in landfills or burned. Given this, in order to meet projected increase in ethanol demand, a good deal of attention is now being paid to biomass to support the corn-based ethanol. In other words, we can make use of this cheap abundant waste as an input for ethanol production.

Biomass wastes that can be converted to ethanol include agricultural residues (e.g., rice straw or sugar cane bagasse), forestry residues, and biomass components in municipal solid waste (MSW). The benefit gained by ethanol is not limited to an increase in ethanol production. MSW-ethanol conversion can be an alternative waste disposal process. In both industrialized and developing countries, MSW has been buried on land, or burned, as the final disposal process. Both methods have significant environmental impacts through air, water, and ground pollution. Although the U.S. has much more abundant landfill space, land scarcity is observed in populated urban areas. Because approximately 90% of MSW could be reused by available technology (GeneSyst 2004; Masada 2004), MSW-to-ethanol conversion would be a promising approach to reducing the material in landfills and to extend landfill life.

A few previous studies have analyzed the costs and benefits of biomass-to-ethanol conversion. Several private and public organizations have surveyed regional biomass availability and feasibility of ethanol production. For example, the California Energy Commission estimates the potential statewide ethanol production from available biomass, including MSW, in California (2001b). Motivation of the study is largely a result of the impending ban of MTBE. The state of Hawaii (1994) began researching biomass availability and the technological feasibility of biomass-ethanol conversion at an early date in an effort to reduce heavy dependence on oil imports. BBI International (2003) estimated the potential economic impact of biomass-ethanol production, such as employment impact in Hawaii. Mann and Bryan (2001) also addressed the feasibility of producing ethanol from various kinds of biomass available in northeastern North Dakota and northwestern Minnesota as a part of the Western Regional Biomass Energy Program (WRBEP).

However, the vast majority of these previous studies focused on agricultural residues or dedicated energy crops expressly produced as an input for ethanol production. And only a few have analyzed MSW to ethanol conversion. This is largely because of the technological uncertainties and the limited data sources about the recycling market, conversion process, and possible benefit and costs related to this infant industry.

The Tennessee Valley Authority (TVA) initially conducted an economic analysis of a proposed MSW-ethanol plant in Muscle Shoals in Alabama between 1990 and 1992, and found that the profitability was not positively robust, but was economically feasible (Broder *et al*. 1993). However, since the time of TVA's analysis, technological efficiency of cellulose-ethanol conversion has dramatically improved. Fox *et al*. (1999) analyzed the feasibility of regional MSW based ethanol production in the city of Phoenix, in Maricopa County, Arizona, in the part of WRBEP with state-of-art technology using a gravity pressure vessel (GPV). However, estimates of plant economics were site-specific and they did not assess nation-wide potential for MSW-ethanol conversion.

Now the technology is ripe. In fact, three private firms, Pencor-Masada OxyNol (PMO) in the city of Middletown in Orange County, New York, GeneSyst International Inc. in the city of Canton in Stark County, Ohio, and Genahol-Arizona Inc. in the city of Phoenix in Maricopa County, Arizona, are planning to begin operation on a commercial scale in near future. Thus, this research, assessing financial feasibility of this infant industry, is timely.

1.2 Research Objective

The key to succeed in MSW-ethanol industry is “profitability.” This research is aimed to provide a comprehensive analysis of financial feasibility of MSW-ethanol production at a national scale with the current best available technology.

To begin with, sustainable input flow should be guaranteed to maintain business. To attack this question, the paper initially studies the trend of MSW generation, recycling, and landfilling in the U.S. Then, the paper determines not only aggregate MSW availability, but also the lignocellulosic composition in MSW that is convertible to ethanol. Equally important, regional MSW availability will be addressed. The paper identifies regions that can supply enough MSW for an ethanol plant to maintain business.

Second, the paper analyzes the financial feasibility of MSW-ethanol production. To carry out this analysis the potential yield of ethanol and a set of by-products per ton of MSW should be known. The next step is modeling a firm’s profit function by taking potential revenue sources and costs, related to production, into account. Timing of cash outflows and inflows is also important for a firm’s investment decision. Cash flow is estimated over the entire economic life of the plant. Next, the key economic parameters, which are significant in determining plant economics, are identified and the robustness of profitability is analyzed with respect to variations in these parameters. Last, technical, economic, political barriers that inhibit commercialization are discussed.

1.3 Thesis Outline

This thesis consists of five parts. Chapter II provides the overview of the current ethanol market. In the last section of Chapter II, the advantage of MSW-ethanol production over traditional corn-starch based production is summarized. Further discussion about how it can contribute to currently rapidly growing demand for ethanol is also included. Chapter III examines MSW biomass availability. Although there are substantial differences in terms of MSW composition by region and season, it provides an approximate range of MSW lignocellulosic compositions. Also, the distribution of MSW across the U.S. is presented. Chapter IV describes state-of-art technology and the operational steps of MSW-ethanol production. Moreover, it discusses the potential yield of ethanol and by-products based on the theory, laboratory-based and assumptions by the plants in the field. Chapter V, the core chapter of this thesis, analyzes profitability of ethanol conversion. Plant economics, the base case, are estimated based on the data by Titmas (2004), and sensitivity analysis is performed. Chapter VI is the concluding chapter that presents a summary of all research and suggests further research recommendations.

CHAPTER II

THE OVERVIEW OF ETHANOL MARKET

The purpose of this chapter is to provide an overview of the ethanol market. It is important to identify how MSW-ethanol producers can play as niche players in the clean fuel energy industry. The key issues to address this question are (1) the trend of national ethanol supply and demand, (2) the potential effect of a coming MTBE ban, (3) ethanol supply and demand across the U.S. region by region, (4) ethanol transportation problems, and (5) current ethanol market structure. The research results are presented in the above order. Finally, I provide a summary on how MSW based ethanol producers can contribute to the ethanol market.

2.1 Data

The main source for secondary data is from the Energy Information Administration (EIA) in the U.S. Department of Energy (DOE) and Renewable Fuel Association (RFA). These organizations estimate and report data on the United States' ethanol and MTBE production on a monthly and yearly basis. Furthermore, EIA provides data on national and regional ethanol consumption as oxygenate, and as an alternative fuel to conventional gasoline (CG).

2.2 U.S. Ethanol Supply

Ethanol use began to boom in the early 1970s, when oil supply disruptions in the Middle East affected U.S. national security. In addition, our growing concern for a clean environment became a driving force to eliminate lead (an octane booster) from gasoline. Lead is a cumulative toxin that builds up in soft tissue, such as kidneys, bone marrow, liver, brain bones, and teeth. Lead can be extremely damaging, especially for children, because it inhibits the body's oxygen and calcium transport and alters nerve transmission in the brain. Lead poisoning can cause mental retardation, impaired growth, and, at high doses, even death. The advent of the environmental movement in the 1970s hit the gasoline market when the U.S. Environmental Protection Agency (U.S. EPA) issued restrictions on the use of lead in fuel in 1978. Over the next ten years various levels of regulation resulted in a phase down of lead levels in gasoline. Ethanol and MTBE are the two common chemicals used to enhance gasoline's oxygen and octane content. Ethanol has been commonly used by blending it directly into gasoline in a mix of 10% ethanol and 90% gasoline, called “gasohol” or “E10” (DOE 2003).

Ethanol production in the U.S. increased considerably in two decades. While only 175 million gallons were produced in 1980, the ethanol supply has skyrocketed to approximately 2.6 billion gallons by 2003 (Figure 2.1). This success in the ethanol industry is attributed to CAA90, which mandating the use of oxygenated gasoline in certain geographical areas not meeting the National Ambient Air Quality Standard (NAAQS) for carbon monoxide (CO). The main source of CO emissions is the combustion engine. While many types of these engines are used in products such as lawnmowers, chain-saws, and other gasoline powered equipment, the primary source of ambient CO in most areas is motor vehicles.

Designed to increase combustion efficiency, oxygenated gasoline was viewed by the government as a practical way to help reduce CO emissions. Two programs have been implemented to achieve the goals under CAA90. The Oxygenated Fuel Program (Oxyfuel Program) is in effect only during fall and winter months in certain urban areas to reduce CO emissions. It has been a tremendous success, with the number of non-attainment areas decreasing by two-thirds since 1990, and areas continue to demonstrate attainment each year. The Reformulated Gasoline Program (RFG Program) requires the use of oxygenated fuel on a year-round basis in metropolitan areas with high levels of CO and ground-level ozone.

Ethanol is already used in Federal RFG in populated metropolitan areas such as Chicago and Milwaukee (Figure 2.2). The Oxyfuel Program requires a minimum oxygen content of 2.7% in non-attainment areas, and the RFG Program requires 2% oxygen content. The two most common ways of boosting oxygen levels to the required Oxyfuel levels are to add either 15% MTBE or 7.5% ethanol to gasoline (ethanol required to be blended into gasoline is as half of MTBE because ethanol has higher oxygen content than MTBE).

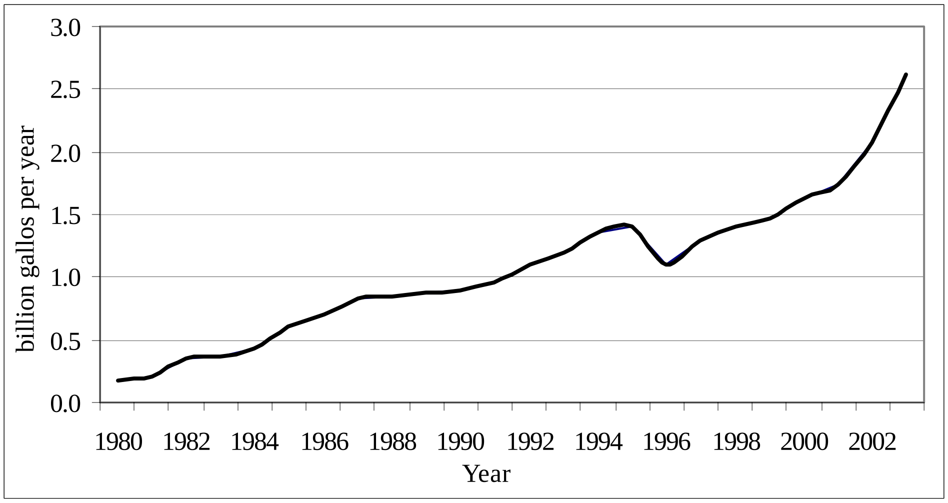

Figure 2.1 Trends of Domestic Ethanol Productions in the US
Source: 1980-2000 by RFA (2001a) and 2001-2003 by EIA (2004b)

Figure 2.2 RFG Program Areas
Source: U.S. EPA, 2004b

2.3 MTBE Ban

2.3.1 History of Ethanol and MTBE

Recently, MTBE has become quite controversial. Claims have been made that MTBE has caused widespread contamination of drinking water wells, which can result in adverse health effects, including cancer, to consumers of MTBE contaminated water. Concern over the use of MTBE in gasoline began to grow with the detection of the chemical at low levels in groundwater nationwide; especially when it was found in relatively high levels in some municipal water supply wells (U.S. EPA 2004a). High profile cases, such as the closure of the Santa Monica, California well field and contamination of the public wells in South Tahoe, California. brought national attention to this issue.

MTBE is more soluble in water than any other gasoline component. It is 30 times more soluble than benzene. When MTBE is released into the soil as a result of a spill or leak it may separate from the rest of the gasoline, lead the plume to the groundwater, and dissolve rapidly once there. MTBE travels at the same rate as groundwater and is therefore often the leading edge of any petroleum plume. This puts receptors at a greater risk of MTBE contamination when gasoline leaks occur. On the other hand, ethanol has high solubility but is biodegradable. Thus, it degrades into harmless byproducts before it reaches any potential receptor.

On March 25, 1999, Governor Gray Davis released Executive Order D-5-99, which ordered the removal of the additive MTBE from California gasoline at the earliest possible date, but no later than December 31, 2002. In addition to the State of California, sixteen other states also plan to phase out MTBE use at a state level (Table 2.1). On December 13, 1999, Chicago became the first city to ban MTBE when city council unanimously voted to ban the petroleum-based oxygenate (Ames 2001). As long as the Federal requirement for 2% oxygen in RFG continues in all states, ethanol (as a substitute good for MTBE) will replace MTBE. At the same time, these regulations initiated by those states created incentives to the ethanol industry to expand production in order to prepare for growing demand after the law is enacted. Figure 2.3 shows monthly ethanol and MTBE domestic production during 1997-2003. Obviously, ethanol production capacity rapidly grew while MTBE production diminished. Growth in 2002 was particularly remarkable in that ethanol production eventually exceeded MTBE production by 2003. The growth of ethanol is expected to increase steadily for at least another couple of decades (EIA 2004a; Hutzler 2003; DiPardo 2002; RFA 2001a; California Energy Commission 2001b).

While ethanol will take the place of MTBE, it has not yet been competitive with fossil fuel. Current ethanol producers are largely supported by government subsidies. The U.S. Congress passed the National Energy Act of 1978, which gave a Federal tax exemption for gasoline containing 10% ethanol. The Federal subsidy, now at $0.52 per gallon, allows the price of ethanol to remain close to the price of CG. However, if another alternative fuel is found to be more economically and environmentally efficient by technological development in future, the tax incentive programs above could expire. Congress is now debating an amendment to the Energy Bill in which MTBE will be completely eliminated from all gasoline in the United States. The amendment, which still must be part of the final Senate Energy Bill passed and signed by President Bush, would boost the use of renewable energy fuel including ethanol to five billion gallons by 2012 (Abbott 2003). Thus, the long-term ethanol production growth in the near future heavily depends on government policy.

Table 2.1 The MTBE Ban Schedule

State	MTBE Ban Schedule	MTBE Consumption (% of U.S. total)
California	MTBE started January 1, 2004 (Firstly announced to ban in December 31, 2002, but postponed)	31.7
Colorado	MTBE ban started April 30, 2002	0
Connecticut	MTBE ban started October 1, 2003	3.1
Illinois	MTBE prohibited by July 2004	0
Indiana	MTBE limited to 0.5% by volume, starting July 23, 2004	0
Iowa	0.5% MTBE by volume cap, already in effect	0
Kansas	MTBE limited to 0.5% by volume, starting July 1, 2004	0
Kentucky	MTBE ban starting January 1, 2006; beginning in January 1, 2004, ethanol encouraged to be used in place of MTBE	0.8
Maine	Law merely expresses state's "goal" to ban MTBE; it is not an actual ban. The "goal" is to phase out gasoline or fuel products treated with MTBE by January 1, 2003	0
Michigan	MTBE prohibited by June 1, 2003	0
Minnesota	All ethers (MTBE, ETBE, TAME) limited to 1/3 of 1.0% by weight after July 1, 2000; after July 1, 2005, total ether ban	0
Missouri	MTBE limited to 0.5% by volume, starting July 1, 2005	1.1
Nebraska	MTBE limited to 1.0% by volume, starting July 13, 2000	0
New York	MTBE ban started January 1, 2004	7.5
Ohio	MTBE ban starting July 1, 2005	0
South Dakota	0.5% MTBE by volume cap, already in effect	0
Washington	MTBE ban started December 31, 2003	0

Source: EIA, 2002a

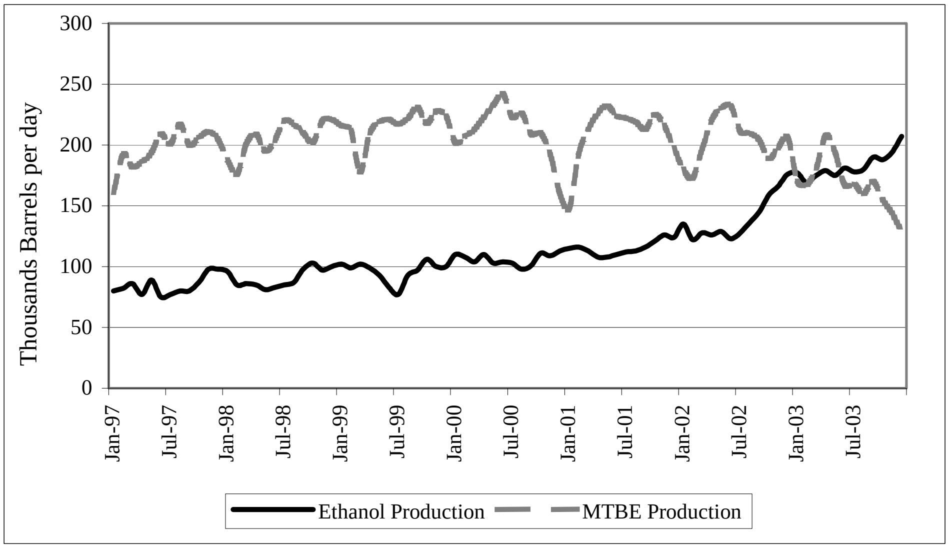

Figure 2.3 Monthly Ethanol and MTBE Production in 1997-2003 in the U.S.
Source: EIA, 2004b

2.3.2 Economic Advantage and Disadvantage of Ethanol over MTBE

One of the major disadvantages of ethanol over MTBE is that its production is sensitive to change in corn prices. In Figure 2.1, ethanol production substantially dropped in mid-1996. Figure 2.4 points out high corn prices in mid-1996. This was due to wet conditions resulting in small corn supply and higher corn prices. Unlike MTBE, which can be produced from a chemical reaction of methanol (derivative of natural gas) and isobutylene (an oil refinery product), corn based ethanol production is affected by weather conditions. Note that this is not the case with MSW biomass based ethanol production. Daily MSW biomass supply is not as sensitive to weather conditions as are agricultural products.

Although ethanol production is influenced by corn prices, the empirical analysis states the price of corn has very little to do with the price of ethanol (CFDC 2004). Ethanol prices are more highly correlated with the price of gasoline and gasoline blending components (Figure 2.5). Thus, low corn prices do not always indicate low ethanol prices, and high corn prices do not always indicate high ethanol prices. Holding the ethanol price constant, a low biomass price enhances the profitability of ethanol production. To put it another way, as the biomass price increases, profits by ethanol production diminish.

Figure 2.6 is the historical ratio of unleaded gasoline (proxy for the ethanol price) to corn price available. The horizontal straight line indicates the historical average price ratio. The corn based ethanol production is now well above this level. Although it is still uncertain that price of ethanol will be unchanged in the future because the price is maintained at a certain level by the Federal and State tax exemption program, the cost reduction by biomass-ethanol production is surely the key factor for the profitability of the ethanol industry in near term.

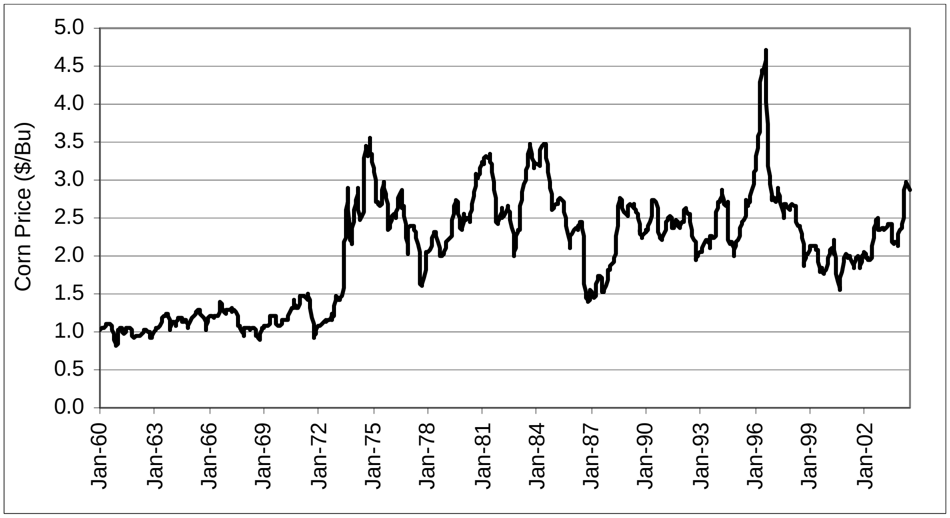

Figure 2.4 Monthly Average Corn Farm Price Received in Illinois
Source: Farmdoc, 2004

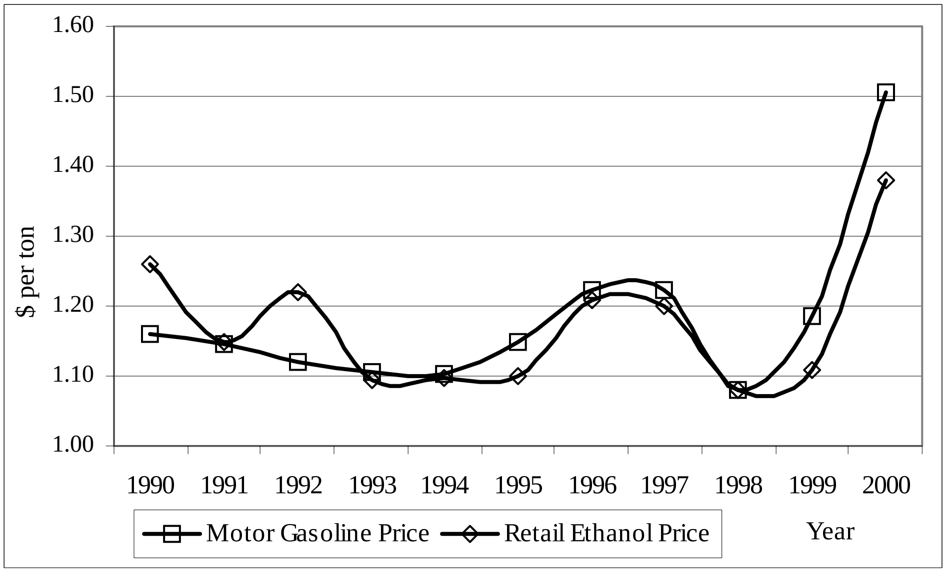

Figure 2.5 Trends of Gasoline Price and Retail Ethanol Price
Source: CFDC, 2004

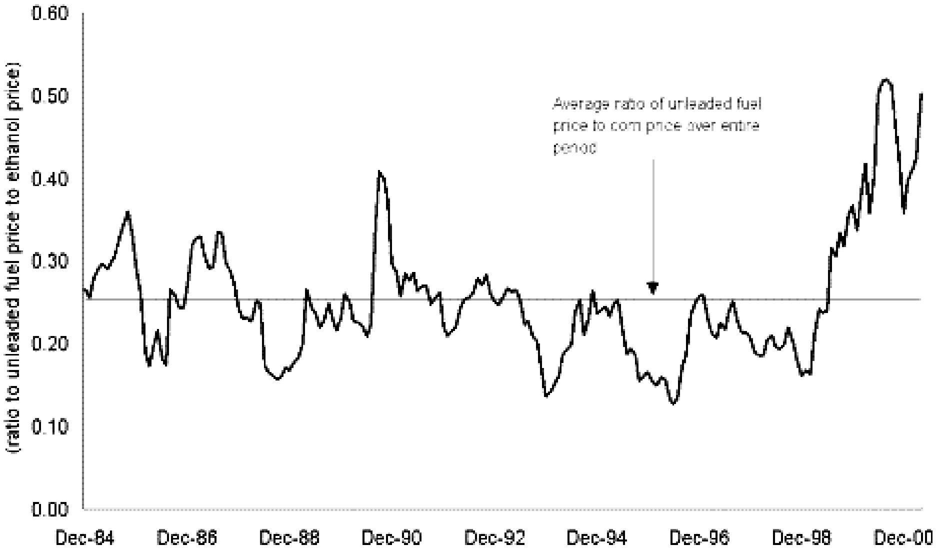

Figure 2.6 Trend of Ratio of Unleaded Fuel Price to Corn Price
Source: Missouri Value Added Development Center, 2001

2.4 U.S. Ethanol Consumption

2.4.1 Historical Ethanol Oxygenate Consumption

Figure 2.7 depicts the historical consumption of both ethanol and MTBE as oxygenate. Ethanol consumption has not changed much in a decade and was still less than half of MTBE consumption in 2002. However, after California begins banning all MTBE use as oxygenate, demand for two oxygenate fuels is expected to be changed, or will potentially even be reversed. According to the estimate of the U.S. General Accounting Office (GAO) and the U.S. Department of Transportation (Figure 2.8), an additional eight million gallons of ethanol will be needed to meet ethanol demand in California after the phase-out of MTBE.

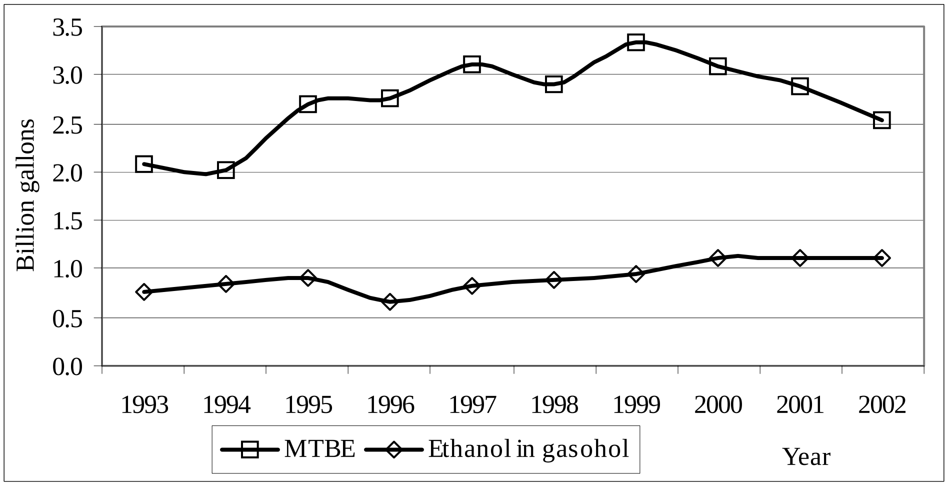

Figure 2.7 Historical Ethanol and MTBE consumption as an Oxygenates
Source: EIA, 2002b

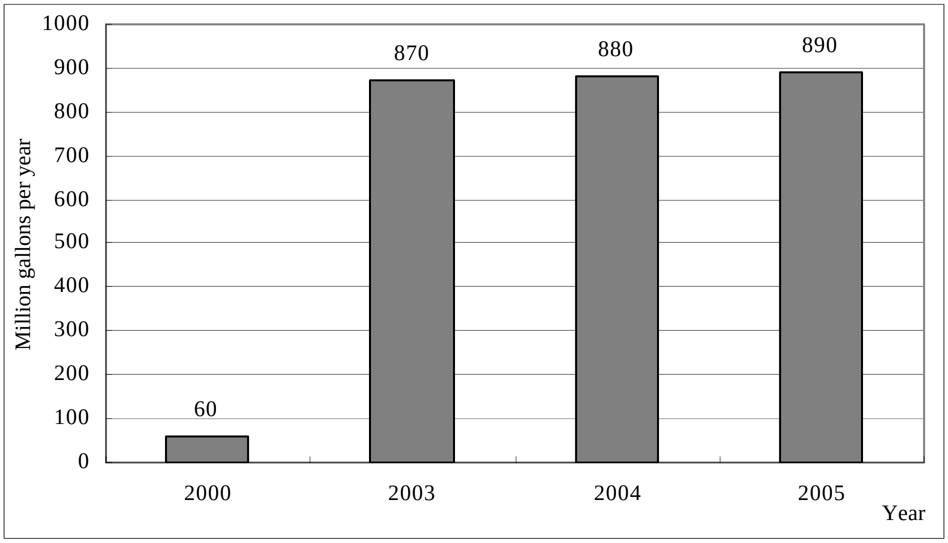

Figure 2.8 California Ethanol Consumption in 2000 and Projected Consumption in 2003-2005
Source: GAO, 2002

2.4.2 Historical Ethanol Consumption as Alternative Fuel

Ethanol is not only used as an oxygenate fuel, but also used as an alternative fuel. Oxygenate use of ethanol, such as E10, is a complement to petroleum, but higher blends, such as E85 (85%ethanol blending with 15% CG), is a substitute for the petroleum.

Currently, 394 million gallons of fuels are consumed as alternative fuels in the U.S. Fuels made of natural gas, such as liquefied petroleum gases (LPG), compressed natural gas (CNC) and liquefied natural gas (LNG) account for roughly 96% of total U.S. alternative fuel consumption. Natural gas is cheaper and more abundant non-renewable resource than oil. The U.S. natural gas reserves are expected to last at least 80 years. It is easier to process than oil, can be easily transported, produces less air pollution and burns hotter than any other fossil fuel.

However, natural gas has some environmental drawbacks. When it is processed it releases highly toxic hydrogen sulfide into the air and when it is transported, it could cause huge explosions. Also, the largest component of natural gas methane is more potent than carbon dioxide as a greenhouse gas. However, because of its abundance it is useful as a transition from nonrenewable to renewable energy sources.

Renewable alternative fuels include E85, E95 (95% ethanol), M85 (85% methanol), M100 (100% methanol). Ethanol as alternative fuel use is not as promising as blending use in the near term for a few reasons. First, most automobile engines do not allow the use of E85 fuel. Second, gas stations also do not allow the use of E85 fuel, so a new infrastructure would be needed to popularize it. Studies of the DOE and the General Service Administration (GSA) have shown that refueling stations need at least 200 steady customers for any single grade in order to make profitable use of the facilities. Though large numbers of flexible-fuel vehicles are being sold, they are spread out over the entire nation, and achieving a "critical mass" of 200 that use a single refueling station is still difficult to achieve (U.S. Department of Transportation 2002). Finally, a gallon of ethanol has only two-thirds the energy content of a gallon of gasoline (Hadder 1997). To be competitive with CG, further engine modifications are necessary in order to make up for low energy content.

Although there are some drawbacks to ethanol use as an alternative fuel, E85 is gradually gaining popularity. Figure 2.9 shows historical consumption of alternative fuels and Figure 2.10 indicates the number of vehicles using alternative fuels (renewable fuels and electricity). Noticeably, E85 is consumed more than methanol or electricity.

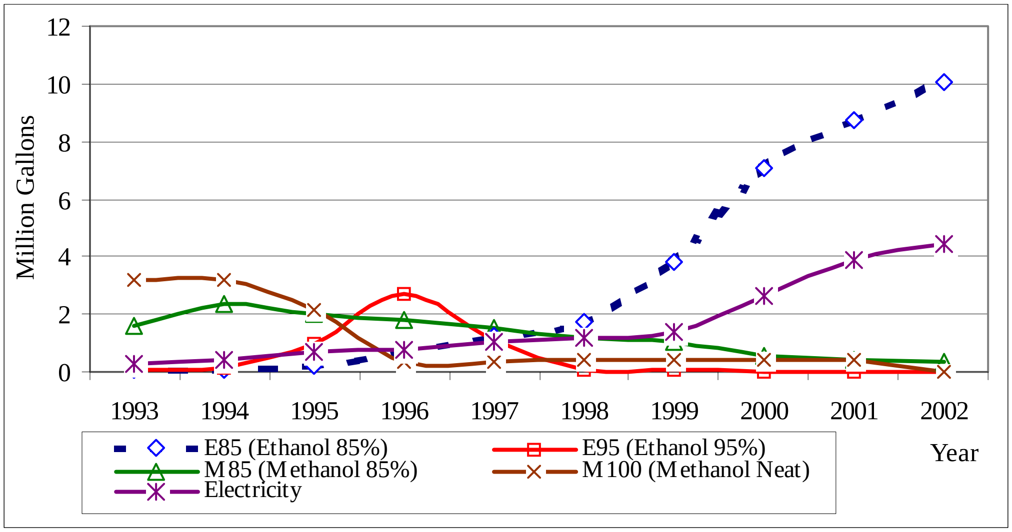

Figure 2.9 Trends of Alternative Fuel Consumption in the U.S.
Source: EIA, 2002b

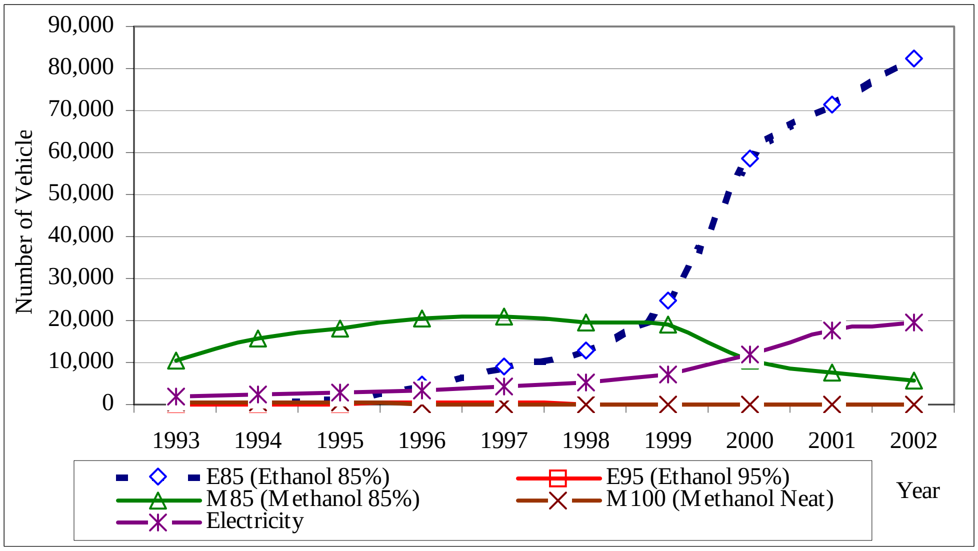

Figure 2.10 Trends of Number of Vehicle using Alternative Fuel in the U.S.
Source: EIA, 2002b

2.5 Regional Ethanol Production and Consumption

As mentioned earlier in this chapter, ethanol is now dominantly produced in the Corn Belt of the Midwest region.[1] Figure 2.11 plots ethanol plants on a U.S. map. This excessive concentration of the ethanol industry in one region results in heavy reliance on MTBE as an oxygenate fuel outside the Midwest area of the U.S. (Figure 2.6 and 2.7). Remarkably, about 75% of ethanol is solely consumed in Midwest areas, while other regions only account for 25% of total ethanol consumption. For MTBE consumption, Midwest consumption remains at the no more than 2%, and almost all is exclusively outside of the Midwest region. Thus, in reality, ethanol and MTBE are not competitive in the market, but divvy up the oxygenate fuel market share by region.

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[1] All States are divided into four regions (i.e., West, South, Midwest, Northeast) corresponding to the Census Region and Division of U.S. Bureau of the Census (2001). West is AK, AZ, CA, CO, HI, ID, MT, NM, NV, OR, WA, WY, South is AL, AR, DC, DE, FL, GA, KY, LA, MD, MS, NC, OK, SC, TN, TX, VA, WV, Midwest is IA, IL, IN, KS, MI, MN, MO, NE, ND, OH, SD, WI, and Northeast is CT, MA, ME, NH, NJ, NY, PA, RI, VT.

Table 2.2 summarizes the historical MTBE consumption in 17 states that plan to phase out their MTBE use as oxygenate fuel. It is apparent that only 5 out of 17 States will be affected by state regulation (i.e., California, New York, Connecticut, Kentucky, and Missouri). It is unlikely that other States will be seriously distressed by a MTBE ban because 9 out of 12 States are located in the Midwest. Nevertheless, the five states noted above consume 44.2% of total U.S. MTBE consumption. Especially California, the most automobile dependent state in the nation, which accounts for 32% of total U.S. MTBE consumption.

It is a conceivable eventuality that the states that have not yet announced a MTBE ban will shift to ethanol use to accommodate public opinion. If these states, especially heavily MTBE dependent states such as Texas and New Jersey, begin to phase-out MTBE use by regulation, the increase of ethanol demand will be further accelerated. Similar to California, there is a huge potential market for clean fuels in the Northeastern states (NESCAUM 1999). These states have such a small number of ethanol plants and would be driven by necessity to import ethanol from the Midwest in the near future to meet the boost in ethanol demand.

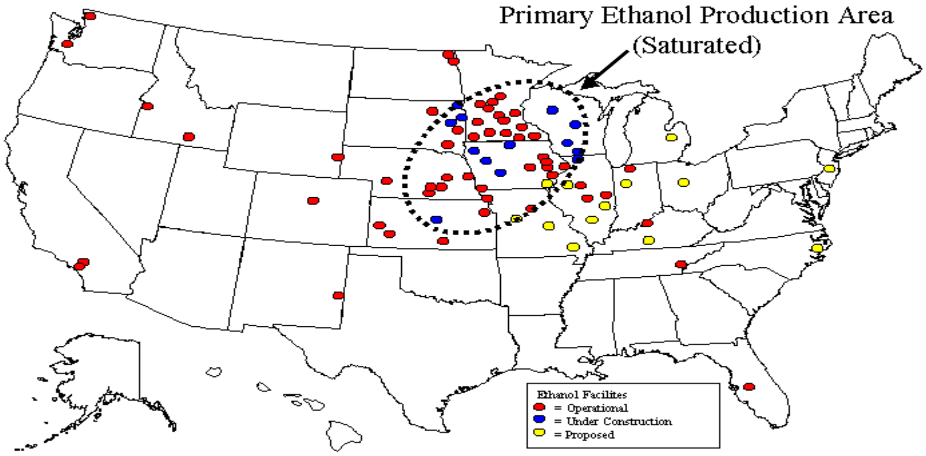

Figure 2.11 Map of Ethanol Plants in the U.S.
Source: Frazier, Barnes & Associates, LLC., 2004

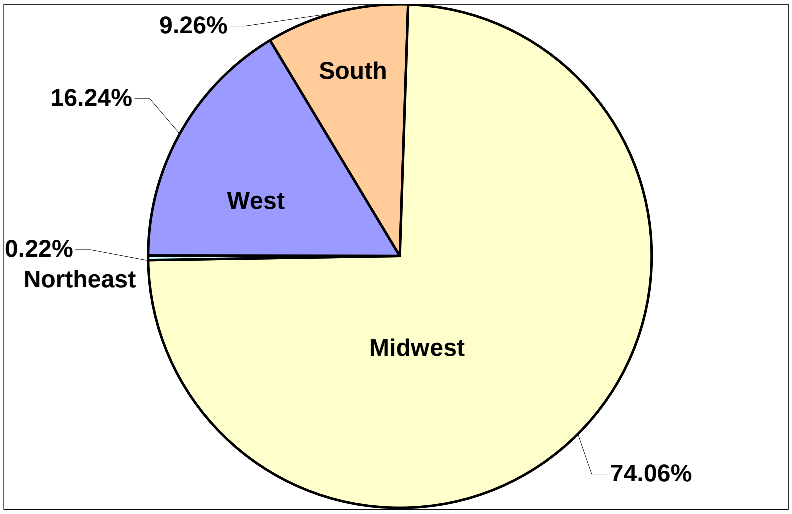

Figure 2.12 Ethanol Consumption by Region in 2000 in the U.S.
Source: EIA, 2003

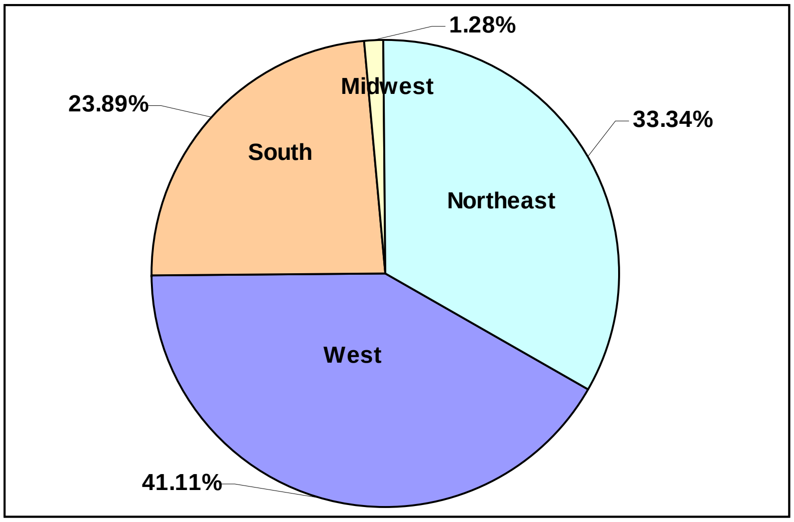

Figure 2.13 MTBE Consumption by Region in 2000 in the U.S.
Source: EIA, 2003

Table 2.2 Historical MTBE consumption in the U.S. (million gallons)

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
States Enacting MTBE Ban							
California	71.2	78.8	86.5	97.3	103.6	102.4	79.7
Connecticut	10.6	9.4	10.0	10.0	9.0	8.5	9.4
Kentucky	1.8	2.2	2.4	2.1	2.2	2.2	2.2
Missouri	0.0	0.0	0.0	0.0	2.3	3.3	3.2
New York	22.7	22.0	23.7	24.4	21.4	19.7	21.1
Illinois	3.2	1.0	0.9	0.4	0.0	0.0	0.0
Colorado	0.3	0.3	0.3	0.2	0.1	0.0	0.0
Indiana	0.4	0.1	0.1	0.1	0.0	0.0	0.0
Maine	3.7	3.7	3.7	3.7	0.8	0.0	0.0
Iowa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kansas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Michigan	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Minnesota	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nebraska	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ohio	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Dakota	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Washington	0.0	0.0	0.0	0.0	0.0	0.0	0.0
States Consuming MTBE and not Announcing MTBE Ban							
Arizona	0.3	0.3	1.8	3.7	3.7	3.6	3.6
Delaware	2.6	2.2	2.6	2.8	3.0	3.0	3.0
Dist. Of Columbia	1.1	0.8	0.9	0.8	0.8	0.8	0.7
Maryland	13.4	10.1	11.2	11.1	11.2	11.7	12.6
Massachusetts	16.2	16.0	16.9	16.4	14.8	16.5	16.8
New Hampshire	2.0	2.1	2.3	2.6	2.6	2.9	3.2
New Jersey	30.7	29.0	31.4	32.6	28.1	26.3	27.1
North Carolina	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Pennsylvania	9.3	8.7	9.2	9.4	8.8	9.3	9.7
Rohde Island	3.8	3.5	3.4	3.5	2.9	2.9	2.6
Texas	25.9	23.7	27.0	29.2	31.2	30.3	30.5
Utah	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Virginia	14.0	11.4	12.3	13.1	13.2	13.6	13.6
United States	233.6	225.3	246.7	263.5	259.7	257.0	239.0

Source: EIA, 2003

2.6 Transportation Problem

The major drawback of ethanol is the high transportation cost, because ethanol cannot be shipped through pipelines. Although Federal and state tax incentives have made ethanol producers competitive in the market and economically profitable, high transportation costs prevent other regions from consuming ethanol. MTBE can be piped to a refinery, then blended with gasoline, and piped to pumping stations throughout the

United States. Generally, pipelines are the fastest and most economical method for transporting liquids.

There are three main reasons why ethanol cannot be moved through pipelines. First, ethanol absorbs water and impurities that normally reside in fuel pipelines. Water, typically containing dirty particles such as rust, separates ethanol and gasoline, and these dirty particles reduce engine performance (Whims 2002). Therefore, ethanol needs to be carried by other means and must be blended at the terminal instead of the refinery.

Second, the location of a pipeline is problem. Most of the pipelines in the U.S. run from the Gulf Coast to the East and West Coasts. Thus, corn based ethanol in the Midwest needs to be transported to the Gulf Coast for piping. Construction of a new pipeline connecting the Midwest and other regions is not likely in the near future due to high establishment costs.

The third and final weakness is the logistical limitation of the existing pipelines. Compared to the volume of liquids normally shipped via pipelines, ethanol has insufficient volume. This cannot justify the construction of new pipelines.

Therefore, ethanol must be transported by barge, rail, or truck to fuel stations. Downstream Alternative, Inc. (DAI) has estimated the possible transportation costs and capital investment costs when the national production of ethanol is less than five billion gallons per year (BGY) by 2012 scenario (Table 2.3 and 2.4). DAI's study has estimated the shipping cost from PADD (Petroleum Administration for Defense District[2]) II from

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[2] The United States is divided by the U.S. DOE into five PADD regions for planning purposes. PADD 1 is the East Coast, including CT, DC, DE, FL, GA, MD, ME, MA, NC, NH, NJ, NY, PA, RI, SC, VA, VT, and WV. PADD 2 is the Midwest, including IA, IL, IN, KS, KY, MI, MN, MN, MS, ND, NE, SD, OH, OK, TN, and WI. PADD 3 is the Gulf Coast, including AL, AR, LA, MS, NM, and TX. PADD 4 is the Rocky Mountain area, including CO, ID, MT, UT, and WY. PADD 5 is the West Coast, including AK, AZ, CA, HI, NV, OR, and WA.

other regions. PADD II is not expected to import any of its ethanol. In contrast, PADD I and V will have to incur a burden of high freight cost ($0.11/gal and $0.13/gal, respectively) to import most of their ethanol from PADD II. In terms of capital investment cost, DAI study results show an estimated average national cost of about 8 cents per gallon of ethanol to transport it to markets.

The DAI concludes that the transportation industries could increase capacity to meet increased ethanol transportation demands without serious risk of sustained supply disruption (EIA 2002c). However, high shipping costs would become a disturbance in extending the ethanol market.

Again, this is not true for biomass-ethanol production. Biomass is an abundant and inexpensive regionally-available renewable resource. Furthermore, in the case of MSW-ethanol, it substantially reduces freight cost when compared to agricultural or forest residues based ethanol production. MSW availability is positively related to population; thus, urban areas have more abundant MSW biomass resources than do rural areas. These are also the places that ethanol is most needed. Consequently, Ethanol produced from MSW quickly and easily meets the needs of ethanol demand in urban areas.

Table 2.3 Total Freight Costs for Ethanol Transportation for 5 BGY by 2012 Scenario (million 2000 dollars)

PADD	Ethanol shipped (BGY)	Ethanol imports from PADD II			Shipments within PADDS				Total	
		Ship/ Barge	Rail	Avg. (cents/ gal.)	Truck	Rail	Barge	Avg. (cents/ gal.)	Total	Avg. (cents/ gal.)
I. East Coast	1.3	$57.4	$70.0	9.8	$13.1	-	$4.0	1.3	$144.5	11.1
II. Midwest	2.2	-	-	-	$77.9	$12.8	$3.2	4.3	$93.9	4.3
III. Gulf Coast	0.7	$2.6	$35.3	5.4	$8.0	-	$0.3	1.2	$46.2	6.6
IV. Rocky Mountain	0.1	-	$4.5	4.5	$0.2	-	-	0.1	$4.7	4.7
V. West Coast	0.8	$51.1	$32.9	10.5	$17.8	-	-	2.2	$101.8	12.7
Total	5.1	$111.1	$142.7	30.2	$117.0	$12.8	$7.5	2.7	$391.1	7.7

Source: Technology and Management Services, Inc., 2002. Data taken by DAI, 2002

Table 2.4 Total Estimated Capital Investment for Terminal Improvements and Retail Conversion for E10/E5.7 for 5 BGY by 2012 Scenario (million 2000 dollars)

PADD	New ethanol volume (BGY)	Cost of new tanks	Cost of tank conversion	Cost of blending systems	Modifying for rail receipt	Contin-gency	Retail conversions	Total	Amortized cost (cents/gal.)
I. East Coast	1.102	$8.89	$0.65	$24.30	$7.10	$1.26	$6.50	$48.66	0.69
II. Midwest	1.072	$5.40	$0.31	$33.00	$5.33	$2.02	$7.44	$53.49	0.78
III. Gulf Coast	0.626	$5.74	$0.34	$22.20	$3.55	$1.24	$5.28	$38.34	0.96
IV. Rocky Mountain	0.042	$0.75	$0.02	$2.40	$1.07	$0.12	$0.31	$4.66	1.73
V. West Coast	0.145	$2.33	$0.06	$4.20	$0.36	$0.24	$1.25	$8.42	0.91
Total	2.987	$23.11	$1.38	$86.10	$17.41	$4.88	$20.78	$153.57	0.80

Source: Technology and Management Services, Inc., 2002. Data taken by DAI, 2002

2.7 Ethanol Market Structure

Another problem for the ethanol industry is the fact that ethanol production is a highly concentrated industry. Illinois based Archer Daniels Midland (ADM), controls approximately 40% of all ethanol production in the United States. Since ADM is such a dominant market power, the concern is that only a few ethanol producers will be able to expand production to meet demand as long as we rely only on corn-produced ethanol. Many complain that only ADM can benefit from the banning of MTBE (Pace 2003). Further, large producers have typically partnered with smaller producers or farm coops to market the smaller producer’s supplies of ethanol; thus, the concentration ratio may underestimate the actual market concentration.

On the other hand, the GAO forecasts that a MTBE ban attracts new small producers into the market, and the market share of the large producers is projected to decline (GAO 2002).

There are both advantages and disadvantages of concentrated ethanol market structure. One advantage is that the industry can take advantage of economies of scale; industry could lower unit costs to produce a gallon of ethanol. Moreover, pricing coordination is easier if fewer firms control most of the market shares.

A disadvantage of the current ethanol market structure is that it discourages competition. New suppliers tend to be left out of the market so that only the preferences of a few big agribusiness giants are counted.

There are a few reasons why competition is not emerging. First, ethanol is a homogeneous commodity. Even though it is made from different feedstocks such as corn, rice straw, or MSW, it seems identical to consumers. Thus, consumers choose products mainly based on the price. New suppliers cannot appeal to consumers by differentiating the market. The second reason is a technological barrier. Ethanol conversion needs high technology and well-trained employees that are not easily available. Third, small suppliers cannot afford the enormous initial capital investment cost. Fourth, the fuel distribution network is controlled by the oil industry, whose products compete with ethanol. Large oil companies prefer to contract with a few large producers instead of a number of small ethanol producers.

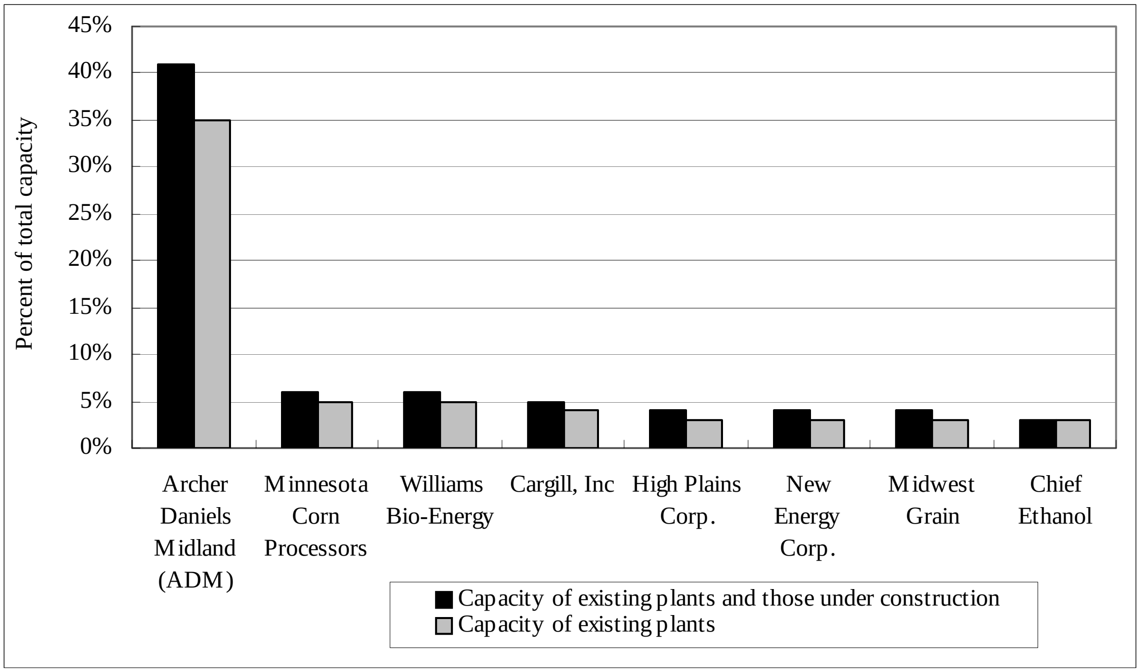

Figure 2.14 Top Eight U.S. Ethanol Producers by Production Capacity (2002)
Source: GAO, 2002. Data taken by RFA

2.8 Concluding Remarks

In this chapter I looked at the current ethanol market condition. Ethanol demand in the near future will rise because of the phase-out of MTBE, especially in California. Now, I summarize how MSW-ethanol production contributes to the future ethanol market.

First, ethanol demand is projected to increase. States need to guarantee a sustainable flow of ethanol with the MTBE ban. Biomass-, including MSW, based ethanol production is increasingly seen as an important and capable approach to meet the anticipated boost in ethanol needs. For example, New York and northern New Jersey need about 391 million gallons of ethanol to replace MTBE. According to Masada, less than half of New York's MSW would meet this need (Masada 2004).

Second, the U.S. currently depends excessively on imported oil from other countries. The U.S. presently imports 56% of its petroleum needs and is expected to reach 60% by 2010 (EIA 2004a). At the beginning of the 1970s OPEC decreased the output of oil, which resulted in a dramatic increase in oil prices. The world’s interest in alternative fuels increased significantly. The aim was to become less dependent on oil and to reduce the cost of expensive oil imports. Ethanol production reduces the U.S. trade balance by $2 billion annually (EIA 2004a). It is estimated that if existing landfill inventories and newly generated MSW were converted to ethanol, as much as 25% of oil and gasoline resources could be saved and used in industry or power generation. (GeneSyst 2004)

Third, corn-based ethanol production is sensitive to corn prices. Corn-ethanol plants face ceaseless uncertainty about meteorological factors. Thus, excessive inclination to corn-based production could result in a shortfall of the ethanol supplies. A biomass-based ethanol plant, on the other hand, generally deals with more than two biomass inputs for ethanol production. MSW is a mixture of miscellaneous waste, including biomass that it is not as sensitive to weather as corn-based production. Paper, the most abundant biomass in MSW, is not affected by seasonality. Thus, MSW-based ethanol can contribute to the stability of ethanol availability and its price.

Fourth, ethanol is now exclusively produced in the Midwest. Unless regional plants are constructed, ethanol must be transported to gas terminals far away from plants. Automobile dependent states on the West and East coasts are forced to incur high shipping cost. This burden indirectly goes to tax payers, because ethanol price manages to be competitive with other fuels through Federal and state tax incentives. Unlike corn-based production, MSW-ethanol production can be operated regionally. It provides ethanol quickly to urban markets where it is most needed. It is unlikely MSW-ethanol could bring about regional fuel self-sufficiency, but it would support some self-sufficiency.

Finally, the ethanol market is controlled by a few big agribusiness firms. It is quite controversial as to whether or not competition is ideal to expand the ethanol market. It should be subject to public choice. Even though the current ethanol market is dominated by a few firms, MSW-ethanol producers still have the potential to enter into this monopolistic market. Furthermore, there are various kinds of jobs relevant to ethanol industry (RFA 2001b). MSW-ethanol production would create jobs for local community.

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CHAPTER III

MSW BIOMASS FEEDSTOCK AVAILABILITY

This chapter describes potential MSW biomass availability. The “biomass” refers to all the Earth’s vegetation and many products and co-products that come from it. Biomass waste, which can be converted to ethanol, is generally divided into three categories: (1) forest waste, (2) agricultural waste, and (3) biomass component in municipal solid waste (DOE 2004). Of all three potential biomass wastes, agricultural residue is now regarded as a potential alternative feedstock to conventional corn-starch for ethanol production. The corn stover-to-ethanol industry especially can potentially contribute largely to ethanol production in the Midwest (Tally 2002). California also seeks to take advantage of rice straw, which used to be burned on the field. After state regulations banned all field burnings due to environmental considerations, huge amounts of rice straw was being landfilled. Now California proposes to use this abundant resource to meet the rapid increase in ethanol demand (California Energy Commission 2001a).

MSW is defined by the DOE as “residential, commercial and institutional post-consumer waste.” MSW contains a significant proportion of plant-derived organic material that constitutes a renewable energy source. Waste paper, cardboard, construction and demolition wood waste, and yard waste are examples of biomass resources in municipal waste (DOE 2004). The U.S. EPA (2003) categorizes MSW into following components: (1) paper and paperboard, (2) glass, (3) metals, (4) plastics, (5) rubber and leather, (6) textiles, (7) wood, (8) yard trimmings, and (9) food scraps. Of all eight components, paper, wood, yard trimmings, and food scraps are so-called MSW biomass and could be converted to ethanol.

The chapter is organized in the following manner: first, the historical trends of MSW landfill operation are identified; second, I define MSW material composition and derived lignocellulosic component of total MSW; finally, the paper provides regional MSW availability data over the U.S.

3.1 Data

Data exclusively came from secondary sources. Reliable data was obtained by the U.S. EPA (2003) and the series of *The State of Garbage in America* in *BioCycle* magazine (Goldstein and Madtes 2001; Kaufman *et al*. 2004). Estimation methodologies conducted by the two organizations, however, differed substantially. The EPA's estimation was based on an annual survey using the national material flow analysis method conducted by Franklin Associates. This data was useful when our interest was to get intuition for a fraction of each MSW composition at a national aggregate level. However, it lacks regional detailed information. *BioCycle* estimates utilized an annual survey of state level MSW officials. As a result, regional level MSW generation details were available, but no details on the composition of MSW were reported.

There was a large discrepancy between The EPA and *BioCycle*. This was principally due to different definitions of MSW. The EPA (2003) states, "MSW as defined here does not include construction and demolition (C/D) debris, biosolids, industrial process wastes, or a number of other wastes that may well go to a municipal waste landfill." Therefore, the EPA's data did not include (C/D) waste, sewage sludge and non-hazardous industrial wastes that are normally disposed in MSW landfills. *BioCycle* estimates were based on total disposal at MSW landfills (Themelis 2003;

Themelis and Kaufman 2004). Consequently, *BioCycle* estimates of MSW tended to be greater than the EPA's estimates.

To estimate MSW availability, *BioCycle* data was more appropriate for my research since a MSW-ethanol plant would utilize all kinds of MSW that is disposed in landfill. Nevertheless, the EPA's data was useful to obtain the United State's typical MSW composition. In section 4 of this chapter, I make comparison among several previous MSW composition surveys, ranging from statewide, countywide, and citywide to observe the breadth of distribution of typical MSW composition in the United States. The chapter is not aimed to provide precise estimates, but rather to identify the trends in MSW generation and landfill, regional MSW availability, and MSW composition in general. Thus, I used data estimates from both the EPA and *BioCycle* for analysis.

3.2 Trends in National MSW

3.2.1 Trend of MSW Generated, Landfilled, Incinerated, and Recycled

As seen in Table 3.1 and Figure 3.1, MSW generation has been steadily increasing in the past decades (tripled since1960). Behind it, there is a continuing augmentation of the U.S. population in the last couple of decades. However, while the population increased by 55% in the last four decades, the pace of increasing rate of MSW generation per capita is more rapid, at 67%, to be exact. Approximately, the weight of daily MSW generated per capita in 2000 was 1.8 pounds (820g) greater than 40 years ago. This change is rooted in mass production, mass consumption, and mass waste producing life styles in the U.S.

Regularly, when material is thrown away it is subject to one of the three solid waste management (SWM) approaches: landfilled, incinerated, or recycled. SWM in the U.S. has been dominated by landfilling. It is obvious from Figure 3.1 that the amount of MSW landfilled has been much greater than both that of incinerated and recycled MSW in the last 40 years. Figure 3.2 tells us that more than half of MSW (55.3%) was landfilled in 2000. Nowadays, the rate of increase in MSW landfilled has diminished, while recycling is growing steadily. The amount of MSW landfilled is, however, still predicted to grow in the future as MSW generation continually grows.

A high percentage of MSW landfill is very attractive to MSW-ethanol producers. They will not face difficulty in obtaining MSW due to competition with the recycling industry, except in some regions where the government encourages municipal recycling programs.

Table 3.1 Trend of MSW Generation, Recycling, and Landfilling in 1960-2000

	Million Tons								
	1960	1970	1980	1990	1994	1995	1998	1999	2000
Generation	88.1	121.1	151.6	205.2	214.4	211.4	223.4	230.9	231.9
Increment rate	-	37.4%	25.3%	35.3%	4.5%	-1.4%	5.7%	3.4%	0.4%
Population[3] (million)	181	205	227	250	260	263	270	273	281
MSW per capita (ton)	0.49	0.59	0.67	0.82	0.82	0.80	0.83	0.85	0.82
Recycling	5.6	8.0	14.5	29.0	42.2	45.3	48.0	50.1	53.4
Composting*	-	-	-	4.2	8.5	9.6	13.1	14.7	16.5
Total Recycling**	5.6	8.0	14.5	33.2	50.6	54.9	61.1	64.8	69.9
Incineration	27.0	25.1	13.7	31.9	32.5	35.5	34.4	34.0	33.7
Landfilled	55.5	87.9	123.4	140.10	131.2	120.9	127.9	132.1	128.3
	Percent of Total Generation								
Total Recycling**	6.4%	6.6%	9.6%	16.2%	23.6%	26.0%	27.4%	28.1%	30.1%
Incineration	30.6%	20.7%	9.0%	15.6%	15.2%	16.8%	15.4%	14.7%	14.6%
Landfilled	63.0%	72.6%	81.4%	68.3%	61.2%	57.2%	57.2%	57.2%	55.3%

Source: U.S. EPA (2003)

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[3] Population data in 2000 is taken by U.S. Bureau of the Census (2001).

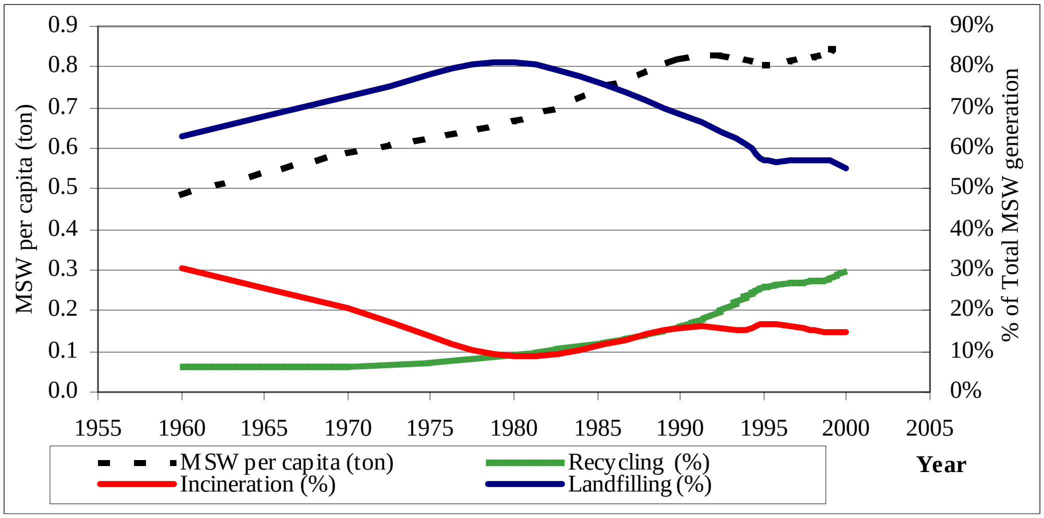

Figure 3.1 Trend of MSW Generation per Capita and SWM in the U.S.
Source: U.S. EPA, 2003

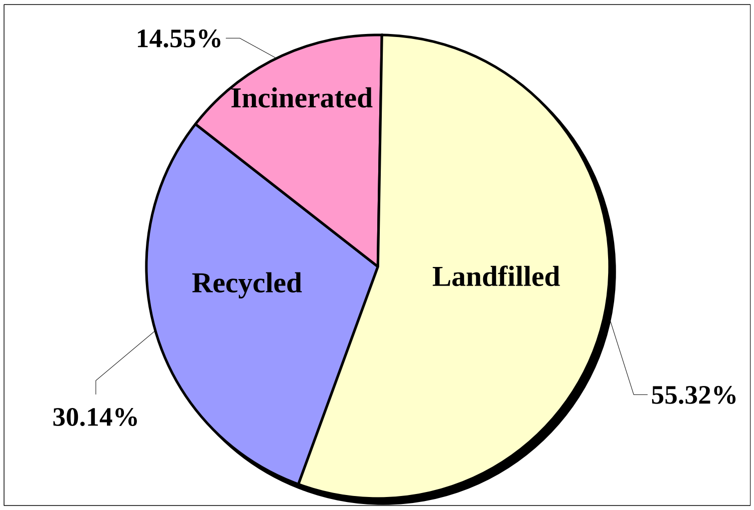

Figure 3.2 Percentage of SWM in 2000
Source: U.S. EPA, 2003

3.2.2 Trend in Landfills

It should be noted here, however, that the number of landfills is steadily decreasing in spite of the fact that the amount of MSW landfilled is growing. Today there are fewer landfills, and those are mostly large and privately owned (U.S. EPA 2003).

Small landfills have been closed, while big landfills have grown in number and size (See Figure 3.3 below). Typically, until the 1970's, each municipality operated its own small landfill, charging a modest "*tipping-fee*" for commercial and industrial users and for the trash of small towns and villages on its periphery. Things have changed dramatically, however, in the past 20 years.

The change comes after regulation of the Resource Conservation and Recovery Act (RCRA) in 1980s. The increasing concern about the effects of dumps on our health and the environment has led to new regulation for the opening, operation, closing, and post closure monitoring of sanitary landfills. This change is also attributed to economies of scale of landfill management (Porter 2002). First, some regulations of the RCRA imposed nearly uniform costs (e.g., decontamination equipment cost or monitoring cost) on landfills almost regardless of their size, which meant that the cost per ton of such regulations was much higher for small landfills. Second, many of the new regulations eventually required expertise (e.g., engineer or legal experts), so high personnel expense became a heavy burden for small landfills owners. Finally, new regulations applied only to new landfills. This resulted in the expansion of existing landfills since it was costly option.

Inevitably, small municipalities quickly recognized their inability to handle the new and complex regulations at a reasonable cost. Even large cities began to close their landfills. Only 38 out of the 100 largest cities own their own landfills (Ezzet 1997). On the other hand, large private companies acquired massive amounts of landfill capacity. Regulation changed the ownership structure of landfills. Figure 3.4 illustrates the trend of ownership of landfill and Figure 3.5 shows the trend of volume of waste managed by private and public landfills. Clearly, landfilling activity has shifted towards private ownership, hence more waste is now being managed by private owners than it used to be as a result of the RCRA. This tendency was accelerated when MSW of closed public facilities is shipped to private landfills rather than new publicly owned facilities (Repa 2000).

Consequently, in many states, remaining landfill capacity is limited by both physical and economic reasons. Between 1986 and 1991, thirteen States (Connecticut, Georgia, Kentucky, Massachusetts, Mississippi, New Jersey, New York, Oklahoma, Pennsylvania, Rhode Island, Vermont, Virginia, and West Virginia) reported less than five years of landfill capacity (Repa 2000). Although landfill capacity has increased over the past decades because of newly established landfills, *BioCycle* reported that 6 out of 11 Northeastern states (Connecticut, Massachusetts, Rhode Island, New Hampshire, New York, Rhode Island, and Vermont) have less than 10 years of landfill capacity remaining (Goldstein and Madtes 2001).

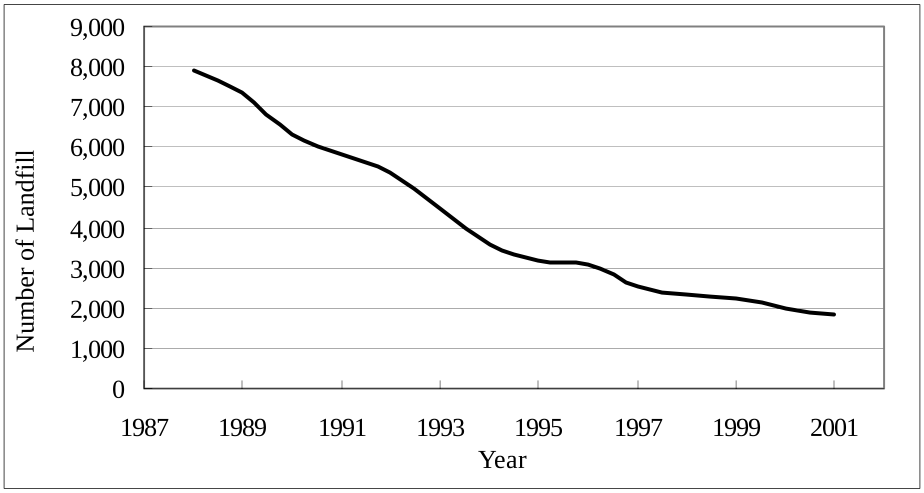

Figure 3.3 Trend of Number of Landfills in the U.S.
Source: U.S. EPA, 2003

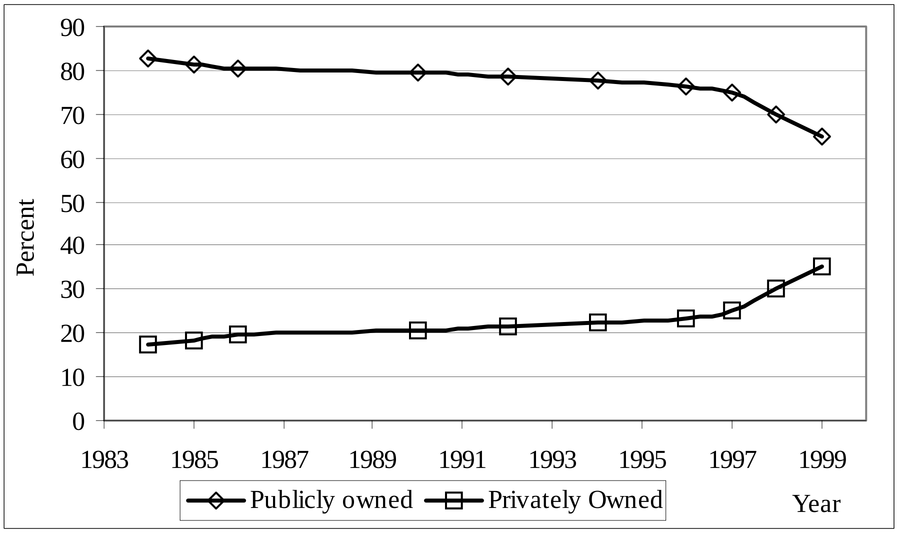

Figure 3.4 Trend of Landfill Ownership
Source: Repa, 2000

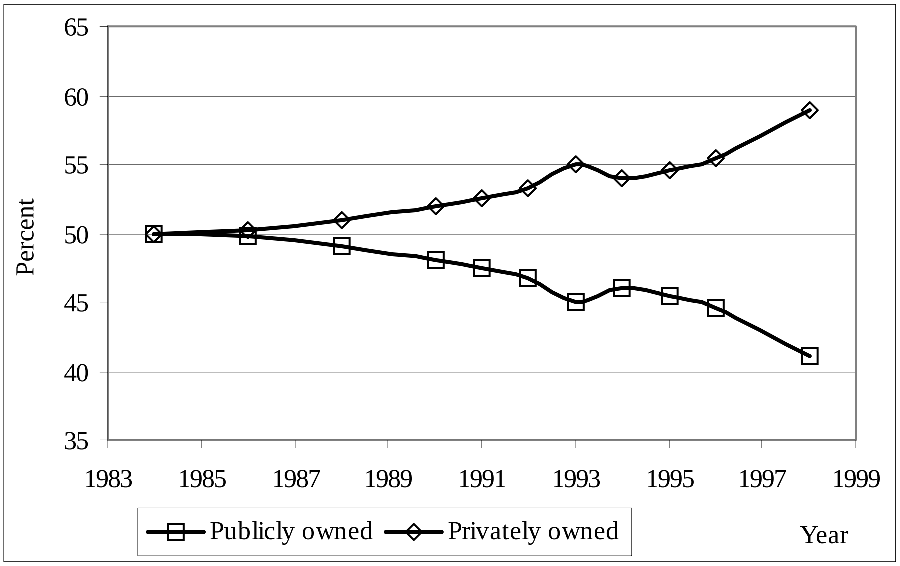

Figure 3.5 Trend of MSW Volume Managed by Ownership
Source: Repa, 2000

3.2.3 Trend of Tipping Fee

The big motivation for a MSW-to-ethanol producer would be to gain sizable amounts on the tipping fee. One of the disadvantages to ethanol producers is high waste separation cost. Before processing, they need to sort out recyclable and non-recyclable products, and then separate lignocellulosic composition from the others. Weekly waste collection costs are also not ignorable if a plant is not collocated with an existing landfill or material recovery facility (MRF). However, if a tipping fee is high enough to offset this cost, producers could overcome this weakness.

Figure 3.6 shows historical tipping fee across regions in the United States. The national average nominal tipping fee has increased fourfold from 1985 to 2000. The real tipping fee has almost doubled, up from a national average (in 1997 dollars) of about $12 per ton in 1985 to just over $30 in 2000 (Repa 2000).

Equally important, it is apparent that the tipping fee is much higher in densely populated regions.[4] The trend differs by municipality level, from $9 a ton in Denver to $97 in Spokane. Statewide averages also vary widely, from $8 a ton in New Mexico to $75 in New Jersey (Ackerman 1997). The average tipping fee in the Northeastern region is particularly high at more than double the national average tipping fee.

Sometimes the tipping fee is regarded as a landfill scarcity indicator because it is inversely related to the remaining landfill capacity (Porter 2002). The less landfill space, the higher the tipping fee residents are charged. This sizable tipping fee is available in metropolitan areas where waste is abundant and ethanol is mostly needed.

Chartwell Information publishes *Solid Waste Digest*, which reports the tipping fee and daily MSW volumes of existing MSW dumping landfill, waste-to-energy facilities (WTE) including incinerator, transfer station (TS) including MRF across the U.S. (Chartwell Information 2003). According to this report, the national average tipping fee

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[4] According to data of Repa (2002), Northeast is CT, MA, ME, NH, NH, NY, RI, and VT; Mid-Atlantic is DE, MD, NJ, PA, VA, and WV; South is AL, FL, GA, KY, MS, NC, and SC; Midwest is IA, IL, IN, MI, MN, MO, OH, and WI; South Central is AR, AZ, LA, NM, OK, and TX; West Central is CO, KS, MT, ND, NE, SD, UT, and WY; and West is AK, CA, HI, ID, NV, OR, and WA.

of all types of SWM facilities is $36 per ton. The national average tipping fees charged by landfills, TS, and WTE were $33.12, $40.76, and $57.34 per ton, respectively.

Detailed data of *Solid Waste Digest* is summarized in Appendix A. Landfill data is used for cross-sectional econometric analysis and it is found that the tipping fee is significantly related to the location of facility (region) and type of facility, but not related to daily waste volume that the facility accepts.

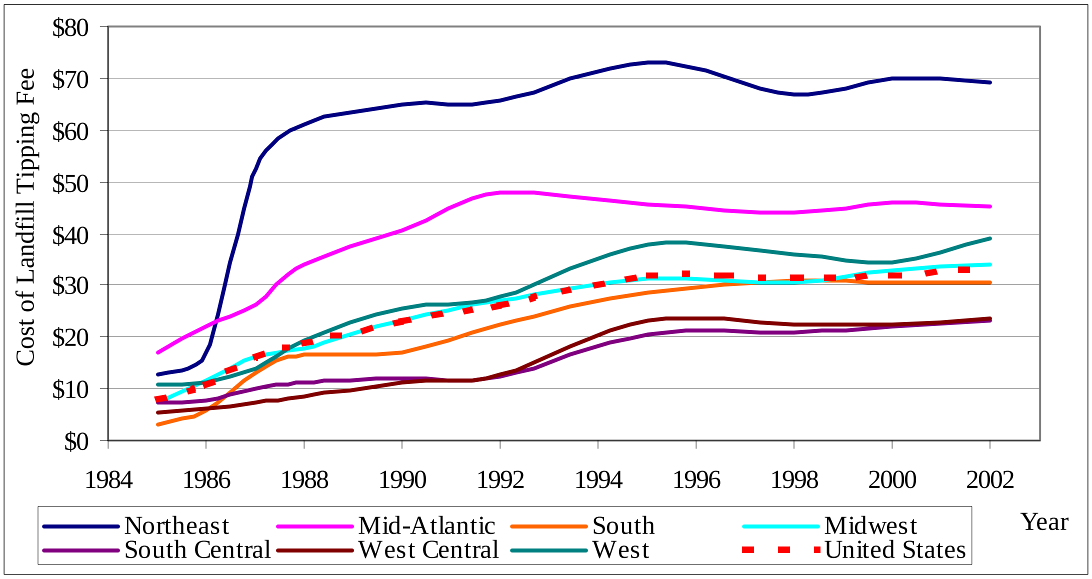

Figure 3.6 Trend of Tipping Fee in the U.S. (Dollar per ton)
Source: Repa, 2002

3.3 MSW Components Convertible to Ethanol

3.3.1 Total Lignocellulosic Composition in MSW

In the U.S., overall composition of MSW was reported by the U.S. EPA (2003) as paper and paperboard 37.4%, wood 5.5%, yard trimmings 12.0%, food scraps 11.2%, glass 5.5%, metal 7.8%, plastics 10.7%, rubber and leather 2.8%, textile 4.1%, and other waste 3.3%. As noted above, paper and paperboard, wood, yard trimmings, and food scraps are components that can be converted to ethanol.[5] These account for 66.0% of the total MSW generated (Table 3.2 and Figure 3.7).

MSW composition normally includes moisture content.[6] Many civil engineers assume a roughly 30% moisture content in total MSW. If this assumption is incorporated, approximately 46.3% of initial waste by weight can be feedstock for ethanol production.

As later discussed in Chapter IV, incoming daily MSW is sorted out to recyclables and non-recyclables by existing municipal MRF that is collocated by the ethanol plant or by plant itself. The remaining waste, so-called “MSW fluff” is used as primary input for ethanol production. Recyclable composition in MSW is counted as input for ethanol production because it would have a higher salvage value in the recycling market. In other words, only landfilled MSW is used for ethanol production.

Under this more realistic case, 59.7% of landfilled MSW accounts for lignocellulosic composition (Table 3.3 and Figure 3.8). Assuming a 30% moisture content, 49.8% of MSW fluff is pure lignocellulosic component. The fraction of lignocellulosic composition in landfilled MSW is relatively lower than that of total generated MSW. This is largely due to the high recycling ratio of paper and paperboard goods and soaring composting rate of yard waste. In the next section, I look into the historical and current availability of biomass in MSW.

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[5] Lignocellulose consists of cellulose, hemicellulose, and lignin. Cellulose and Hemicellulose contains sugars that can be fermented into ethanol. The structure of lignocellulose is explained in Chapter IV in detail.

[6] Moisture content in typical MSW is estimated by the University of Central Florida (2004).

Table 3.2 Summary of Total Generated MSW Component in the US in 2000.

	Paper	Wood	Yard Trim	Food Scraps	Glass	Metal	Plastics	Rubber/ leather	Textile	Other Waste	Total MSW
Million Tons	86.7	12.7	27.7	25.9	12.6	18.0	24.7	6.4	9.4	7.7	231.9
MT	78.7	11.5	25.2	23.5	11.4	16.4	22.4	5.8	8.5	7.0	210.3
% of Total MSW	37.4%	5.5%	12.0%	11.2%	5.44	7.8%	10.7%	2.8%	4.1%	3.3%	100%
	Lignocellulosic Composition				Non- Lignocellulosic Composition						
Million Tons	153.1				78.8						231.9
MT	138.9				71.5						210.3
% of Total MSW	66.0%				34.0%						100%
Moisture Content	6%	20%	60%	70%	2%	3%	2%	6%	10%	8%	-
Million tons (dry)	81.5	10.2	11.1	7.8	12.4	17.5	24.2	6.0	8.4	7.1	186.1
MT (dry)	74.0	9.2	10.1	7.1	11.2	15.9	22.0	5.4	7.7	6.4	168.8
% of total dry MSW	43.8%	5.5%	6.0%	4.1%	6.6%	9.4%	13.0%	3.2%	4.5%	3.8%	100%
	Lignocellulosic Composition				Non-Lignocellulosic Composition						
Million tons	110.6				75.6						186.1
MT	100.3				68.5						168.8
% of total MSW	59.4%				40.6%						100%

Source: U.S. EPA, 2003

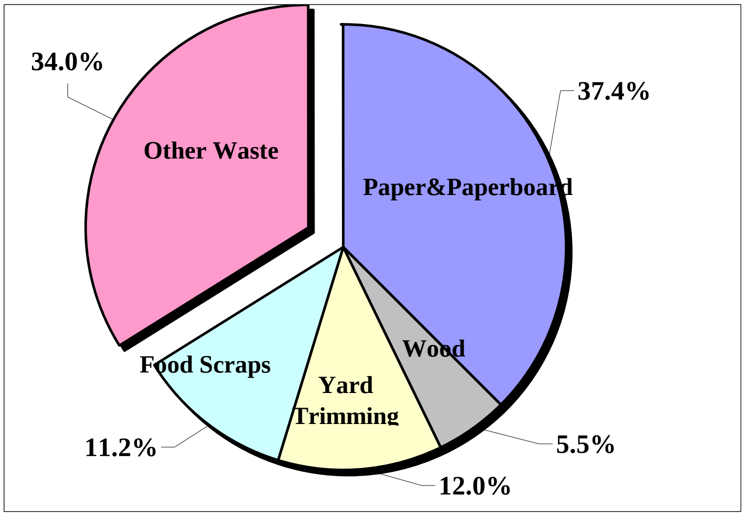

Figure 3.7 Lignocellulosic Compositions in MSW in the U.S. in 2000
Source: U.S. EPA, 2003

Table 3.3 Summary of Total Landfilled MSW Component in the US in 2000.

	Paper	Wood	Yard Trim	Food Scraps	Glass	Metal	Plastics	Rubber/ leather	Textile	Other Waste	Total MSW
Million Tons	47.4	12.2	12.0	25.2	9.8	11.6	23.4	5.6	8.1	6.7	162.0
MT	43.0	11.1	109	22.9	8.9	10.6	21.2	5.1	7.4	6.1	147.0
% of Total MSW	29.2%	7.5%	7.4%	15.6%	6.1%	7.2%	14.4%	3.5%	5.0%	4.1%	100%
	Lignocellulosic Component				Non-Lignocellulosic Component						
Million Tons	96.8				65.2						162.0
MT	87.8				59.2						146.945
% of Total MSW	59.7%				40.3%						100%
Moisture Content	6%	20%	60%	70%	2%	3%	2%	6%	10%	8%	-
Million tons (dry)	44.5	9.8	4.8	7.6	9.6	11.3	22.9	5.3	7.3	6.1	129.2
MT (dry)	40.4	8.9	4.3	6.9	8.7	10.2	20.8	4.8	6.6	5.6	117.2
% of total dry MSW	34.5%	7.6%	3.7%	5.9%	7.5%	8.7%	17.7%	4.1%	5.7%	4.8%	100%
	Lignocellulosic Component				Non-Lignocellulosic Component						
Million tons	66.7				62.5						129.2
MT	60.5				56.7						117.2
% of total MSW	51.6%				48.4%						100%

Source: U.S. EPA, 2003

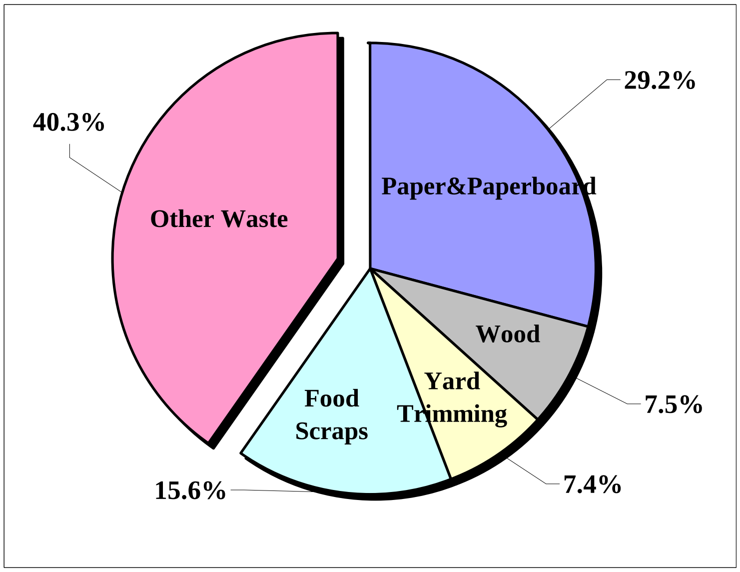

Figure 3.8 Lignocellulosic Compositions in Landfilled MSW in the U.S. in 2000
Source: U.S. EPA, 2003

3.3.2 Paper and Paperboard

Paper-based ethanol plants are in fact being operated in some regions (SENES Consultant, Limited 1993; BioCycle 1992). As discussed in Chapter IV, paper contains a high percentage of cellulose (convertible to glucose) and has the highest ethanol yield among all kinds of biomass feedstock. Furthermore, paper and paperboard are the largest component of total MSW generated (37.4%). Thus, the recyclability of paper and paperboard is a key factor for sustainable input flow for MSW-to-ethanol conversion.

The variety of products that comprise the paper is summarized in Table 3.4. Newspaper and corrugated boxes show extraordinarily higher recycling rates (58.2% and 70.1% respectively) than other paper product, although the rate is still much lower than other industrialized countries, such as EU nations or Japan. Generally, paper products for packaging and container use are more recycled than non-durable use. A total of 45.4% of total paper products are recycled in the U.S. in 2000.

In fact, at the present, paper and paperboard product shows the highest recycling rate among all materials in MSW. Despite growing paper recycling over time, as seen from Figure 3.9, production volume of paper product has amplified at the almost same rate. More than half of paper products are still landfilled in 2000. Thus, a huge amount of paper product is available for ethanol production.

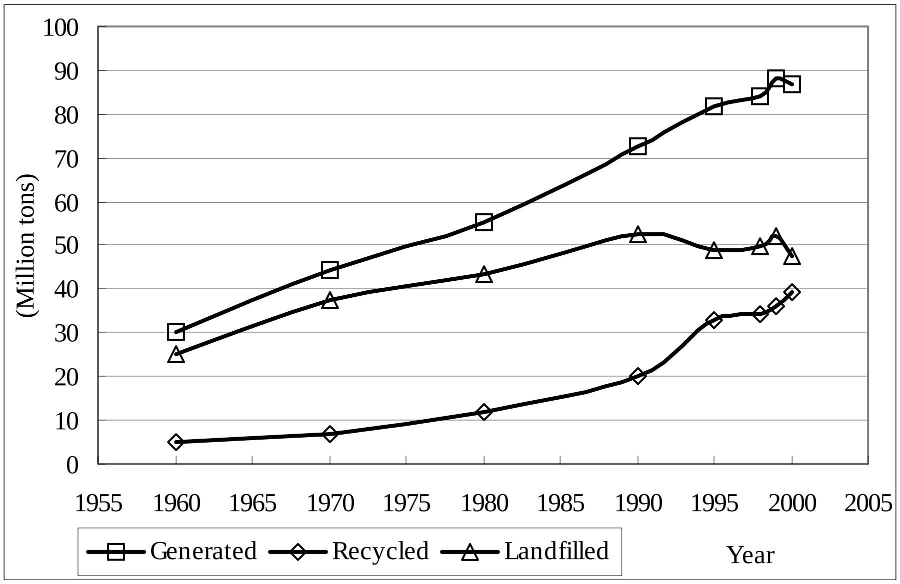

Figure 3.9 Trends of Paper & Paperboard Generation, Recycling, and Landfilling
Source: U.S. EPA, 2003

Table 3.4 Paper and Paperboard Generation in MSW, 2000[7]

	Generation	**Recovery**		**Landfilled**
Product Category	(Million tons)	(Million tons)	(% of generation)	(Million tons)
Nondurable Goods				
Newspaper	15.030	8.750	58.2%	6.280
Books	1.140	0.220	19.3%	0.920
Magazines	2.130	0.680	31.9%	1.450
Office Papers	7.530	4.070	54.1%	3.460
Telephone Directories	0.740	0.130	17.6%	0.610
Standard Mail	5.570	1.780	32.0%	3.790
Other Commercial Printing	7.040	1.650	23.4%	5.390
Tissue Paper and Towels	3.210	Neg.	Neg.	3.210
Paper Plates and Cups	1.040	Neg.	Neg.	1.040
Other Non-packaging Paper	3.910	Neg.	Neg.	3.910
Total Nondurable Goods	47.340	17.280	36.5%	30.060
Containers and Packaging				
Corrugated Boxes	30.210	21.360	70.1%	8.850
Milk Cartons	0.490	Neg.	Neg.	0.490
Folding Cartons	5.580	0.430	7.7%	5.150
Other Paperboard Packaging	0.200	Neg.	Neg.	0.200
Bags and Sacks	1.550	0.300	19.4%	1.250
Other Paper Packaging	1.370	Neg.	Neg.	1.370
Total Container and Packaging	39.400	22.090	56.1%	17.310
Total Paper and Paperboard	86.740	39.370	45.4%	47.370

Source, U.S. EPA, 2003

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[7] Neg. = less than 5,000 tons or 0.05 percent.

3.3.3 Wood, Yard Trimmings, and Food Scraps

The trends of generation, recycling, and landfilling are similar in wood and food scraps (Figure 3.10 and 3.11). These two components are not recycled in the market at all, thus almost all goes to landfill. Landfilling of a large amount of wastes can be avoided if these un-recycled wastes are converted into ethanol.

It should be noted that the quantity of wood waste in Figure 3.10 has a problem with the data. As noted above, the EPA's data does not count wood waste generated at C/D sites as MSW. Normally, large amounts of wood waste are generated as a C/D waste, more than household or offices. Thus, there are some missing wood wastes disposed in MSW landfill in EPA's data.

Fehrs (2003) estimates national wood waste generated as both MSW and C/D wood wastes. He estimates generated wood waste in MSW at 11.8 million MT (12 million tons), which is close to the EPA's result. He estimates C/D waste at 15 million MT and 24 million MT respectively, and a total 39 million MT. Thus, approximately 4 times greater wood waste is generated in C/D. Alternatively, Walsh (2000) utilizes a study by Glenn (1998ab) supplemented with additional data from Araman (1997) to estimate total urban wood waste quantities generated by the states, and then for the entire U.S. at 34 million MT (dry). It includes C/D wastes and yard trimming, but not paper and food scraps, which account for a large part of the lignocellulosic component in MSW. The sum of dried wood and yard waste by the EPA is 19 MT. Thus, here we confirm again that a much larger quantity of wood waste generated as C/D waste.

Figure 3.12 shows that the amount of yard trimming landfilled has decreased dramatically since 1990's. This is due to boost in number of yard waste municipal composting program (Goldstein 2003). Furthermore, yard waste tends to be used as a cover of bioreactor landfill since it is biodegradable. Now the amount of yard waste recovered closely catches up with that of generated yard waste. Considering 60% moisture content, dried lignocellulosic portion in yard waste accounts for only 3% in total waste landfilled. Thus, based on EPA’s typical waste composition estimate, yard waste cannot contribute as a significant input for ethanol production.

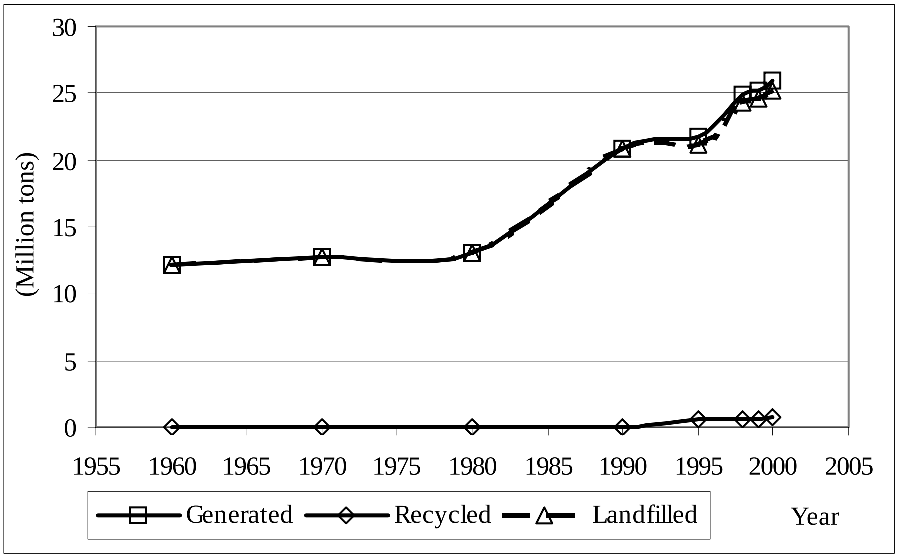

Figure 3.10 Trends of Wood Generation, Recycling, and Landfilling
Source: U.S. EPA, 20003

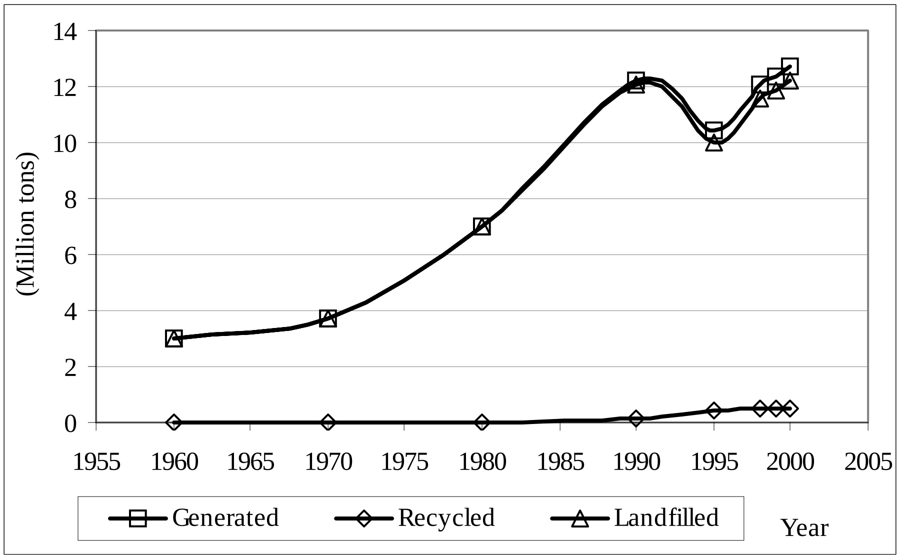

Figure 3.11 Trends of Food Scraps Generation, Recycling, and Landfilling
Source: U.S. EPA, 2003

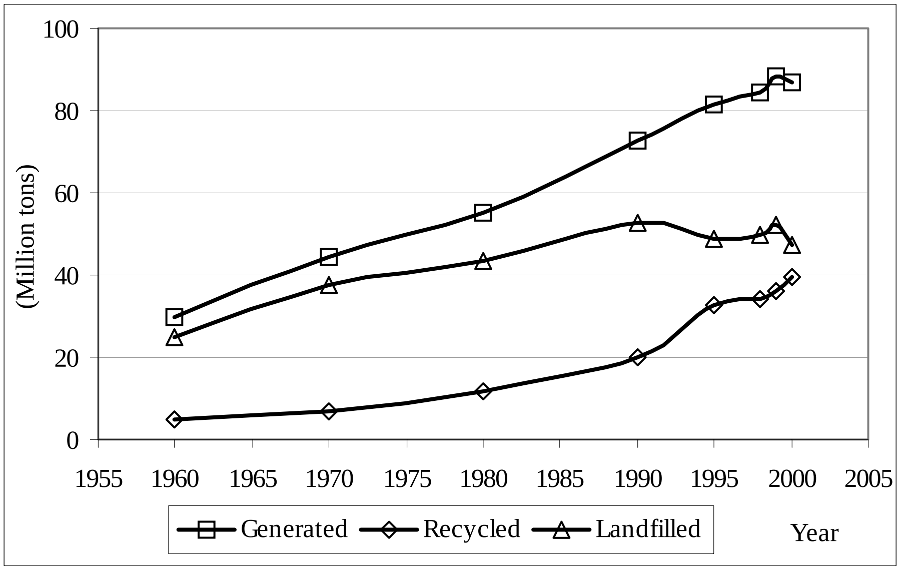

Figure 3.12 Trends of Yard Trimming Generation, Recycling and Landfilling
Source: U.S. EPA, 2003

3.4 Comparison of Previous MSW Composition Surveys

Table 3.5 below summarizes the comparison of several MSW composition surveys conducted by local government, private sector, and academic institutions, ranging from statewide, countywide, to citywide. Research methods were not inconsistent. Some surveys are based on material composition as collected curbside by each household, while others are based on reports from landfill or MRF owners. The definition of MSW composition also varies by study. Some categorizes “green waste” or “organic waste” as the sum of wood and yard waste. The survey year also is different among studies. Thus, some numbers need to be adjusted for more accurate comparison study.

Regardless of limitation to application, we still can generalize some points from Table 3.5. First, although there are some margins of error from the EPA’s estimate and a few minor exceptions, total lignocellulosic component is constantly more than half and roughly consists of 55-70% of total MSW. Stated another way, 55-70% can be used as an input for ethanol production and 45-30% of MSW avoids being landfilled. . Note that ethanol yield can be different even if the percentage of lignocellulosic composition of two communities is identical. Yield still depends on paper, wood, yard, and food waste composition in total MSW.

Second, paper waste, ideal feedstock for ethanol production due to rich cellulose content, consistently accounts for the lion’s share of total MSW composition - almost 30%. High paper content leads to high ethanol yield, and, therefore, profitability of the ethanol plant. Frankly speaking, most communities are filled with valuable MSW biomass feedstock.

In the rest of paper, I consistently use the assumption of 55-70% lignocellulosic content for further research.

Table 3.5 Comparison of MSW Composition Survey

	Scale	Paper and paperboard	Wood waste	Yard trimming	Food scraps	Other biomass	Biomass Composition
U.S. EPA	Nation	29.2%	7.5%	15.6%	7.4%	-	59.7%
Hawaii[8]	State	26.0%	32.0%		8.0%	-	66.0%
Minnesota[9]	State	34.3%	7.5%	2.3%	12.4%	3.5%	60.0%
Pennsylvania[10]	State	33.3%	4.2%	8.3%	5.2%	12.0%	67.5%
Wisconsin[11]	State	29.2%	N/A	1.8%	14.3%	9.1%	54.4%
Denton, TX[12]	County	37.9%	7.0%	8.0%	12.2%	-	65.1%
Maricopa, AZ[13]	County	24.0%	26.0%		11.0%	-	61.0%
Canton, OH[14]	City	41.1%	3.7%	17.9%	7.9%	-	70.6%
New York, NY[15]	City	22.1%	2.2%	4.1%	12.7%	7.8%	58.1%
Seattle, WA[16]	City	22.5%	N/A	N/A	32.9%	1.6%	57.0%

3.5 Regional MSW Biomass Availability

MSW biomass availability differs regionally. The annual state average MSW generation per capita was estimated by *BioCycle* (Kaufman *et al*. 2004). Available information is summarized in Table B.1 in Appendix B. As noted above, estimates by *BioCycle* unfortunately do not include data for material composition in MSW by region. As a result, we cannot obtain state level MSW lignocellulosic composition. Nevertheless, it is still useful to look at regional MSW yield differences. Multiplying *BioCycle* data by county or metropolitan area population data, as reported by the U.S. Bureau of the Census (2002), yields regional annual MSW generation. Figure B.1 illustrates the population distribution across the United States. Figure B.1 plots the different color on

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[8] Data taken by the state of Hawaii, Department of Business, Economic Development & Tourism (1994).

[9] Data taken by "Statewide MSW Composition Study" conducted by the Solid Waste Management Coordinating Board (2000)

[10] Data taken by "Statewide Municipal Waste Composition Study" conducted by the state of Pennsylvania, Department of Environmental Protection (2003)

[11] Data taken by "Wisconsin Statewide Waste Characterization Study" conducted by the Cascadia Consulting Group, Inc. (2003)

[12] Data taken by "Surveying the Commercial Municipal Solid Wastestream in Denton, Texas" conducted by Brady *et al*. (2000)

[13] Data taken by Fox *et al*. (1999)

[14] Data taken by Fox *et al*. (1999)

[15] Data taken by "Energy recovery from New York City Solid Wastes" written by Themelis *et al*. (2002)

[16] Data taken by "2002 Residential Waste Stream Composition Study" conducted by the Cascadia Consulting Group, Inc. and Sky Valley Associates (2003)

the county corresponding to county population. Figure B.2 also shows annual MSW generation by county.

It is apparent from these two figures that MSW is much more generated in the East and West coasts, followed by the Great Lakes and Gulf Coast areas. Taking into account the regionally different tipping fee, the Northeast area would be the most attractive region for MSW-ethanol producers.

According to *GeneSyst* (2004), a county or metropolitan area where population exceeds 100,000 supplies enough MSW for profitable ethanol production. In 2000, there were 524 out of 3,141 U.S. counties with populations over 100,000. The U.S. Bureau of the Census (2001) also provides population data of metropolitan areas in 2000. There are 260out of 280 metropolitan areas which exceed 100,000 in population. . Thus, so-called metropolitan areas are materially applicable for MSW-ethanol production.

One concern about the above analysis is that the scale of the area varies by county and metropolitan area to a large extent. Thus, MSW-ethanol producers need to consider MSW density – MSW availability within a certain area (tons per square mile). Even though MSW generation is enough by county as a whole, MSW hauling costs need to be considered to reflect more reality. If the targeted amount of MSW is not available in a small compass, high waste hauling cost discourages waste suppliers to transport MSW to ethanol plants.

Gallagher *et al*. (2003) estimated the minimum radius supplying enough agricultural residues to ethanol plant. I use their concept to estimate MSW density:

$$Q = (\pi r^2) dy \text{ ....} (3 - 1)$$

where,

Q = Capacity of the processing plant
r = Radius (distance) from the plant
d = Population density (capita/square miles)
y = Daily MSW yield (daily MSW generation per capita; tons/capita)
dy = Daily MSW density (tons/square miles)

The term *dy* is MSW density. Table B.2 summarizes the MSW density of the U.S. top 20 metropolitan areas. MSW density in New York City is 7.39 tons per square mile. On the other hand, only 2.05 tons of MSW are available per square mile in Los Angeles.[17] Although total MSW generations in these two cities are nearly the same, MSW is more abundant in New York City than in a small area. Using equation (3-1), we can estimate MSW availability in a certain square area. For example, daily MSW availability in N.Y. City in the circular area with a 10 mile radius (100π square miles) is approximately 2,321 tons, while in L.A. it is only a quarter, at 643 tons.

The next step is to estimate the minimum radius or areas that provides enough MSW for operation. Converting equation (3-1) above yields the following function:

$$r = \sqrt{\frac{Q}{\pi dy}} \text{..........................} (3-2)$$

Suppose the targeted daily MSW volume is 500 tons per day (TPD). The 500 TPD is available within 4.64 miles in New York City, while L.A. needs to haul MSW nearly double the mileage. As seen in Table B.2, range of minimum radius that supplies 500 TPD is huge, as some metropolitan areas needs more than a 40 mile radius from

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[17] Daily MSW yield is obtained by the yearly state average MSW generation per capita, estimated by Kaufman *et al*. (2004) and divided by 365 days a year.

ethanol plants. This magnitude would be expanded when county, instead of metropolitan area, is at issue.

Unfortunately, almost of all previous literature estimating waste hauling cost is based on weight basis ($ per ton). This is because hauling cost is not affected by the distance waste is transported, but rather, more sensitive to the number of trucks used for waste hauling. Usually, waste collection and hauling is labor intensive and this cost accounts for nearly 80% of total costs in the waste management industry by the national average. Hauling cost is <u>at least</u> $0.50 per mile per ton of garbage to haul collected wastes (Heimlich 2004). MSW density would be the part of function that affects waste hauling cost.

There are some research limitations in terms of regional waste availability. First, even among the same county or metropolitan area, MSW density is still different. The volume of waste is also dependent upon the major industry located in the area, since sizeable amounts of industrial waste are included in MSW. At the initial planning process, MSW-ethanol producers need to survey community's MSW availability in more detail.

Next, and more fundamentally, MSW-ethanol producers would not collect and haul waste by themselves. Instead, they would make use of already existing private or public waste collection services, as PMO and *GeneSyst* plan to do. The city of Middletown in Orange County will supply waste to PMO (City of Middletown 2004). *GeneSyst* also has made several contracts with waste suppliers. The plants will actually be operated in collaborative mode with waste suppliers rather than collected individually. Thus, collection cost may not be an obstacle for MSW-ethanol plants. Instead, plants would be more interested in the credibility of historical record of daily waste collected by waste suppliers.

3.6 Concluding Remarks

Throughout this chapter I looked through national and regional MSW availability and its lignocellulosic composition. There are several research limitations that should be noted before going further in this thesis.

First, MSW composition is different by region. There are enormous disparities in material composition, even among the same waste category. In particular, food waste would not be identical in two communities. Some food wastes contain rich cellulose, while lignocellulosic content in other wastes would be scarce. The areas that consume more moisture content food waste might make MSW-ethanol conversion complicated.

There are numerous reasons why massive disparity of waste composition exists. The primary reason is rooted in economic factors. Consumption patterns of urban areas might be different from that of rural areas. Usually, wealthy urban areas generate much more waste, especially food waste.

Moreover, as studies by the Cascadia Consulting Group Inc., and Sky Valley Associates (2003) show, even among the same category of “residential waste”, waste composition of a single family and multi-families is dissimilar. Thus, MSW composition is also influenced by non-economic factors, such as family structure.

MSW composition is also affected by the characteristics of main industry located in a certain region. Large amounts of agricultural waste are produced in rural areas, while metal and plastic are exclusively doomed to be scrapped in industrial zones. Business districts could be attractive for MSW-ethanol producer because of the daily mass disposal of office paper. This massive industrial waste is finally landfilled, usually with regular household waste.

The second research limitation concerned with MSW availability analysis is the seasonal effect of MSW biomass availability. MSW composition is not consistent within the entire year, but is sensitive to season. For example, loads of MSW is generated at a popular spot during site-seeing season. Those wastes generated at that time may not be similar to the waste composition of the local community. Consequently, annual MSW generation is not as simple as multiplying the daily MSW generation by 365 days. For further MSW availability analysis, we should know the MSW biomass availability at peak and off-peak periods.

Despite the data limitations, I found several important conclusions in Chapter III. First, the growth rate of MSW generation diminishes in a decade, but MSW generation per capita still steadily increases. Although recycling rates, especially for paper and yard waste, has improved greatly, a considerable amount of waste is still currently shipped to landfills without being converted into usable goods. MSW-ethanol plants still have chances to enter into the SWM industry.

Second, roughly 55-70% of total waste is expected to be converted to ethanol. This implies not only potential large ethanol production, but also huge reduction of waste landfilled. Thirty percent of paper composition would also be an economic incentive for MSW-ethanol producers. Given some portions of non-lignocellulosic MSW (e.g., aluminum, ferrous metal, or plastic) can be recycled, approximately 80-90% of total MSW currently landfilled can be economically processed.

Third, MSW biomass availability is correlated with population. A region with a population of more than 100,000 can be qualified for profitable MSW-ethanol production. Nonetheless, some communities are not feasible for ethanol production because the MSW density differs completely by region. A key economic parameter is tipping fees which are correlated to population density. Densely populated regions tend to have landfill site scarcity problem; therefore they have economic incentive to export MSW out of region (Repa 1997; McCathy 1998; Duff 2001). Tipping fees are a cost to use landfill, so landfill scarcity would result in an increase in tipping fees. Opening a MSW-ethanol plant nearby populated region would prevent interstate waste exporting and stabilize tipping fees.

The next step is to estimate the yield of ethanol and other sets of by-product per ton of MSW. Chapter IV describes the current available technology and presents reasonable yield estimations.

CHAPTER IV

TECHNOLOGY AND POTENTIAL PRODUCTS YIELD

The main objective of this chapter is to estimate the yield of ethanol and by-products under available technologies. No plant has started MSW-ethanol production at a commercial scale. Hence, uncertainty is an inevitable problem. Several technologies are available for biomass-ethanol production; their conversion efficiencies at a commercial scale are not proven. The paper focuses mainly upon a gravity pressure vessel (GPV). GPV is state-of-art technology that makes huge reduction of operation costs possible.

This chapter is organized in the following manner. First, I briefly describe current available technology and anticipated processing steps in MSW-ethanol plant at the commercial level. Note that the technology description section is not intended to compare cost-effectiveness among alternative technologies. Instead, it is aimed to present the trends of mainstream technology in both lab scale and commercial scale. This will help readers to realize that the technology is already ripe, but the problem lies in economic viability.

The next step is to estimate the yield of products per ton of MSW. The estimate is based on laboratory scale estimates from previous literature of engineering and biology, and also from personal communication with practitioners in the field. Although there are inconsistencies among researchers, the chapter presents a range of reasonable estimates. This is a vital step for Chapter V, which analyzes financial feasibility and sensitivity of MSW-ethanol production.

4.1 Molecular Mechanism of Biomass-Ethanol Conversion Process

First, the paper describes chemical structure of biomass itself, and the conversion process of biomass to ethanol. Biomass is principally composed of cellulose, hemicellulose, and lignin. The first two are composed of chains of sugar molecules. Cellulose contains glucose, which is the same type of sugar (a six carbon (C_6) sugar) that is found in corn-starch. In the plant cell wall, the cellulose molecules are interlinked by another molecule, hemicellulose. Hemicellulose contains mainly non-glucose sugars (five carbon (C_5) sugars), such as xylose. Lignin is a biopolymer rich in phenolic components, which provide structural integrity to plants. Current technological improvement allows the glucose and xylose to be extracted from cellulose and hemicellulose. These sugars are finally fermented to produce ethanol.

Figure 4.1 illustrates conversion of cellulose to glucose. Glucose is produced from cellulose by a step called *hydrolysis*; splitting the bonds in the cellulose to produce monomeric sugars.

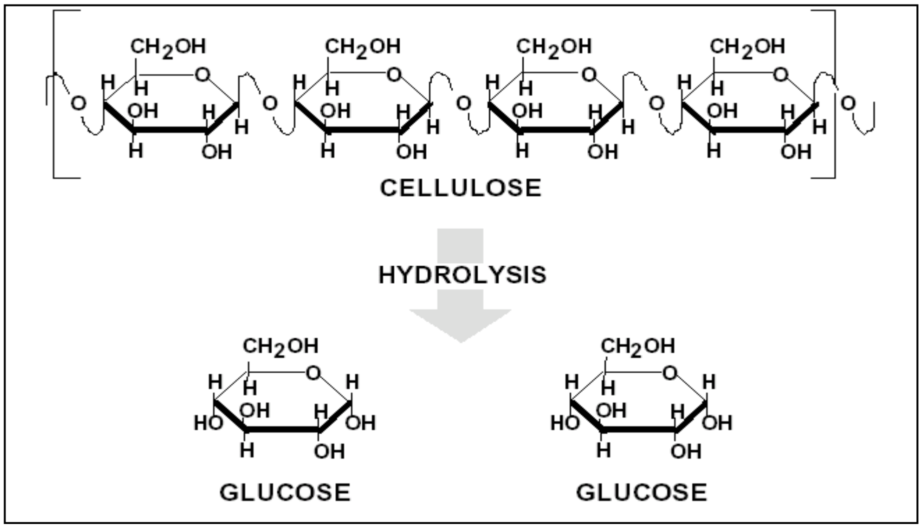


Figure 4.1 Conversion Process from Cellulose to Ethanol
Source: State of Hawaii, 1994

After the hydrogen bonding between cellulose chains is disrupted, cellulose is decrystalized and converted to glucose by using the appropriate technologies explained in next section. Ethanol is then produced from glucose in a process called *fermentation*. Figure 4.2 describes the fermentation process from glucose to ethanol.

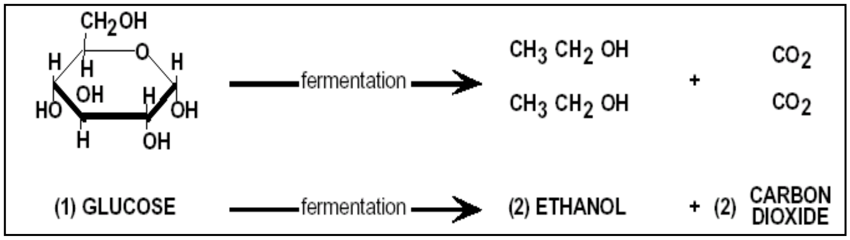


Figure 4.2 Glucose Fermentation
Source: State of Hawaii, 1994

Figure 4.1 shows that one molecule of glucose ferments into two molecules of ethanol and two molecules of carbon dioxide. Molecular weights of glucose, ethanol, and carbon dioxide are 180, 46, and 44 respectively. The molecular weight of two molecules of ethanol is 92 (46*2). Thus, the weight of ethanol produced is just over half (51%) of the weight of glucose input, and carbon dioxide accounts for the other half (49%).

Similar to glucose, hemicellulose can also be extracted from biomass and be transformed into xylose. Figure 4.3 illustrates the xylose fermentation process. Fermentation changes xylose into ethanol, carbon dioxide, and water. However, this fermentation process is not as simple as glucose fermentation. Different laboratory results show different potential yields of ethanol from hemicellulose (Roberts and Hilton 1988). Table 4.1 shows assumed technological efficiency. It is apparent that hemicellulose-xylose-ethanol conversion indicates a wide range of variation (20-81%). However, special microorganisms have recently been genetically engineered to ferment 5-carbon sugars into ethanol with relatively high efficiency (Badger 2002).

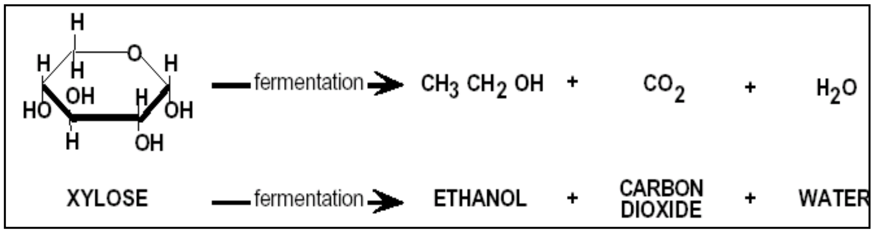


Figure 4.3 Xylose Fermentation
Source: State of Hawaii, 1994

Table 4.1 Technological Efficiency of Biomass to Ethanol Conversion

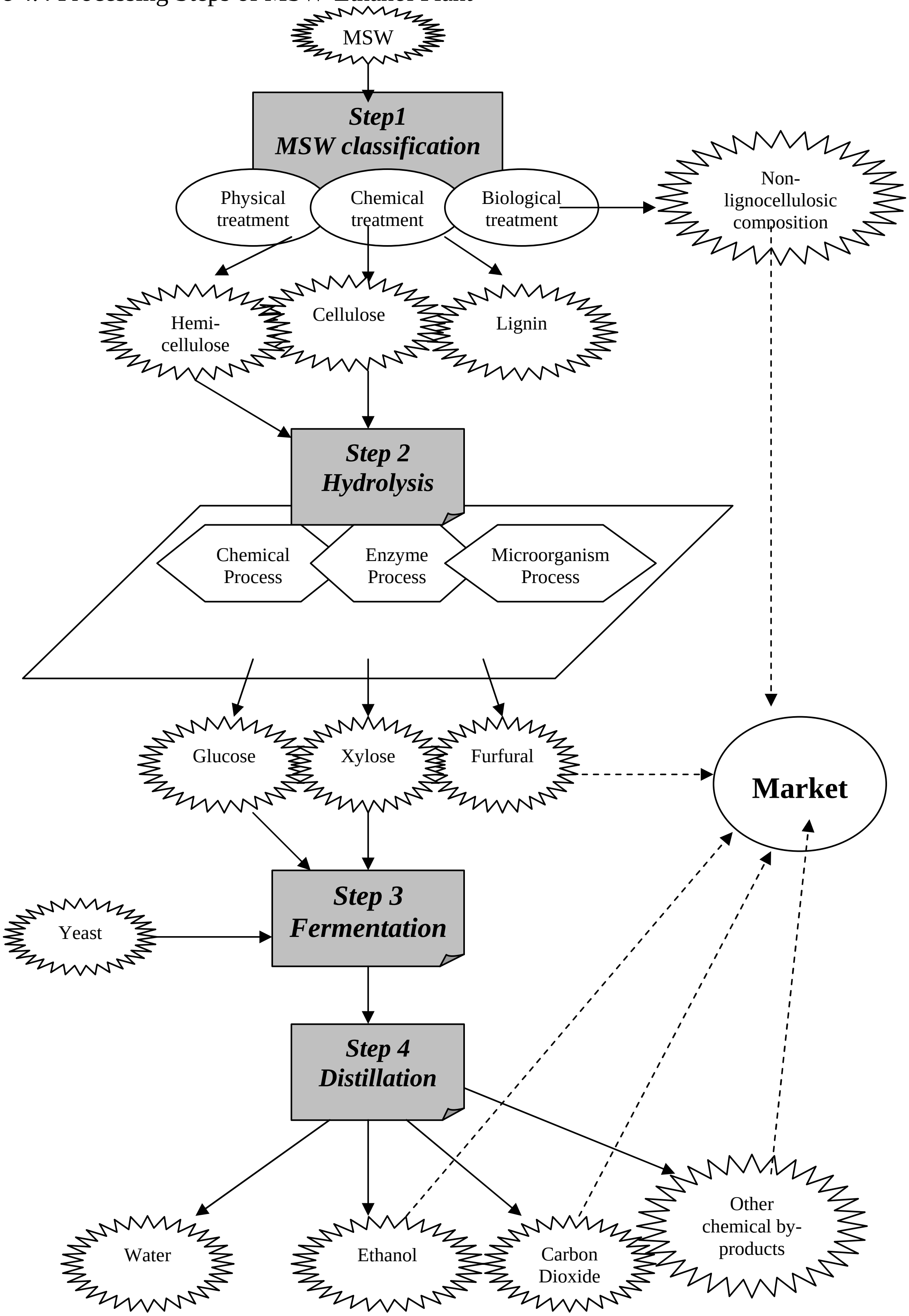
	Low estimate	High estimate
Cellulose to glucose	95%	100%
Hemicellulose to xylose	50%	90%
Glucose to ethanol	95%	100%
Xylose to ethanol	40%	90%
Cellulose to ethanol	90%	100%
Hemicellulose to ethanol	20%	81%

Source: State of Hawaii, 1994

4.2 Processing Steps

This section describes the technical steps that convert MSW lignocellulosic biomass into ethanol. In general, MSW-ethanol production processes comprise the following four components: (1) MSW classification, (2) hydrolysis, (3) fermentation, and (4) distillation. Figure 4.4 visually illustrates the operation of an MSW-ethanol plant. It is a simplified material flow chart, which omits details on many materials and chemicals added and generated at each step, but captures the key processes that occur.

Figure 4.4 Processing Steps of MSW-Ethanol Plant



4.2.1 MSW Classification

An initial step is used to separate the four principal components of biomass (i.e., cellulose, hemicellulose, lignin, and extractives) and make them accessible to further chemical and biological treatment (Mann and Bryan 2001). The process is generally followed by physical, chemical, and biological steps. *Physical pretreatment* is essentially cleaning, grinding, or shredding feedstock to sizes that are appropriate for subjecting to the hydrolysis process to liberate sugars. *Chemical pretreatment* is the process that uses chemicals to make feedstock more digestible. *Biological pretreatment* is done to solubilize lignin and make cellulose more vulnerable to hydrolysis and fermentation.

Non-lignocellulosic composition in MSW is sorted out and shipped to the recycling market if it has high salvage value. Aluminum, ferrous metal, or plastic is potentially salable if appropriately extracted. These are recovered either by hand picking or by automated waste separation processes from daily MSW fluff.

Note that the pretreatment procedure varies depending on the choice of the hydrolysis technology. Usually enzymatic hydrolysis requires more costly pretreatment. Identifying optimal pretreatment steps would result in the reduction of capital investment required for hydrolysis and fermentation steps.

4.2.2 Hydrolysis

There are many approaches to the process of converting cellulose, hemicellulose, and other complex forms of sugars into monosaccharides appropriate for fermentation.

Most commonly known hydrolysis technologies are *dilute acid hydrolysis*, *concentrated acid hydrolysis*, and *enzymatic hydrolysis*.

The dilute acid hydrolysis process is one of the oldest, simplest, and most efficient methods of producing ethanol from biomass. The economic analysis of TVA is based on this process (Broder *et al*. 1993). Dilute acid hydrolysis is used to hydrolyze the biomass to sucrose. In dilute acid hydrolysis process, lignocellulosic biomass is treated with low concentration acids at high temperatures for a short duration, ranging from a few seconds to minutes. The advantages of dilute acid hydrolysis are quick reaction times and low acid consumption. However, high temperatures increase the rates of 5-carbon sugar decomposition and equipment corrosion (Jones and Semrau 1984). Sugar degradation products can also cause inhibition in the subsequent fermentation stage (Larsson *et al*. 1999). Consequently, under these conditions the glucose yield is only between 50% and 60% of the theoretical yield (Wyman 1996).

To decrease sugar degradation, a two-stage process has been developed. The first stage is conducted under mild process conditions to recover the 5-carbon sugars, while the second stage is conducted under harsher conditions to recover the glucose. However, even after using the two-stage dilute acid hydrolysis process, even though 5-carbon sugars are recovered somewhat, the yield of glucose is still only about 50%.

Concentrated acid hydrolysis dissolves and hydrolyzes cellulose into glucose sugar using concentrated sulfuric acid, followed by dilution with water (Mann and Bryan 2001). It uses relatively mild temperatures and the only pressures involved are usually those created by pumping materials from vessel to vessel. TVA began developing this technology in the 1950s (Broder *et al* 1991). Arkenol Inc. uses this technology in its rice straw ethanol plant at Rio Linda in Sacramento County, California, in the late 1990’s (Arkenol 2004). The proposed plant of PMO in the city of Middletown, New York, also utilizes concentrated acid hydrolysis.

The advantage of concentrated acid hydrolysis is a high sugar recovery efficiency of nearly 90% of both cellulose and hemicellulose yields. The drawback of this process is that it is relatively slow, and cost effective acid recovery systems have been difficult to develop. Without acid recovery, large amounts of lime must be used to neutralize the acid in the sugar solution and this neutralization forms large quantities of calcium sulfate, which requires disposal and creates additional expense.

Enzymatic hydrolysis is the process that uses enzymes as catalysts to break down the biomass in a similar way. Since cellulose is usually protected by a matrix of hemicellulose and lignin, enzymatic conversion of cellulose to sugar is extremely slow (Galbe and Zacchi 2002). Thus, for an enzyme to work, pretreatment of the raw material is necessary to expose the cellulose.

One example of enzymatic hydrolysis is the simultaneous saccharification and co-fermentation (SSCF) that combines hydrolysis and fermentation in one vessel. Because sugars produced during hydrolysis are immediately fermented into ethanol, this process can eliminate problems associated with sugar accumulation and enzyme inhibition. Moreover, the SSCF process can control by-product yield effectively with much less process energy requirement. Unfortunately, the SSCF process, including input cost of enzymes, is very expensive and is still in its early stages of development.

Until now, acid hydrolysis is considered a technologically and economically more feasible process compared to enzymatic hydrolysis. If enzymatic process became a cheaper option, however, it would be a more efficient way to produce ethanol from MSW in the long run.

4.2.3 Fermentation

Fermentation is the process of yeast converting sugar into ethanol and carbon dioxide. The efficiency of fermentation by yeast has dramatically improved over the past decade. Bacterial fermentation processes have also drawn increasing attention from researchers because of their speed of fermentation. One example is a genetically engineered microorganism, developed by the University of Florida, that has the ability to ferment both 5- and 6-carbon sugars. In general, bacteria can ferment in minutes as compared to the hours of yeast (Badger 2002). Thus, the speed of fermentation is predicted to be shorter in the near future.

4.2.4 Distillation

Ethanol is initially obtained in a mixture with water. Distillation is the primary step in removing the ethanol from water and other residual solids after fermentation. The water and ethanol mix is heated to evaporate the ethanol, which is then cooled and collected. However, it is impossible to purify the ethanol beyond about 95% purity (190 proof), because there is a homogeneous azeotrope at a composition of roughly 95% ethanol and 5% water. At this composition the liquid and vapor phases in a distillation operation have the same composition and so no further separation of water from ethanol can be accomplished. In order to blend with gaolisne, the last 5% must be removed. This is typically acomplished using azeotropic distillation or molecular sives (Mann and Bryan 2001).

4.2.5 Processing Steps by GeneSyst

This section describes ten actual processing steps used by GeneSyst. In each of the following steps that are outlined, MSW progressively chanbges from a random size and flow rate, to a consistent material ready for industrial process methods, and then converted into ethanol and other chemical by-products.

The first step is to receive wastes. Wastes are imported to the tipping floor of the processing facility. Wastes are handled indoors to prevent wind blown debris and to effect vector control.

Then, MSW is subjected to a picking line to remove marketable goods (e.g., aluminum) or materials that will interfere with the reaction to convert cellulose fibers to glucose (e.g., tires, plastic, or leather). The hand picked separation is the simplest way to accomplish both visual inspection as well as selective removal of selected items. Certain wastes such as florescent lights and batteries are segregated due to their toxic content.

The next three steps are automated MSW classification steps. The third step chops the remaining waste into uniform size of roughly two to four inches. The solid waste piece is then discharged into water flood tank at the fourth step. At this step, light material bits such as styrofoam float to the surface and materials that are dense sink to the bottom and are removed by a small conveyor. These washed materials are recycled or shipped to landfill. The fifth step uses a conventional clarifier. At this process, materials which are rich in cellulose settles to the bottom since cellulose is slightly heavier than water. The same tank will remove the last of the plastics that are lighter than water.

The sixth process is hydrolysis. GeneSyst uses GPV for its hydrolysis with technologically and economically efficient way. The next section presents technological description of GPV process.

After hydrolysis, water mix including sugars converted from cellulose, goes through one more cleaning step, which is similar to the fifth step. Dirt particles, dust, lime, gypsum sink to the bottom, while bits of wax or plastic float to the surface. The next two steps are conventional fermentation and distillation processes. At the final step, liquids prepared for sale are stored.

4.3 Technological Description of GPV

Historically, production of ethanol has been limited to using sources of soluble sugar or starch (primarily in the Midwest using corn). This is because producing glucose from cellulose and hemicellulose at high yields is a far more complex process than deriving sugars from corn starch. Therefore, although the feedstock cost of lignocellulosic biomass is far lower, the cost of obtaining sugars from such materials has been historically far too high to attract industrial interest.

However, new technologies have been developed that now allow for the production of ethanol from lignocellulosic biomasses. The technical progress has been accompanied by commensurate economic improvement. There are various technological options available to convert lignocellulosic biomass into ethanol. Some government laboratories, academic institutions, and private sector companies have devised various techniques to accomplish each of the steps required to process biomass to ethanol.

To our best knowledge, GPV is one of the most promising technological developments applicable to MSW-ethanol production; in fact, it will be used by both GeneSyst and Genahol-Arizona. GPV is a pipe that hangs vertically inside a steel-lined chamber, drilled and cemented into the earth (illustrated in Figure C.1 in Appendix C). Wastes and water enter at the top of the pipe, and are directed downward to the bottom of the pipe and then back up and out. The principles of the technology are that water at very high pressure is contained underground in the form of liquid steam. Water at this supercritical state will dissolve oil, coal, and most any organic chemical. The more pressure, the more heat, and it is the heat that speeds up the reactions that deteriorate waste.

Once dissolved in water, organics are quickly manipulated by injecting oxygen, acid, or a catalyst to achieve the desired end product (GeneSyst 2004). The ability of GPV to cause the entire flowing stream can make chemical condition induced or quenched within seconds so that the chemical yields of interest can be controlled. Thus, GPV functions simultaneously as a means of pressurization and de-pressurization, a counter-flow heat exchanger, a pump with gas and thermal lift, a liner, and a plug flow chemical reactor. This technology is applicable to the largest identified U.S. waste market.

The major advantage of the GPV process is as follows:

- Temperature and chemical condition can be controlled, so yields of desired chemical product are maximized.
- Temperature and chemical condition can be controlled, so plants can handle a broad spectrum of wastes.

- Due to simultaneous pressurization, de-pressurization, preheating, and chemical reaction, plants can economize time significantly. The reaction time is much shorter than a biological reaction, and even shorter than conventional technology.
- GPV uses the gravity of pressurization. The pressure in the depth of water increases without regard to whether the water or fluid is moving or not moving, so pressurization without moving parts is accomplished. This results in a reduction of operation cost.
- GPV process does not need de-watering prior to treatment, so it is not hampered by the wetness of the wastes that typically occurs during the rainy seasons, when wastes can become too wet to incinerate.
- The cost to place a facility with GPV is inexpensive. Facilities require much less space compared to a conventional landfill. Moreover, it requires a shorter period (one year) of construction compared to the old technology (one and half years, estimated by TVA).
- GPV is a closed linear process vessel. Additionally, neither CO nor nitrogen oxide (NOx) is produced during oxidation in water. Thus, plant operators are not exposed to air emissions and plants can be located near areas of high concentrations of MSW, including existing or old landfill sites. It can be located even in the city.

In Chapter V, I estimate plant economics of 500 tons per day plant based on GeneSyst's technological efficiency.

4.4 Potential Ethanol Yield

4.4.1 Theoretical Assumption

In section 1, molecular transformation mechanism of lignocellulosic biomass into ethanol is briefly explained. Though the idea is quite straightforward, estimation of potential ethanol yield is complex. This is primarily because 5-carbon and 6-carbon sugar content is dissimilar among various kinds of biomasses. An example is illustrated in Figure 4.5 that is prepared for a plant in California, which converts agricultural residues into ethanol. The percentage of glucan and xylan (a polymer of glucose and xylose respectively) is different among the three plants. While poplar sawdust contains more glucan and less lignin, corn stover contains a higher percentage of lignin and a low fraction of glucan. Theoretically, biomasses resourced that have high cellulose content and low lignin content are more desirable as feedstock for ethanol production.

Current available technology makes it possible to convert most 5-carbon sugars and 6-carbon sugars into ethanol (Titmas 2004). Thus, as long as we know the sugar composition, we can obtain an approximate estimation of the ethanol yield. However, MSW is a mixture of miscellaneous wastes. Not only lignocellulosic composition of MSW (paper, food, wood, and yard waste) is different, but also the sugar content of each material is different among communities.

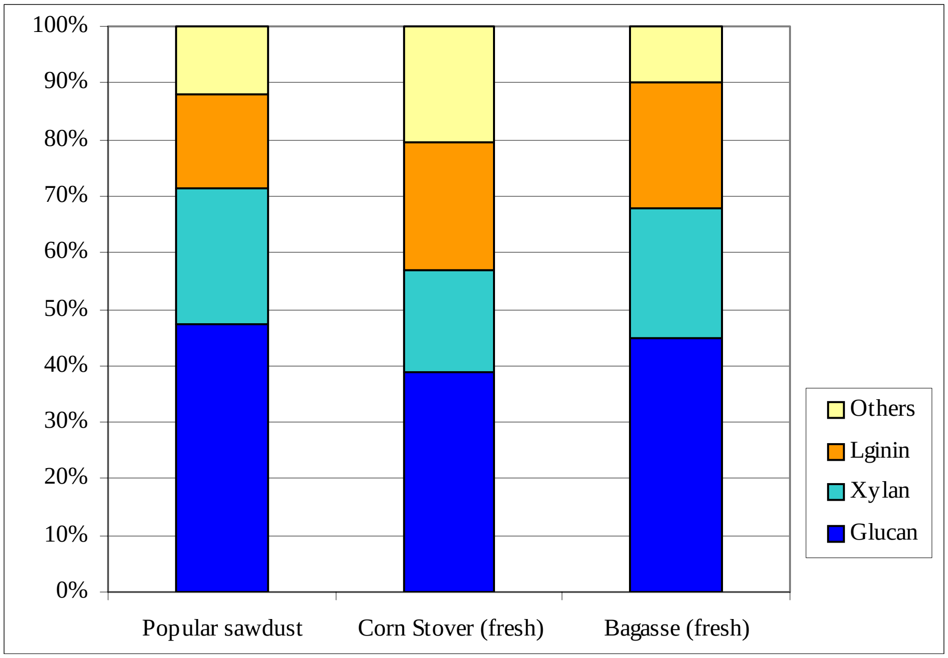


Figure 4.5 Sugar compositions of Poplar Sawdust, Corn Stover, and Bagasse
Source: Titmas, 2004

Table 4.2 summarizes the theoretical yield, near-term yield, and mid/long-term yield of ethanol from various kinds of biomass resources. Expected conversion yields at a commercial ethanol plant are based on the estimation by the National Renewable Energy

Laboratory (NREL) (Wooley *et al*. 1999). Estimation is measured by gallons of ethanol per bone-dry ton (BDT). Mann and Bryan (2001) further process the NREL data to estimate feedstock requirements that sustain sufficiently the different size of facilities; 20, 40, 60 million gallons per year (MGY), case respectively.

It is obviously seen that theoretical ethanol yields vary by biomass feedstock. Additionally, as noted several times in this paper, ethanol yields of paper waste are the highest among all kinds of biomass feedstock. Near-term estimation is based on the hydrolysis conducted by dilute acid processes. Technological efficiency may be different if other technologies are used. However, Mann and Bryan (2001) state that other hydrolysis processes with dilute acid or enzymatic hydrolysis should not vary by more than ±15% from estimation. Furthermore, yields from concentrated acid hydrolysis process, as typified by PMO and Arkenol, may be close to Mid-long-term yield in Table 4.2.

Table 4.2 Estimated Feedstock Requirements for Various-Sized Biomass-Ethanol Plant

Category of biomass resource	Category of waste	Theoretical yield[18] (gal/BDT)	Near-term yield[19] (gal/BDT)	Biomass required to supply various-sized ethanol facilities (K BDT)			Long/mid-term yield[20] (gal/BDT)	Biomass required to supply various-sized ethanol facilities (K BDT)		
				20MGY	*40MGY*	*60MGY*		*20MGY*	*40MGY*	*60MGY*
Paper	MSW	127.8	63.0	317	635	652	95.3	210	420	630
Urban Wood Waste	MSW	108.2	45.6	439	877	1316	66.6	300	601	901
Urban Yard Waste	MSW	91.8	45.6	439	877	1316	66.6	300	601	901
Food Processing Waste	MSW	N/A	43.6	459	917	1376	64.4	311	621	932
Field and Seed Crop Residue	Agriculture Residue	102.0	55.1	363	726	1089	85.5	234	468	702
Wheat Straw	Agriculture Residue	114.1	57.6	347	694	1041	84.2	238	475	713
Corn Stover	Agriculture Residue	113.3	57.2	349	699	1049	83.6	239	478	718
Switch Grass	Energy Crops	97.4	43.6	458	917	1375	64.4	311	621	932
Forest Sslash/Thinning	Forest Residue	112.8	66.5	301	602	902	94.8	211	422	633
Lumber Mill Waste	Forest Residue	112.8	59.5	336	642	1008	82.5	242	485	727
Aspen	Forest Residue	131.0	77.3	259	518	776	110.0	182	363	545
Ponderosa Pine	Forest Residue	112.9	66.6	300	601	901	94.8	211	422	633
Poplar	Forest Residue	111.4	65.7	304	609	912	93.6	214	427	641

Source: Mann and Bryan, 2001

Recall that the national average of lignocellulosic composition in MSW generated estimated by the U.S. EPA is paper at 37.4%, wood 5.5%, yard trimmings 12.0%, and food scraps 11.2%, respectively by weight. Applying the moisture content assumption in Table 3.2 results in 27.9 gallons per ton of MSW by dilute acid hydrolysis, and 41.9 gallons per ton by concentrated acid hydrolysis.

More realistically, suppose a MSW-ethanol plant only utilizes landfilled MSW, and some fractions are recovered due to high value in salvage market. Recall again that the U.S. EPA's estimate of lignocellulosic composition in MSW landfilled is paper 29.2%, wood 7.5%, yard trimmings12.0%, and food waste 15.6%. This assumption leads to 23.4 gallons per ton of MSW by dilute acid hydrolysis and 35.3 gallons per ton by concentrated acid hydrolysis. Projected ethanol yield is lower in the case that landfilled

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[18] Data compiled by Quang Nguyen, National Renewable Energy Lab (NREL).

[19] Near-term yields are based on current NREL two-stage dilute acid experiments and models.

[20] Mid/long-term yields are based on NREL projections for performance of the SSCF.

MSW is converted to ethanol because lignocellulosic composition is lower in landfilled material due to the high recycling rate in paper and yard waste.

Table 4.3 Estimated Ethanol Yield per Ton of MSW

		Theoretical yield (Gal/BDT)	Dilute acid hydrolysis (Gal/BDT)	Concentrated acid hydrolysis (Gal/BDT)	Composition in MSW (%)	Moisture content (%)	Theoretical yield (Gal/T)	Dilute acid hydrolysis (Gal/T)	Concentrated acid hydrolysis (Gal/T)
MSW generated	Paper	127.8	63	95.3	37.4%	6%	44.9	22.2	33.5
	Wood	108.2	45.6	66.6	5.5%	20%	4.7	2.0	2.9
	Yard	91.8	45.6	66.6	12.0%	60%	4.4	2.2	3.2
	Food	N/A	43.6	64.4	11.7%	70%	N/A	1.5	2.3
Total Yield per Ton =							**>54.1**	**27.9**	**41.9**
MSW landfilled	Paper	127.8	63	95.3	29.2%	6%	35.1	17.3	26.2
	Wood	108.2	45.6	66.6	7.5%	20%	6.5	2.8	4.0
	Yard	91.8	45.6	66.6	7.4%	60%	2.7	1.3	2.0
	Food	N/A	43.6	64.4	15.6%	70%	N/A	2.0	3.0
Total Yield per Ton =							**>44.4**	**23.4**	**35.2**

4.4.2 Assumptions in the Field

There are wide ranges of variation in the estimates of ethanol yield per ton of MSW at front-line businesses. According to personal communication with Yaency in BBI International, Inc., ethanol yield can be 60 gallons per BDT of MSW biomass feedstock (Yaency 2004). He further stated that this was a conservative estimate and that it could be increased to 80 gallons in the future. Assuming moisture content is 30% and lignocellulosic composition in MSW is 55-70%, ethanol yield ranges from 23.1 gallons per ton to 39.2 gallons per ton.[21]

According to a laboratory simulation of GeneSyst, yield with its GPV process may run as high as 100 gallons per BDT or as low as 35 gallons per BDT (Titmas 2004). Assuming again that moisture content is 30%, yield ranges from 24.5 gallons per ton to 70 gallons per ton. GeneSyst uses an assumption that ethanol yield would be 50 gallons

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[21] Low end of estimate is 60*(1-30%)*55%. High end of estimate is 80*(1-30%)*70%. 30% is moisture content, 55%-70% is estimated lignocellulosic composition in MSW landfilled.

per ton of MSW fluff as their proforma that was presented to financial and permitting authorities.

Estimated ethanol yield by Arkenol (2004), though it focuses on agriculture residues (i.e. rice straw) instead of MSW biomass feedstock, would be a good indicator since their technology is concentrated acid hydrolysis. This is used by both PMO and GeneSyst. Arkenol estimated 120 gallons of ethanol could be yielded per BDT of prepared feedstock.[22] Derived ethanol yield per MSW would be 46.2 gallons to 58.8 gallons.[23]

Fox *et al* (1999) estimated the ethanol yield of a MSW-ethanol plant of Genahol-Arizona, Inc with GPV acid hydrolysis in Maricopa County, Arizona to be approximately 33.3 gallons.[24]

This inconsistency largely comes from different technological efficiency assumptions. MSW-ethanol production requires innovative technology without a precedent operation. Processing steps, though fundamentally identical, may also be different by plants. Estimates are based on the MSW composition of the local community where the plant is supposed to be located. The richer the lignocellulosic composition in MSW, the higher the estimation. No two communities show the same material consumption pattern; therefore, it results in dissimilar ethanol yield estimations. In this sense, a prior material balance survey is vital to avoid potential loss of a raw material supply.

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[22] Arkenol estimates 500 tons of feedstock generates 60,000 gallons of ethanol daily.

[23] Low end of estimate is 120*(1-30%)*55%. High end of estimate is 120*(1-30%)*70%.

[24] Fox *et al*. (1999) mentions 150 tons MSW/day results with 300 days operation a year results in 1.5 million gallon ethanol/year, and 250 tons MSW/day results in 2.5 million gallons ethanol/year. From this assumption, we can derive ethanol yield per ton (33.3 gallons).

Compared by NREL estimates, yield assumption of GeneSyst and Arkenol seems too bullish to be true. Their estimate is close to theoretical ethanol yield per ton of landfilled MSW. Taking the uncertainty inherent in technological possibility of MSW-ethanol conversion on a commercial basis, yield assumptions between 25 gallons and 30 gallons per ton of MSW are more reasonable for the base case economic analysis. In Chapter V, 25 gallons per ton is first used for the base case. This would be a conservative estimate since it is only half of GeneSyst's estimate – 50 gallons per ton of MSW. Later in Chapter V, I conduct sensitivity analysis to see how profitability is vulnerable to assumed ethanol yield per ton of MSW.

4.5 Potential By-Product Yield

4.5.1 Assumption in the Field

Between the conversion of cellulose to sugars and then fermentation, several chemical by-products are produced that can be extracted and sold. For profitability analysis, yield of the by-product should be known. However, a set of by-products generated and their yield per ton of MSW also varies by technology and procession steps. Even though technology makes it possible to produce by-products, it is not always sellable unless a sufficient amount is produced and salvage price is high enough to offset extraction and marketing costs. Therefore, we cannot generalize by-product yield.

Table 4.4 illustrates by-product yield per ton of MSW by laboratory simulation of GeneSyst. Other than the by-products illustrated below, several other by-products including xylose, acetic acid, levulininic acid, glycol, and urea are produced (Titmas 2004). However, these are not significant in total economic impact due to small their quantities. If marketing cost and extraction cost is unreasonable, it exceeds the revenue from these by-products. I use these by-product yield estimates for the base case in profitability analysis in the next chapter.

Table 4.4 Yield of Marketable Chemical Product per ton of MSW by Material Balance Survey by GeneSyst

	Yield by one ton of MSW
Furfural	20 lbs
Yeast	12 lbs
Gypsum	11 lbs
CO_2	50 lbs

Source: Titmas, 2004

4.5.2 Description of By-Products

Furfural

Xylose, the primary sugar in hemicellulose, can be further processed in the presence of acid to furfural and it is separated before the fermentation step (ARI 1999). Therefore, yield of furfural is dependent on the hemicellulose composition of incoming MSW. Furfural is a chemical intermediate that can be reacted to manufacture furfuryl alcohol and other specialty products used in foundry resins, urethanes, building materials, chemical intermediates, and refining solvents (Great Lakes Chemical Corporation 1987). It can also be used as a selective solvent for refining high quality lubricating oils (State of Hawaii 1994) and can be used as a substitute for formaldehyde (Fox *et al*. 1999). As long as the market is identified, furfural is valuable product.

Furfural is usually produced from agricultural wastes that contain pentosans. The most common materials used for furfural production are corncobs, cottonseed hull bran, oat hulls (cleaned), cottonseed hulls, bagasse and rice hulls. U.S. furfural consumption in

2000 amounted to over 35 thousands MT. Between 1995 and 2003, four furfural plants were shut down, causing an annual capacity loss of 90 thousand MT. This is attributed to inexpensive furfural imports from China and the Dominican Republic.

During the early 1990s, world furfural production shifted from developed countries to developing countries. The largest furfural producers today are China and the Central Romana Corporation in the Dominican Republic, while U.S., Europe (excluding Russia) and Japan are all net importers of furfural (Levy and Yokose 2004). It eventually resulted in the fact that there is only one U.S. producer, Quaker Oats-Pepsico, which uses oat by-products to make furfural. Overall, U.S. furfural consumption is expected to remain constant over the next five years.

Carbon Dioxide

As noted in section 1, for every ton of ethanol produced, theoretically one ton of carbon dioxide is produced from the fermentation process. Carbon dioxide can also be recovered from combustion flue gases. It is a common practice for industrial gas companies to supply and install equipment to recover, purify, and liquefy the CO_2 produced during fermentation (Broder *et al*. 1993). Its major use is food freezing, chilling, and as a refrigeration agent after it is compressed to be dry ice. Another usage is for the carbonation of beverages. Both PMO and GeneSyst plants recover and sell carbon dioxide as a by-product of MSW-ethanol production.

Gypsum

A certain amount of gypsum is produced as a salable by-product. It can be used in agriculture to raise the pH level of the soil. Also, lime and gypsum are demanded in the construction industry. There are plenty of other uses, including acid mine drainage neutralization, industrial applications, raw material for quick lime production, industrial waste pretreatment, landscaping, structural soil conditioning, electric utility and industrial steam emissions control, and steel making (Fox *et al*. 1999). Use of MSW by-product gypsum would provide several advantages to a cement plant. Cement plants using by-product gypsum would be able to reduce operating costs, since no grinding or crushing would be required (Broder *et al*. 1993).

Yeast

The metabolism of saccharine by yeasts (fungi) produces carbon dioxide, ethanol, and degraded protein, which end up as more yeast.[25] Yeast contains rich protein. Protein is a valuable component of biomass that is currently neglected in fuels and chemicals from biomass schemes (Dale 1983). As long as extraction cost is reasonable, yeast is sold to the animal feed industry as a livestock or pet food protein enhancements, but can also be suitable for human consumption.

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[25] Yeast can be recycled; however, it is usually best to separately cultivate a pure strain desired by the process, then feed it into the fermentation tank (Titmas 2004).

4.6 Concluding Remarks

Chapter IV briefly describes technology applicable to MSW-ethanol production, operation structure, and potential ethanol and by-product yield. Main findings of this chapter are as follows.

First, MSW-ethanol conversion is typically a four step process: MSW classification, hydrolysis, fermentation, and distillation. Since enzymatic process is not yet ripe technology and cost reduction is not yet achieved, taking this present state into consideration, acid hydrolysis is currently the most economically and technologically applicable hydrolysis process. GPV technology appears to have significant economic and environmental advantages in making commercial scale MSW-ethanol production feasible.

Second, ethanol yield estimate is uncertain, but we can assume a potential yield between 20-50 gallons per ton of MSW. Inconsistency attributes to different technology and local variations in MSW composition. For the base case economic analysis, I used 25 gallons per ton of MSW assumption.

Finally, various salable chemical by-products can be produced from the MSW-ethanol conversion process. Yield of these products cannot be generalized. Different technologies create different sets of by-products. Marketability of by-products is site specific. Even though yield is high, the by-product is not salable unless the market is identified. In Chapter V, I use the by-product yield assumption summarized in Table 4.2 for profitability analysis and assume markets for these products are available.

CHAPTER V

ECONOMICS OF MSW-ETHANOL PRODUCTION

This chapter answers the key question of the thesis: is the MSW-ethanol production industry economically feasible? Since there are no commercial operating MSW-ethanol production plants in the U.S., or anywhere in the world for that matter, uncertainty is an inevitable problem. I cannot use econometric analysis to derive a firm's profit function due to lack of historical/observational data. Instead, I use estimates from a real firm's private cost of an ethanol plant with the best available technology. Throughout the chapter I evaluate profitability of plant economics over the plant's economic life. Analysis is organized as follows. First, I identify possible revenues and costs of ethanol plant. Second, I estimate cash flow of a MSW-ethanol plant by processing available data. Third, partial sensitivity analysis is presented to analyze possible combination of input influencing profitability and robustness of profitability of plant economics. Finally, I discuss the potential economic and political barriers a MSW-ethanol plant would face when it entered the SWM market.

5.1 Data

I obtained data on the estimated costs for a 500 TPD MSW-ethanol plant through personal communication with Mr. Titmas, the chief executive officer (CEO) of GeneSyst International, Inc. (Titmas 2004). These data are based on a preliminary profitability analysis of a 500 TPD plant. The yields of various kinds of by-products are based on laboratory and pilot plant simulation of GeneSyst, which is summarized in Table 4.2 in Chapter IV. The prices for several salable products are derived from miscellaneous literature. The sources are discussed in the following section.

5.2 Estimate of MSW-Ethanol Plant Economics

5.2.1 Net Profit Function Model

First of all, the paper specifies the annual net profit function of the ethanol plant. Although there are some inconsistencies, previous studies identify three revenue sources: sales of ethanol, sales of recycled materials, and sales of chemical by-products. Recyclables include aluminum, ferrous, and plastic. Chemical by-products include furfural, yeast, lime/gypsum, and liquid carbon dioxide.

Cost associated with MSW-ethanol production is divided into three prominent types. These are MSW biomass feedstock costs, plant operation costs, and overhead costs associated with general administration. The following model explains the economic structure of MSW-ethanol plant:

Profit function model,

$$\begin{aligned}\pi = [P_E Q_E (Q_{MSW}) + P_{RE} Q_{RE} (Q_{MSW}) + P_{BP} Q_{BP} (Q_{MSW})] \\ -[EF(P_{TIP} Q_{MSW}) + C_D Q_{MSW} + C_{ID}] \text{......................}(5\text{-}1)\end{aligned}$$

where,

Q_E = Quantity of ethanol generated (gallon/year)
Q_{MSW} = Quantity of MSW accepted by ethanol plant (tons/year)
Q_{RE} = Quantity of product recovered in MSW (tons/year)
Q_{BP} = Quantity of chemical by-product generated
P_E = Market value of ethanol ($/gallon)
P_{RE} = Salvage value of recycled material ($/ton)
P_{BP} = Market value of series of by-products ($/each unit)
P_{TIP} = Tipping fee charged by ethanol plant ($ton)
C_D = Direct cost ($/ton)
C_{ID} = Indirect cost ($/year)
EF = Efficiency factor (%)

5.2.2 Ethanol Sales

The first term in the equation (5-1), $P_E Q_E (Q_{MSW})$ indicates the revenue from ethanol sales. Q_E is function of $Q_{MSW,}$ because a certain proportionate amount of ethanol is generated from a ton of MSW. As noted in the last chapter, I used a 25 gallons yield assumption in base-case analysis.

The price of ethanol is listed in the Chemical Market Reporter. Currently, ethanol is priced around $1.30 per gallon, fluctuating between $1.00 and $1.50 per gallon for the last decade (Figure 2.5). In the base case scenario, a ton of MSW yields $32.50 from ethanol sales.

5.2.3 Sales of Recovered Material

$P_{RE}Q_{RE}(Q_{MSW})$ indicates sales revenue of recovered material. P_{RE} is the salvage value of material recovered by front-end MSW classification system. $Q_{RE}(Q_{MSW})$ expresses that material recovered is dependent on the amount of MSW classified. In a social perspective, this can be regarded as “value of material recovered”, since these materials are normally dumped into landfill without recycling.

All salvage values and possible yield of by-product a ton of MSW are presented in Table 5.1. Yield of aluminum, ferrous, and plastics in MSW were derived from the *Solid Waste Handbook* estimated by the U.S. EPA (1997). Prices for aluminum and ferrous were obtained from *Waste News,* for the Chicago market.

Aluminum is the most valuable recyclable in market. It can be sold to sheet mills and secondary smelters. Aluminum is now worth 22.5¢ per pound. Ferrous metals also have huge markets in the steel and mining industries. Ferrous can be marketed for $30 a ton.

Note that revenue from plastic sales is excluded in the base case because salvaged plastic has a very poor value. To market salvaged plastic, it must be sorted by type and color, chipped, masticated, and converted to palletized form to allow for bulk pneumatic handling. The end value, roughly $10 to $20 per ton in that form, is not a strong profit center. Hand sorted baled plastic has a value of about $8 per ton, but it costs $16 per ton to transport and $4 per ton to sort out from incoming miscellaneous MSW streams (Titmas 2004).

In fact, the choice combination of material recycling is fairly site specific. Thus, a MSW classification system should be modified to match local market trends. If the salvage value of plastic exceeds enough to offset separation costs, MSW-ethanol plants would count plastic as a revenue source. At this time, because of the current poor salvage value of plastic, it is not included in the profitability analysis.

Other materials (e.g., glass) can be marketed but have limited market value and small yield. Moreover, purity is required for other materials to be marketed. Thus, the analysis includes only aluminum and ferrous metal as profitable recovered material.

5.2.4 Chemical By-Product Revenue

As described in Chapter IV, lignocellulosic biomass is converted into several chemical by-products besides ethanol. Yields of furfural, yeast, gypsum (lime), and CO_2 are based on the GeneSyst mass balance calculations (GeneSyst 2004). The market values of gypsum, yeast, and furfural are obtained from *Chemical Market Reporter*. Finally, market value assumptions for CO_2 are based on the sales experience of *GeneSyst* (Titmas 2004). Table 5.1 summarizes the yield and value of by-products. The potential value of furfural, yeast, gypsum, and CO_2 per ton is \$5.00, \$4.44, \$0.06 and \$0.75, respectively.

Table 5.1 Summary of Market and Salvage Value of Products.

	Yield by one ton of MSW	Price	$ per one MSW ton
Ethanol	25 gallon	$1.30 per gallon	$32.50
Aluminum	28 lbs	$450.00 per ton	$6.30
Ferrous	112 lbs	$30.00 per ton	$1.68
Plastic	200 lbs	-	-
Furfural	20 lbs	$0.25 per lbs	$5.00
Yeast	12 lbs	$0.37 per lbs	$4.44
Gypsum	11 lbs	$10.00 per ton	$0.06
CO_2	50 lbs	$15.00 per ton	$0.75

5.2.5 Feedstock Cost

The first term in cost function, $EF(P_{TIP}Q_{MSW})$ is the MSW feedstock cost. The tipping fee is the price of the waste disposing service, or in other words, the cost for leaving the garbage on the tipping floor of the waste processing facility or landfill. This economic structure is opposite to ethanol plants in that it is based on corn-starch or other lignocellulose biomasses. Those plants must bear the cost for purchase input for ethanol production. The motivation of a MSW-ethanol plant is the negative feedstock cost. Waste itself becomes a revenue source for a MSW-ethanol plant.

EF is technological efficiency, which describes the percentage of incoming MSW by weight converted into economically valuable goods. Normally 100% of waste cannot be destroyed, thus, the remaining fraction of MSW that is neither marketed nor reused should be shipped to a landfill, paying the same unit price per ton of MSW. A high efficiency factor implies the substantial amount of waste that can be processed to profitable material, while a low efficiency factor means a large percentage of incoming MSW needs to be landfilled. Waste disposal cost is expressed in the following way:

$$\text{Waste disposal cost} = (1 - EF)(P_{TIP}Q_{MSW}) \text{.........................} (5-2)$$

$$\text{Thus, net feedstock cost} = (P_{TIP}Q_{MSW}) - (1 - EF)(P_{TIP}Q_{MSW}) = EF(P_{TIP}Q_{MSW})$$

Masada (2004) estimates 90% of incoming MSW streams can be used, so only 10% is landfilled. This 90% assumption is the same as the estimate of GeneSyst (Titmas 2004). Fox *et al*. (1999) estimates EF of MSW-ethanol plant by Genahol-Arizona Inc. is approximately 75%. I use 90% assumption as base case.

Recall that the range of variation of tipping fees is very large, as the average tipping fee is considerably different across the nation. Indeed, tipping fee revenues assumed by GeneSyst, PMO, and Genahol-Arizona are \$20, \$65, and \$20-\$30 a ton, respectively. The tipping fee at the base case in the TVA’s economic analysis is \$45 a ton.

It should be noted here that the currently proposed ethanol plant proffers a contract that would not charge full tipping fees, unlike conventional MSW dumping landfills. GeneSyst offers disposition in the municipality for those MSW collecting and hauling companies at 80% of its alternative, \$20 per ton (Titmas 2004). Genahol-Arizona, Inc. charges only half the amount of the tipping fee (Fox *et al*. 1999). Part of the reason is the reduction of waste transportation costs. As noted in Chapter IV, MSW-ethanol plants can be located close to the center of residential area. Thus, waste transportation costs would be saved substantially as compared to landfill, which is normally located near a suburb or rural area (Fox 2004).

For the analysis, I first used the national average tipping fee of \$36 per ton, for the profitability analysis as base case (Chartwell Information 2003). Note that it is assumed that the ethanol plant is collocated with MRF or other sorts of waste processing facilities. Ethanol plants have to incur waste transportation costs if the plant is far from a landfill. Later in this chapter I analyze the impact of collocation on plant economics.

5.2.6 Direct Cost

There are two types of plant direct costs: MSW classification costs and plant operation costs. MSW classification cost is the cost for storing, separating, and pretreating MSW for further operation. Estimated classification cost is $3.85 a ton (Titmas 2004). Plant operation cost is the cost for raw materials, labor, or utilities required for acid hydrolysis and fermentation, product storage cost, and marketing cost. Electricity cost is $0.08 per kwh (kilowatt per hour) and this costs almost $2.13 per ton of MSW. Natural gas cost is $1.60 per MBTU (mega British thermal unit). Natural gas cost spent per ton of MSW is $1.24. Total plant operation cost is $0.46 per gallon of ethanol. Under the base case, ethanol yield assumption (25 gallons a ton) plant operation cost is about $11.50 a ton. Total direct cost is $15.10 a ton under the base case scenario (Titmas 2004).

5.2.7 Indirect Cost

Other than the costs above, several other indirect costs are estimated. These are fixed overhead expenses that are estimated on a per year basis. They include the following: administration expenses at $246,000, insurance costs at $80,000, royalty costs at roughly $389,000 (nearly 3% of annual revenue), contractual costs at $50,000, and labor training costs at $50,000 a year (Titmas 2004).

5.2.8 Annual Net Profit

The next step is to estimate EBITDA (earning before interest, taxes, depreciation and amortization) of a 500 TPD MSW-ethanol plant. It assumes the plant operates 312 days a year (six days a week). The results are shown in Table 5.2. The revenue is huge enough to offset costs required for daily operation.

Figure 5.1 shows the percentage of each revenue source against the total. When the tipping fee charge is considered to be revenue source, instead of negative feedstock cost, it accounts for 39.0% of the total revenue source. This is identical to ethanol sales, at 39.1%. On the other hand, the sum of recyclables and chemical by-products sales revenue only accounts for 30%. Even without tipping fee revenue, profit is robustly positive ($4,626,392 a year) at the base case.

Table 5.2 EBITDA of MSW-Ethanol Production in 500 TPD Case

Categories	U.S. dollar
Ethanol Sales	$5,070,000
Recovered material Sales	$1,244,880
Chemical By-product Sales	$1,598,454
Feedstock Cost	$5,054,400
MSW Classification Cost	($600,000)
Plant Operation Cost	($1,794,000)
Administration Expense	($892,942)
EBITDA	**$9,680,792**

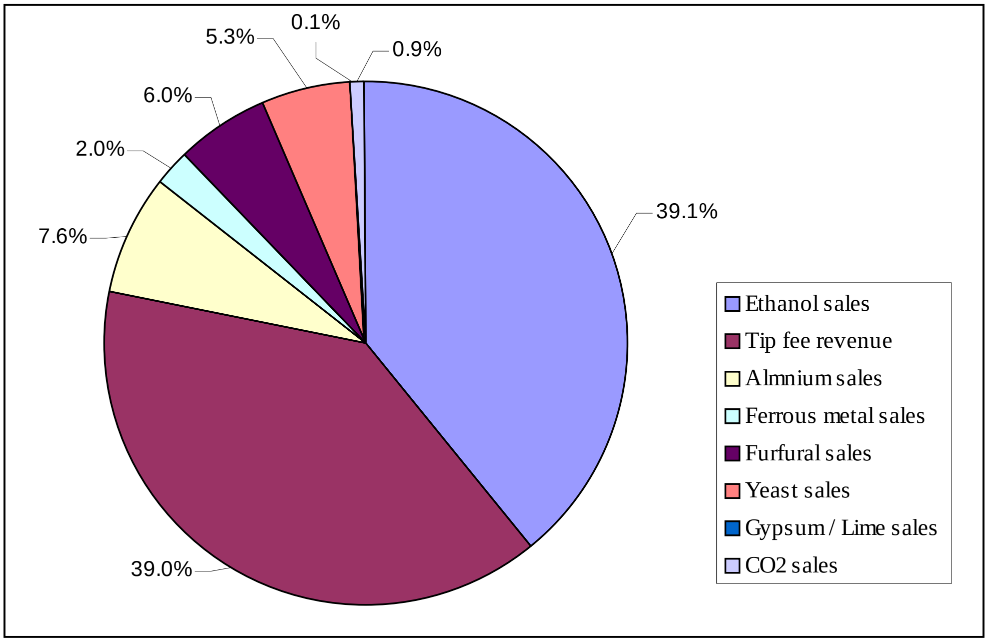

Figure 5.1 Pie Chart of Revenue Source of MSW-Ethanol Production in 500 TPD Case

5.3 Cash Flow Analysis

5.3.1 Methodology

In this section, the concept of time dimension is added to evaluate the desirability of an investment in MSW-ethanol production over time. It is important to consider the time dimension because both private and public decisions can have important consequences that extend over time. For the analysis of profitability of plant and return of capital investment, several economic concepts are provided. The model specified is as follows:

$$NPV = \sum_{t=0}^{T} \rho^t N_t \text{..............................}(5\text{-}3)$$

$$N_t = B_t - C_t - (TX_t - TXC_t) \text{..........}(5\text{-}4)$$

where,

NPV = Net present value.
N_t = Net benefit in year t.
B_t = Benefit accured in year t.
C_t = Cost imposed on in year t.
TX_t = Tax imposed in year t.
TXC_t = Tax credit available in year t.
T = Economic life of MSW - ethanol plant.
ρ = Discount factor $= 1/(1+\delta)$.
δ = Discount rate ($\delta > 0$).

NPV is the net present value of the sum of the present value of all the benefits and costs of a project, including initial investment. Positive *NPV* indicates the project generates benefits greater than costs over time.

Another economic concept used is internal rate of return (*IRR*). Given N_t, IRR is the rate *r*, which when used as a discount rate, would reduce the present value of net benefits equal to zero. Thus, IRR must satisfy the following equation:

$$\sum_{t=0}^{T} \frac{N_t}{(1+r)^t} = 0 \text{...............}(5\text{-}5)$$

When using the IRR as an investment criterion, all independent projects with an IRR less than the cost of capital will be rejected. In other words, a project must satisfy the rule $r > \delta$ to justify initial investment (Conrad 1999).

5.3.2 Capital Cost

Now the research question is to figure out the cash flow a plant acquires during the entire plant life. This section describes capital costs and tax charges at first. Any kinds of projects incur opportunity cost. Opportunity cost theoretically is equal to the value of the goods and services that would have been produced had the resources used in carrying them out been used instead in the best alternative way. Opportunity cost of capital of MSW-ethanol plant is reflected in the interest rate of backs if market is efficient. Thus, again if IRR of MSW-ethanol project is greater than appropriate discount rate, one should proceed with it.

The large portion of capital cost is devoted to facility construction cost expenses. These costs include construction, construction equipment and rentals, engineering, and other construction overhead. Overall construction cost estimated by GeneSyst is \$20.1 million. Of all, 25% is for construction building (\$5 million), 50% is pipe, paving and electrical installment (\$10 million), 15% is for pumps, vessel, and mechanical installment (\$3 million), and 10% is for computer and controls (\$2 million). Table 5.3 summarizes estimated construction cost of each facility for a 300 TPD plant by GeneSyst. Table also presents rough estimate of facility construction cost of a 500 TPD plant.[26]

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[26] The detailed estimate of construction for each facility by GeneSyst is limited to a 300 TPD plant case. Note that capital cost in the analysis is neither the function of plant size nor the volume of daily waste but is assumed to be a fixed cost. Here I assume facility construction cost is a liner function of the volume of

Other than construction cost, \$2.6 million is used for design, consulting, and permitting cost. This cost category covers all costs associated with construction design, drafting, purchasing, communication, consulting with professional engineers, and permitting. Taking working capital and contingencies into account, a total of \$3 million is roughly estimated by GeneSyst for initial capital investment. Contingency factor compensates for the uncertainty in the cost estimate resulting from unpredictable events such as price changes, design changes, estimating errors, unforeseen expenses, or uncertainty in the technical performance at the commercial scale.

Table 5.3 Estimate of Facility Construction Cost

Description	300 TPD plant	Breakdown	Estimate of a 500 TPD plant
Project Management	$349,000	2.22%	$445,590
Sitework	$678,000	4.30%	$864,422
Fluff Receiving Building	$1,765,000	11.20%	$2,251,917
Plastic Separation System	$597,000	3.79%	$761,095
Plastic pelletizing and storage	$379,000	2.40%	$483,154
Sulfuric Acid System	$48,000	0.31%	$61,754
Caustic System	$300,000	1.90%	$382,503
Gravity Pressure Vessel	$1,957,000	12.42%	$2,496,868
Lime Recovery System	$913,000	5.80%	$1,165,179
Fermentation Facility	$1,061,000	6.73%	$1,353,428
Distillation Facility	$1,651,000	10.48%	$2,106,160
Denaturing Facility	$56,000	0.36%	$72,026
Product Storage	$600,000	3.81%	$765,066
Carbon Dioxide System	$725,000	4.60%	$924,575
Office Building & Chattels	$292,000	1.85%	$372,582
Wastewater Control	$224,000	1.42%	$285,720
Process Support	$489,000	3.10%	$623,149
By-product Extraction	$159,000	1.01%	$202,911
Railroad siding w/ ethanol eq.	$400,000	2.54%	$510,244
Truck scales	$74,000	0.47%	$94,749
Certifications and Start-Up	$642,000	4.07%	$818,906
Engineering	$951,000	6.03%	$1,212,467
Permits & Contingency	$1,796,000	11.40%	$2,291,123
Total	$16,106,000	100.00%	$20,100,000

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daily waste. I estimated the percentage of each facility construction cost for total, and multiply it by total facility construction for a 500 TPD plant estimated by GeneSyst. Table 5.3 presents this rough estimate for a 500 TPD case.

Source: Titmas, 2004

5.3.3 Capital Charges

Capital charges are those costs incurred during construction of the facility that must be recovered during its life. These include the cost of debt (interest rate for loan), depreciation, and tax expenses. Income taxes are calculated after depreciation and interest payment are subtracted. The premise for estimating these values are as follows.

Depreciation is calculated under straight-line for 20 years of plant life. Annual depreciation costs are summarized in Table 5.3.

Table 5.4 Annual Depreciation of Capital

Description	Percentage of construct cost	Write-off period (year)	Depreciation ($k/year)
Buildings =	25%	30	$168,000
Piping, Paving, & electrical =	50%	20	$503,000
Pumps, valves, mechanical =	15%	10	$302,000
Computers and controls =	10%	5	$402,000
Design, consulting, permitting =		10	$260,000
Total annual depreciation =		-	**$1,634,000**

Source: Titmas, 2004

The loan interest rate (or bond interest rate) is assumed 7% amortized over 20 years. Under this scenario, annual payment is roughly $2.8 million. The actual debt expenditures vary from year to year as the borrowed principle declines. The interest payment schedule is shown in Table D.3 in Appendix D. The average cost of debt over the life of the plant is approximately $1.3 million a year.

There are three types of income taxes: Federal taxes, State taxes, and local taxes. Federal and state tax rates are assumed to be 32% and 8.5%, respectively. The local tax is $50,000 uniformly every year based on an assumption by GeneSyst. Thus, tax payments account for roughly 40% of pre-tax income.

5.3.4 Government Incentive

Economic incentives, including tax credits or subsidies, are important institutional devices to attract niche players and to promote desirable industries. State governments have been forced to come up with alternatives to MTBE as an acceptable fuel oxygenate. Currently there are no Federal tax incentives available for the development of landfills, whereas systems that convert waste to usable products can receive Federal tax credits. State tax credits vary from county to county, but most of states in the U.S. usually provide tax credits for those who produce economically valuable goods from MSW. Long-term tax credits have been affirmed, and are now even broadening to include state subsidies (Masada 2004).

Ethanol producers have been either wholly or partially exempted from motor vehicle excise taxes since 1978, the exemption having ranged from 40¢ to 60¢ per gallon during the following 20-year period. The Transportation Efficiency Act of the 21st Century (TEA 21) was first enacted in June 1998, and gave a 54¢ per gallon tax exemption to ethanol producers. Revenues from the excise tax were dedicated to the Highway Trust Fund, which provided assistance to eligible transportation projects involving construction or rebuilding of roads. This program extended the current tax credit for ethanol through 2007, but stipulated reductions from the current 54¢ per gallon to 53¢ in 2001, 52¢ in 2003, and 51¢ in 2005. The expiration date of the current 51¢ per gallon tax exemption is December 31, 2007.

Additionally, small ethanol producers are eligible to get additional 10¢ per gallon credit on Federal income taxes. This program is called the *Small Ethanol Producer Credit*. In order to qualify for the credit, the alcohol, including ethanol, must be sold or used by the producer for (1) the use in the production of a qualified fuel mixture in a trade or business, (2) the use as a fuel in a trade or business, and (3) the sale at retail and placed in the purchaser's fuel tank. An eligible small ethanol producer is a producer of ethanol whose production of any type of ethanol does not exceed 30 million gallons per year. The maximum gallons applicable to 10¢ per gallon credit is 15 million gallons produced per year, resulting in a maximum annual credit of $1.5 million. Even under the assumption that 50 gallons of ethanol can be produced per ton of MSW, the annual yield of ethanol is less than $10 million. Thus, the full small producer credit is included in the cash flow analysis.

Although it is still continuation of the tax credit after 2008 is uncertain, *Annual Energy Outlook 2000* (*AEO2000*) by EIA (2004a) assumed that the Federal subsidy would be extended at 51¢ per gallon through 2020, and defined this scenario as a reference case. In this paper, I assume three different scenarios in terms of the tax incentive program. I assumed a MSW-ethanol plant is set up in 2005, and this year is regarded as *t=0*. Then, each scenario is defined as follows:

- Scenario 1 - no tax credit is available from an initial stage of operation.
- Scenario 2 material recover facility (– status quo; both ethanol tax credits and small producer tax credits expire in 2007. Therefore, governmental incentives end in year 2.
- Scenario 3 - both tax credits continue until 2010 as following the prediction by AEO 2000. Therefore, tax programs are available until year 15.

Besides the Federal tax program, each state independently puts tax incentives into effect. Ethanol incentives by state are summarized in Table 5.4. No state tax incentive is included in the profitability analysis due to the broad range of applicability.

Table 5.5 Ethanol Incentives by State

State	Outline of program	Remarks
Alaska	4¢/gal	Winter blends only
Connecticut	1¢/gal	Excise exemption
Hawaii	4%	Sales tax exemption
Idaho	2.1¢/gal	Excise exemption
Illinois	2%	Sales tax exemption
Iowa	1¢/gal	Excise exemption
Minnesota	20¢/gal	Producer payment
Missouri	20¢/gal	Producer payment
Montana	30¢/gal	Producer payment
Nebraska	20¢/gal	Producer payment
Ohio	1¢/gal	(Restrictions apply)
South Dakota	20¢/gal	Producer payment
Wyoming	40¢/gal	Producer payment

Source: Oxy-fuel News, 2001

5.3.5 Economic Premises

Before moving on to the actual estimation, several assumptions are made in developing the base-case analysis that reflects the reality of plant economics.

First, quantity of MSW handled by the plant, Q_{MSW}, is assumed to increase over time. Due to little previous production experience, the plant is assumed to face uncertainty at the initial time, but it may improve operation methods over time by pursuing production efficiency. Moreover, MSW generated by the community is assumed to increase over time. Thus,

$$(Q_{MSW})_t = (Q_{MSW})_{t-1}(1+g) = (Q_{MSW})_1(1+g)^{t-1} \text{.....where, t} = 1,2,\text{....T...}\,(5\text{-}6)$$
$$\text{where } g = \text{Growth rate of MSW dealt by plant}$$

Equation (5-5) assumes that MSW generated increases at constant rate. Q_{MSW} is assumed to increase by 2% each year by following the assumption of GeneSyst (Titmas 2004). Since both revenue and cost functions depend on Q_{MSW}, revenues and costs change over time.

Second, the initial period, when $t = 0$, is only used for facility building. GeneSyst assumes it takes a year to establish facility and all equipments needed for production. On average, the period required to construct an ethanol plant is one to two years. TVA took one and one half years to construct a 400 TPD demonstration plant. For my analysis, I assume regular operation starts from year 1.

Third, I assume that computer equipment is reinvested every five years, and pumps, valves, and mechanical capital are reinvested every ten years, corresponding to estimated life for depreciation purposes. Note that the economic life of equipment has nothing to do with accounting depreciation largely determined by tax or reporting requirements. The depreciated accounting value may have little relationship to the reduced usefulness or the amount of wear and tear of the assets. However, I assume the plant reinvests capital along the lines of write-off periods, in order to simplify the analysis.

Fourth, several assumptions about administration costs are made. According to GeneSyst, six months are needed for inventory of furfural and yeast to accumulate in the first year of operation, $t = 1$. Thus, during this period, only half the amount of furfural and yeast is sold. Next, GeneSyst estimates contractual costs allowing for engaging external consultant expertise to troubleshoot operations or to upgrade operations. I follow their assumption that the contractual cost increases over time by $25,000 per year, proportionately. Last, training expenses are high in the first year of operation, $t = 1$, but after that year training expenses will be less. I assume $150,000 is spent at $t = 1$, while only $50,000 is needed in the following years.

Fifth, perpetual maintenance of facilities (e.g., GPV) is possible (Titmas 2004). The advantage of MSW-ethanol with GPV process over landfill is that it can continue operating at the same place forever. I assume the time horizon of MSW-ethanol production is 20 years.[27] While landfill needs a decade for monitoring processes without operation, a MSW-ethanol plant is not suspected to cause negative cumulative health effects on the neighborhood. Thus, additional costs after $T = 20$ are not considered.

Sixth, there are several ways to estimate terminal value, the net present value of all benefits and costs that occurs after the discounting period. These include terminal values based on simple projection, on salvage value or liquidation value, on depreciated value, or on initial construction cost (Boardman *et al*. 2001). The exact terminal value in $T = 20$ is uncertain.[28,29,30] In the base case analysis, no terminal value is considered for plant economics.

Finally, I assume a 7% discount rate. For the plant to be profitable and economically feasible, projected IRR should exceed the discount rate of 7%.

5.3.6 Base Case Economic Evaluation

Both revenues and costs of a 500 TPD MSW-ethanol plant are summarized in Table D.1 and D.2 in Appendix D. *NPV* is shown in Table D.3. *NPV* before tax (*EBITDA*) is \$87 million at a discount rate of $\delta = 0.07$ with a 20 year economic life. With

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[27] GeneSyst has several proposals in Europe that last for ten year. After ten years of operation, the city purchases (transfers) the facility for perpetual operation. Moreover, the physical life of a GPV was tested at Longmont Colorado by GeneSyst, and was not less than 20 years (Titmas 2004).

[28] Normally there may be some salvage value, if the plant is scrapped, but it would not amount to more than 5% of the initial capital costs with inflation-enhanced correction (Titmas 2004).

[29] Projects by GeneSyst in Europe predetermined that a plant could be sold to the city with a predetermined sale price that amounts to 75% of construction price, albeit corrected to present worth. Thus, terminal value is definitely more valuable if it is sold as a working facility on line.

[30] In the case of a Zimpro plant (high pressure - temperature wastes wet oxidation), it was entirely built of stainless steel, and actually sold at scrap for about 30 cents on the materials purchase price.

regard to tax effects, NPV of cash flow in scenario 1 is $52 million, in scenario 2 is $56 million, and in scenario 3 is $74 million. NPV is positive even when no tax credit is provided, but the impact of a tax credit on profitability is huge. A 15 year incentive program brings $18 million to the MSW-ethanol plant.

Moreover, Table D.3 estimates that IRR of MSW-ethanol production at r=33.5% for EBITDA is much higher than $\delta = 7\%$. IRR of cash flow without a tax credit case is still 24.5%. Thus, under the base case, MSW-ethanol production in the 500 TPD case provides strong incentive to invest today.

5.4 Partial Sensitivity Analysis

5.4.1 Methodology

In the previous two sections, profitability of a MSW-ethanol plant is examined by using the concept of net present value and IRR from available information of current market price and material yield. In the following section, sensitivity analysis is performed. This method is a way of acknowledging uncertainty about the value of important parameters in the economic predictions.

Since profit function (5-1) consists of many variables, conducting sensitivity analysis with regard to all variables would be very complicated. Instead, *partial sensitivity analysis* is provided by picking up some variables that are likely to influence the profitability of plants. As different factors and parameters are varied, the remaining factors and parameters are assumed to be held constant for the base case.

Note that sensitivity analysis does not generally take into account the probability of any of the changes that would actually occur. However, we can still reach the conclusion that our analysis is robust and can have greater confidence in its results if the sign of net benefits does not change when considering the range of reasonable assumptions. Thus, I also perform *worst-and-best case analysis* to see any combination of reasonable assumptions reverse the sign of net present value.

5.4.2 Change in Ethanol Price and Tipping Fee

As noted in Section 1, two major considerations of MSW-ethanol plant economics are ethanol sales and tipping fee revenue, which account for 78% of the revenue source when the ethanol price is $1.30 per gallon and the tipping fee is the national average of $36 per ton. Thus, the combination of these two variables is assumed to considerably change profitability.

Partial sensitivity analysis is conducted with respect to ±10%change of ethanol price and tipping fee. The result of the sensitivity analysis is reported in Appendix D. The *base case* that is most plausible is reported as a 0% change. Figure 5.2 and 5.3 shows the effect of ethanol price and tipping fee on IRR, respectively. It is clearly seen that the sensitivity of these two parameters are quite similar and significant in determining plant economics. The effect of a 10% change in both tipping fee and ethanol price results in a 1.8% change of IRR and $6.2 million change in NPV. Approximately 3.6 cents per gallon increase in ethanol value is equal to a $1 per ton change in the charge for MSW receipt.[31]

However, given the reality of market trends, changeability of these two economic factors is completely dissimilar. The historical trend of ethanol price in Figure 2.5 in Chapter II shows ethanol price fluctuated between $1.10 per gallon to $1.40 in the last

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[31] A 36 cent increase in ethanol price changes the potential value of one MSW ton for ethanol sales, $0.036*25=$0.9. This is equal to a $1 per ton change in the tipping fee, $1*90%(efficiency factor)=$0.9.

decade. Thus, realistic ethanol price is confined to at most to a ±20% to 30% change; it is unlikely that ethanol price will fall below $0.9 per gallon or exceed $1.70 per gallon. On the other hand, the tipping fee is varied by region by a great deal. Even a free tipping fee is quite possible. Moreover, the tipping fee is changeable even in the same region because of landfill site scarcity or environmental regulations. Thus, a ±100% change of the tipping fee is highly probable in reality.

The most important conclusion from the analysis is that the profitability of a MSW-ethanol plant is robustly positive. An 80% reduction of each economic factor still shows positive NPV, even at the no tax incentive program scenario. However, for the region where MSW is accepted at a cheap rate, profitability of the plant is affected by availability of tax incentive programs. Under scenario 1, even a 10% reduction of ethanol price switches the sign of NPV when the tipping fee is $7.2 per ton. However, if tax incentives continue to 2020, estimated IRR with a $7.2 per ton tipping fee is still greater than 10%. Tax incentive programs are needed if the political goal is to encourage MSW-based ethanol production.

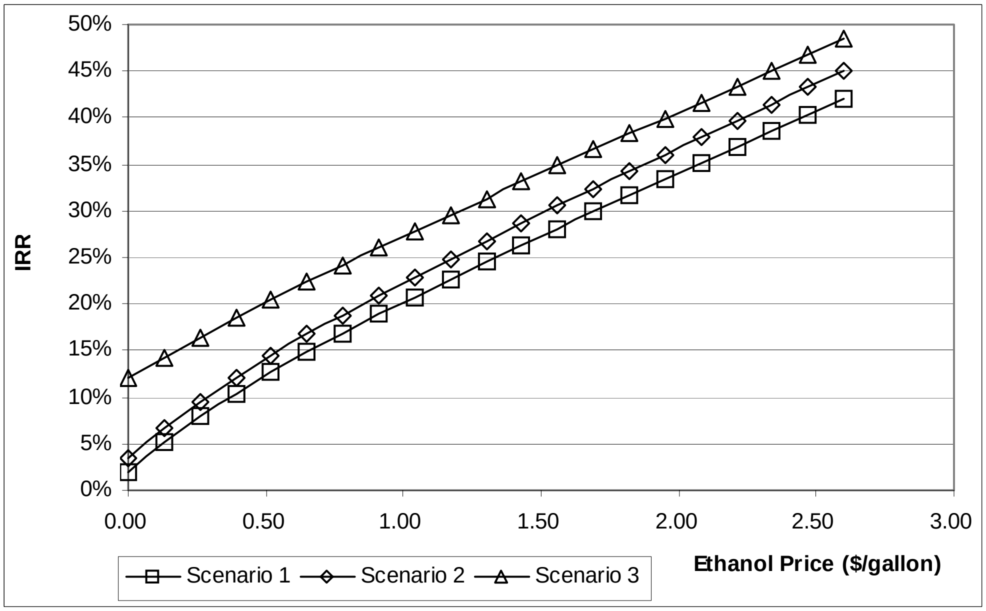

Figure 5.2 Effect of Ethanol Price on IRR

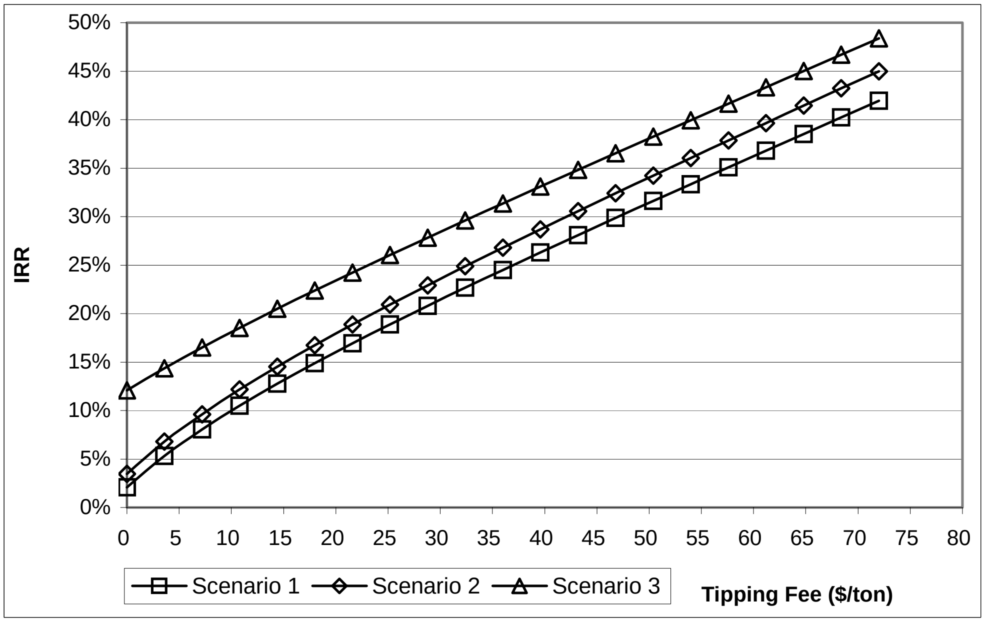

Figure 5.3 Effect of Tipping Fee on IRR

5.4.3 Change in Capital Cost

The sensitivity analysis, with regard to capital investment cost, is performed with a ±25% change from the base case of $30 million. The result of varying capital cost is presented in Figure 5.4. A 25% reduction of capital cost results in an 8, 9, and 10 percentage point increase in IRR in the three scenarios. While a 25% increase in capital cost results in a 5-6 percentage point reduction of IRR, the outcome of a further 25% increase leads only to a 3-4 percentage point decrease of IRR. The sensitivity of IRR to changes in capital investment has marginal diminishing return characteristics.

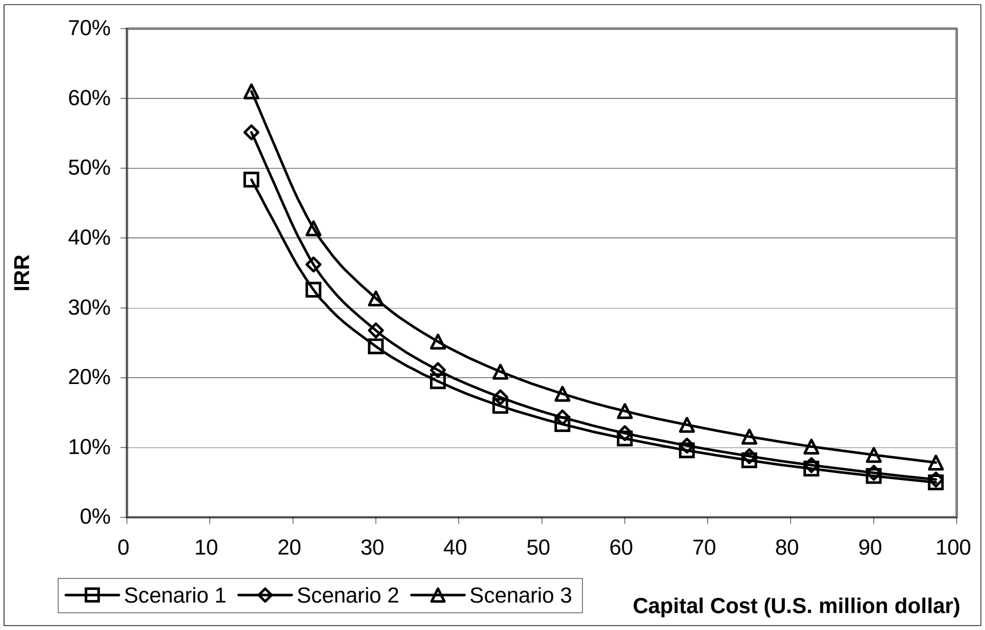

Figure 5.4 Effect of Capital Cost on IRR

The capital cost is the most changeable economic parameter of all variables under different hydrolysis technology and conversion process. The capital cost estimated by GeneSyst is not the typical case of a MSW-ethanol plant. Due to lack of observational data, there is no way to analyze the accuracy of the capital investment cost of GeneSyst.

Table 5.5 presents the summary of an estimated capital cost per gallon of ethanol by several previous studies. The data in the first row of the table presents capital cost estimated by the U.S. Department of Agriculture (USDA), which surveyed 28 corn-ethanol plants producing more than 1.1 billion gallons of ethanol per year (including both wet and dry mills) in 1998 (Shapouri *et al*. 2002). The second and third row show the capital cost of corn starch to ethanol process and corn-stover to ethanol process, estimated in the joint project of USDA and U.S. DOE (McAloon *et al*. 2000). It is evident that the conventional corn-starch to ethanol process requires much less capital cost compared to lignocellulose-to-ethanol conversion.

In terms of capital cost of MSW-ethanol conversion, there is a considerable variation in the estimates. It is evident that capital cost with GPV is much less than other processes. Compared to capital cost per gallon of ethanol by GeneSyst and Genahol-Arizona, both of which use GPV, capital cost per gallon by PMO and TVA is far higher. The substantial variation in capital investment per gallon also can be attributed to the refinement of the design, use of used equipment, and age of the ethanol plant.

Thus, even though it proves to be robustly profitable, investors might still hesitate to invest due to uncertainty of capital cost. Instead, they are able to invest in a conventional corn-starch to ethanol project with more confidence because much of the empirical data shows that capital cost is much less than that of MSW-ethanol process, and feedstock supplies are more reliable both in quality and quantity.

Table 5.6 Comparison of Capital Cost Estimate

Sample	Biomass resource	Ethanol yield (Million gal/year)	Capital Cost (Million)	**Capital Cost per annual gallon capacity of ethanol (Adjusted to U.S. 2000 dollar)[32]**
Survey of USDA[33]	Corn-starch	-	-	**\$1.11-\$2.49**
Joint survey of USDA and DOE[34]	Corn-starch	25.00	\$27.9	**\$1.16**
Joint survey of USDA and DOE	Corn-stover	25.00	\$136.1	**\$5.67**
GeneSyst	MSW	3.90	\$30.0	**\$7.69**
PMO[35]	MSW	7.10	\$200.0-\$285.0	**\$28.17-\$40.14**
Genahol-Arizona[36]	MSW	1.50	\$5.00	**\$3.44**
TVA[37]	MSW	8.39	\$200.9	**\$27.25**

5.4.4 Change in Technological Efficiency

This section analyzes the sensitivity of profitability with regard to technological efficiency. One aspect of technological efficiency is gallons of ethanol produced from one ton of MSW. In the base case analysis above, I assume 25 gallons of ethanol can be made from a ton of MSW. Another technological consideration is the efficiency factor. A 90% efficiency factor was assumed in the base case scenario. Sensitivity analysis, with regard to both ethanol yield and efficiency factor, is performed with respect to a ±10% change.

The result of the analysis is shown in Figures 5.5 and 5.6. The horizontal axis indicates ethanol yield per gallon and efficiency factor, respectively, while the vertical axis of both figures indicates IRR. Two economic parameters have a significant effect on profitability. Ethanol yield has an especially remarkable effect. A 10% change in ethanol yield (a change of 10 gallons per ton) compared to a 25 gallons assumption results in a

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[32] Price is adjusted to U.S. 2000 dollar by deflating with producer price index (PPI) estimated by the U.S. Department of Labor, Bureau of Labor Statistics.
[33] Data taken by Shapouri *et al.* (2002)
[34] Data taken by McAloon *et al.* (2000)
[35] Data of capital cost is taken by the Times Herald-Record Online and data of ethanol yield is taken by Gray (1999)
[36] Data taken by Fox *et al.* (1999)
[37] Data taken by Broder *et al.* (1993)

3.5-4% change of IRR, while a 10% change in efficiency factor from the base case results in approximately a 2% change of IRR.

Chapter IV provides several estimates for ethanol yield in the field and I found that the possible ethanol yield per ton of MSW under current technology lies in between 20 and 50 gallons. Even when ethanol yield is 20 gallons per ton, IRR still exceeds 20%. In terms of efficiency factor, it is unlikely that it falls below 50%. As long as it is between 50 and 100 percent, profitability is positively robust. Thus, neither ethanol yield nor efficiency factor changes the sign of NPV independently.

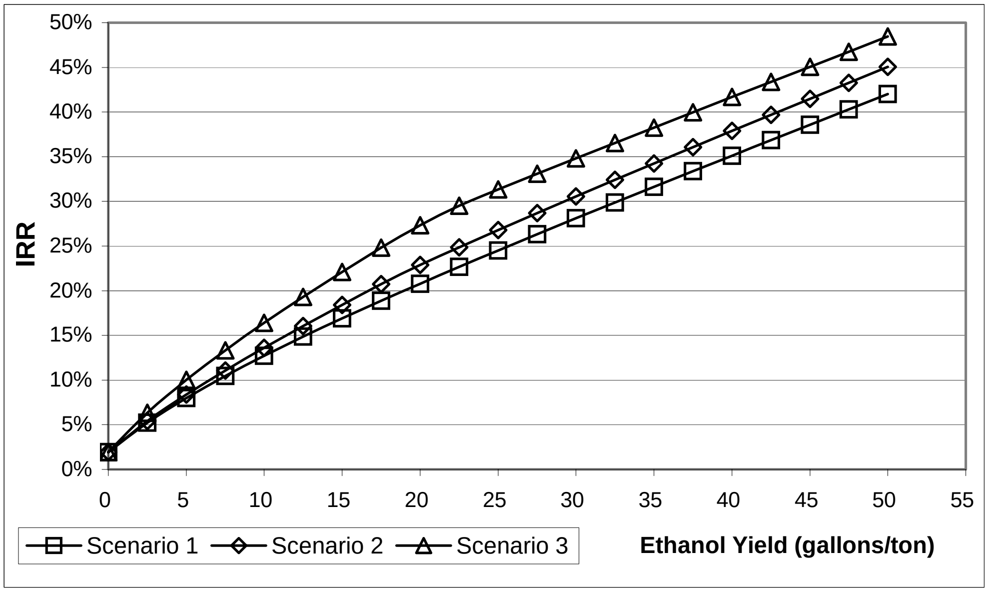

Figure 5.5 Effect of Ethanol Yield on IRR

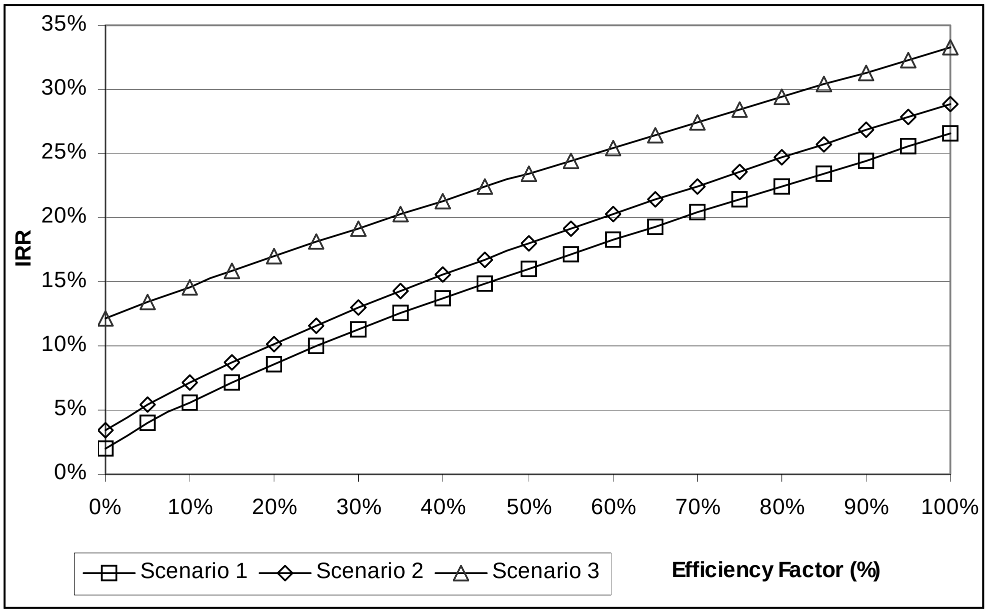

Figure 5.6 Effect of Efficiency Factor on IRR

5.4.5 Effect of Collocation

In the base case scenario, it assumes that a MSW-ethanol plant is collocated with MRF or other sorts of waste management facilities, such as a landfill. This results in no waste transportation costs imposed upon the MSW-ethanol plant. Waste transportation costs might reduce profitability of a plant if the plant is located far from facilities.

Now I assume waste transportation cost is dependent on the weight of waste needing to be landfilled. Waste transportation cost is expressed in following way;

$$EF(C_{WT}Q_{MSW}) \text{..........} (5-7)$$

where,

C_{WT} = Waste transportation cost from plant to waste managing facility ($/ton)

$C_{WT} = 0$ if MSW - ethanol plant is collocated with waste management facility

Fox *et al*. (1999) estimates that C_{wt} from a planned ethanol plant to an existing landfill is $6.00 per ton. Though his estimate is based on an Arizona case, I use this assumption as base case and analyze the effect of waste transportation costs by varying C_{wt}.

The result is described in Figure 5.4. The horizontal axis is waste transportation cost ranging from \$0 per ton, which is collocation with waste managing facility, to \$30 per ton. The vertical axis is IRR. Obviously, collocation has no significant effect on plant economics.

The same is true for transporting ethanol from the plant to ethanol blending facilities. Collocation with an ethanol blending facility is able to reduce ethanol transportation cost (GeneSyst categorizes this cost into sales cost). Thus,

$$EF[C_{ET} Q_E (Q_{MSW})] \ldots\ldots\ldots\ldots (5\text{-}8)$$

where,

C_{ET} = Ethanol transportation cost (\$/gallons)

$C_{ET} = 0$ if MSW-ethanol plant is collocated with ethanol blending facility

Fox *et al.* (1999) estimates ethanol transportation cost from seventeen selected sites to ethanol blending facilities, ranging from 1.39¢ to 3.20¢ per gallon. A 21.6¢ per gallon cost of ethanol transportation is equivalent to \$6 per ton of waste transportation cost at the base case. Thus, it has little effect on profitability. A MSW-ethanol plant can be relocated, although it is not portable. Optimal location that can minimize the sum of waste transportation cost and ethanol transportation cost in the initial planning period results in cost saving over time. However, it is not significant in determining plant economics.

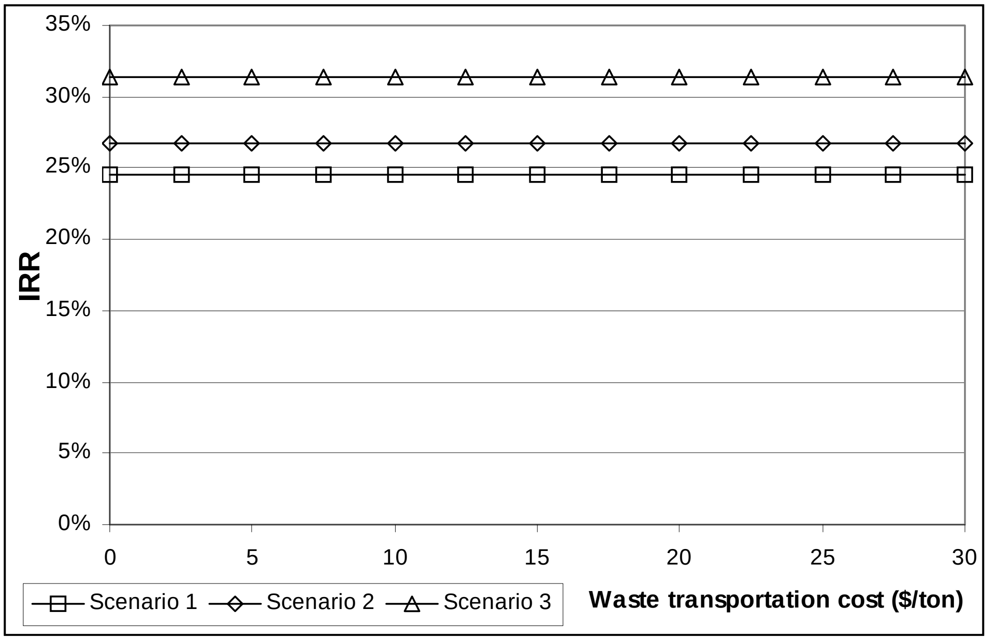

Figure 5.7 Effect of Waste Transportation Cost on IRR

5.4.6 Changing Price of By-Product

Figures D.1 and D.2 in Appendix D show sensitivity with regard to aluminum and furfural price with a ±20% change. These two variables are chosen because each of them shares the largest revenue among recovered material and chemical by-product revenue, respectively. Results show that sensitivity with by-product price has a small effect on profitability.

5.5 Economic and Political Obstacles

In this chapter, robustness of profitability of MSW-ethanol production is proved. However, new question arises: if it is so profitable, why has it not been done before? The following section addresses economic and political issues associated with the waste market.

5.5.1 Competition

The first problem lies within the economic structure of the waste disposal industry. The collaboration between an ethanol plant and a landfill cannot be expected when MSW-ethanol plant and landfill are owned by different owners.[38] Coexistence can extend landfill life and solve both landfill scarcity problems and interstate waste export problems.

However, coexistence with a MSW-ethanol plant in the same region is not attractive to landfill operators because most of the landfill costs are up-front capital costs, which the landfill operators recover over time with tipping fee revenues and by-product sales (e.g., methane gas). The opening of a MSW-ethanol plant nearby results in the reduction of the daily waste stream into landfill, and also a reduction in annual revenue. This implies a decrease in present value of net benefits for the entire landfill life. Benefits created in the distant future are less attractive than benefits of the near future. The economic incentive for landfill operators is to fill landfill with garbage as early as possible to earn benefits quickly. Furthermore, the longer the landfill is operating the greater is its exposure to liability due to leakages, leaching, etc. Hence, MSW-Ethanol plants are opposed by landfill operators.

This is true in the case of WTE, which is also willing to burn as much garbage as possible to raise net present value. For sustainable operation, a certain amount of daily waste supply should be guaranteed. Coexistence threatens the capability of the incinerator to produce energy continuously.

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[38] In the case that ethanol plant and landfill is owned by the same owner, story could change. Under this scenario, the owner would have incentive to use more MSW for ethanol production if NPV of MSW-ethanol process is higher than NPV of dumping MSW into landfill. The owners of GeneSyst, PMO, and Gehanol-Arizona, however, does not take ownership of a collocated landfill or other sorts of waste facilities.

A MSW-ethanol plant is therefore unfavorable to conventional waste facilities. At the present stage, a MSW-ethanol plant is not yet competitive with others. Conventional MSW dumping landfill has economies of scale. Landfill can manage waste with inexpensive cost as the scale of the landfill is enlarged. This results in a decrease in the number of landfills, and expansion of market share by large private waste management firms. Economies of scale of an incinerator are even greater than landfills; large facilities have lower net average total costs (Curlee *et al*. 1994).

For now, it is not clear whether a MSW-ethanol plant has economies of scale. In the financial feasibility analysis of a 500 TPD plant, operation cost is a linear function of weight of waste. This is not based on experience at a commercial scale, but an estimate based on a pilot plant. Moreover, daily waste volume of the vast majority of landfill in the U.S. is greater than 500 tons, or even greater than 1,000 tons (Chartwell Information 2003). Whether a plant has economies of scale would be found only after a large-scale plant starts to operate.

It is also unforeseeable how capital cost reacts when plant size is enlarged. In the financial feasibility analysis above, capital cost is not a function of tonnage of waste. However, according to GeneSyst (2004), one GPV can cover all MSW in a community where its population is no greater than 300,000 residents. But another GPV needs to be established if population exceeds this limit. Thus, the increase in volume of waste would not necessarily result in a decrease in capital cost per ton of MSW.

Another shortcoming of a MSW-ethanol plant is that it needs time and investment to conduct preliminary studies. A MSW composition survey, laboratory analysis, and pilot plant operation are necessary before plant construction. A MSW composition survey is particularly vital.

A plant must be designed carefully so that operation fits well with the waste characteristics of local community (GeneSyst 2004). Seasonality of waste also matters. A plant is carefully designed to be adaptable to fluctuation of MSW volume. If design capacity is too small, the excess amount of MSW cannot be processed. If design capacity is too big, plants operate with technical inefficiency and the capital costs are raised. (This is also true for the incinerator or other sorts of WTE.) This implies that a plant cannot be simply duplicated from one area to another. In comparison for dumping MSW in a landfill, material composition or consumption pattern of the local community does not matter.

5.5.2 Public Acceptance

Establishing sound public relations is important when building new facilities (Broder *et al*. 2001). Historically, building a waste facility has been subjected to criticism, and some of proposed facilities have been cancelled because of public opposition. A MSW-ethanol plant would not be an exception. As a matter of fact, a project of PMO in city of Middletown in Orange County, New York, was delayed in its operation due to fierce opposition from local residents. Table E.1 in Appendix E illustrates the time line of a MSW-ethanol project of PMO from the initial stage. This section analyzes why the public may not support a MSW-ethanol plant based on the case study of PMO.

First, state-of-the-art technology and innovative methods are difficult to accept, especially when local residents in the community are accustomed to solving waste problem by extending landfill capacity. In this case, people can hardly conceptualize the new paradigm of SWM beyond the existing system. A series of public meetings are important to provide enough information for making a decision and to give confidence to the investor. However, it takes quite a while until the new concept is widespread.

Second, even though people have enough information for making a decision, they occasionally oppose the location of a waste facility psychologically, especially when it is situated in the neighborhood. This is referred to as the “Not-In-My-Backyard (NIMBY)” syndrome. This syndrome blocks not only environmentally harmful projects, clean and sustainable projects as well. What is worse is that a waste facility is likely to be inherently stigmatized. People tend to regard it as unwanted as a knee-jerk reaction. Trust claims for acceptable and safe operation are easily deconstructed by worst-case scenarios.

The final issue is the interference of political realities. The case of PMO is a good example. Orange county is controlled by the Republican Party, while Middletown is a Democratic bastion. It is suggested that the county politicians loathed to have the Middletown project succeed because their past policies had turned into a $52 million landfill debacle. They not only declined to adopt the project as the official county waste effort, but also refused to have any association with the project (Edelstein 2004). The anti-PMO advertising campaign, with support from one party, fiercely criticized a MSW-ethanol plant. It repeatedly mentioned that the plant was experimental and the residents were “guinea pigs.” The risks were exaggerated and the benefits were ignored. Media is useful in letting the public know what the project is like; but if the media is controlled, the public can be incited to oppose waste facilities, despite their virtue.

Because it is unprecedented and inherently stigmatized, a MSW-ethanol plant is expected to face opposition by those who want to maintain the existing system. Moreover, public opinion is changeable. Without an understanding of life-style, economy, and the institutional structure of the local community, public relations would hardly be established.

5.6 Concluding Remarks

Throughout this chapter I analyzed the profitability of a 500 TPD MSW-ethanol plant, based on data of GeneSyst. In spite of several research limitations, the chapter reaches a solid conclusion. First, profitability of ethanol-MSW production is robust. Even under different market prices and different technologies, profitability proves to be robust. According to GeneSyst, the profit per ton of MSW is $50 with GPV, while landfill profit is less than $11 per ton of MSW (GeneSyst 2004). Thus, a MSW-ethanol plant creates more value on the same amount of MSW compared to conventional waste management.

Second, tipping fee, ethanol price, technological efficiency, and capital cost are variables that affect the profitability of an ethanol plant. But price of by-products and collocation with other SWM facilities would not be significant. Of all variables, the tipping fee is key when the plausibility of sensitiveness of each variable is taken into account. The range of the tipping fee can be a ±100% change from national average price by region. Thus, this results in a huge difference in tipping fee revenue by location since it is correlated with population.

Third, the sign of NPV is not likely to change, even at the absence of a tax program. However, availability of tax incentives creates motivation for ethanol producers. If the goal of governmental policy is for both clean energy and waste disposal, the extension of the current ethanol tax credit after 2007 is important.

Finally, there are three big obstacles for MSW-ethanol production. First, data is limited and uncertainty is an inevitable problem. Capital cost is especially uncertain, as substantial variation exists in the estimate of capital cost in different studies. Further capital costs are much higher than those of conventional corn-ethanol facilities. This leads to investor hesitation in investing in such projects. Second, it is likely that the entry of a MSW-ethanol plant into the market would encounter fierce opposition by existing conventional waste facilities. To get public acceptance, there are many issues that plants need to overcome. Thus, even though it is potentially profitable, it is not easy to introduce MSW-ethanol conversion as an alternative policy to conventional SWM.

CHAPTER VI

CONCLUSION AND RESEARCH RECOMMENDATION

Throughout this the thesis the economic feasibility of a MSW-ethanol plant is analyzed. This chapter presents the summary of the research.

First, currently most of MSW (55% of total MSW) is landfilled, while MSW generation has steadily increased. Thus abundant MSW biomass resource is available in the U.S. total. Of all MSW, paper products, food scraps, wood, and yard trimmings are lignocellulosic composition, which can be converted into ethanol. Lignocellulosic composition in MSW varies by region, however it is assumed to be between 55% and 70%. MSW landfilled currently is 130 million tons according to U.S. EPA (2003), which can yield 3-4 billion gallons of ethanol, compared to current annual motor gasoline supply of 126 billion gallons in the US (EIA 2004c). Approximately, 2-4% of gasoline can be replaced with MSW-ethanol if all MSW biomass is dedicated to ethanol production.

Second, MSW is abundant in populated regions where ethanol is mostly needed. County or metropolitan areas with a population greater than 100,000 can supply enough MSW for profitable ethanol production (GeneSyst 2004). There are 524 out of 3,141 U.S. counties with populations over 100,000 and most of metropolitan areas defined by U.S. Census Bureau have population greater than 100,000.

Third, Chapter IV presents summary of technology of MSW-ethanol conversion. Usually, MSW is processed in the following order; (1) MSW classification, (2) hydrolysis, (3) fermentation, and (4) distillation. There are several technologies applicable to each step. Under the current available technology, acid hydrolysis is better suited than enzymatic hydrolysis because of technological efficiency and economic reason. GPV is one of the best current available technologies. It can achieve high product yield with less reaction time; therefore economize plant economics. Conservative ethanol yield is 25 gal per ton of MSW with current technology, but it is predicted to be improved in mid and long term future.

Fourth, the major conclusion is that MSW-ethanol production is economically feasible and profitable with currently available technology. Ethanol demand is projected to increase due to the phase out of MTBE, dependence on imported oil, and public interest in clean renewable energy. The significant variables determining plant economics are ethanol price, tipping fee, and technological efficiency. The tipping fee especially shows a wide range of variation across regions. Tipping fee is correlated with population. Thus, MSW-ethanol production is more economically feasible at a location where MSW biomass is abundant. MSW-ethanol process produces a set of recovered products and chemical by-products and its salability is site specific. However, by-product sales do not have significant effects on plant economics.

Finally, although profitability is proved, there are several issues to be addressed in order for MSW-ethanol production to be a common approach toward waste management. First of all, there is a considerable variation in the estimates of the capital cost per gallon of ethanol as compared to capital cost estimate of conventional corn starch into the ethanol process. Investors would invest in corn to ethanol project with more confidence rather than MSW-ethanol project due to proven lower capital cost. Besides, coexistence with a MSW-ethanol facility is not favorable to conventional landfilling/WTE facilities because the incentives for those facilities are for maximizing waste disposal in existing facilities. Without public support, a MSW-ethanol process would be a stillborn approach. People should be fully informed of the usefulness of this new approach without political interference. If the goal is for a MSW-ethanol plant to be an alternative SWM approach, the government should play a key role to foster a favorable climate for future MSW-ethanol producers. Tax credits are one of the examples of such governmental supports. Tax credit program would encourage MSW-ethanol producer to be a niche player in waste industry.

Due to limited data there are several research limitations. First, material balance data was exclusively based on estimates by GeneSyst. Yield of ethanol, recovered material, and chemical by-product changes by MSW composition were also estimates. No same MSW composition is found in two municipalities, so that the results above cannot be generalized nationwide. Yield and composition is affected by economy, life style, and local industry composition rooted in community. For instance, wealthy communities can produce five times the waste per capita than poor communities (GeneSyst 2004). A careful material balance survey is required before public or private sector investment in a MSW-ethanol project for local waste management.

Second, the analysis above simply multiplied 312 days operation a year by tons per day. However, the amount of waste and its composition has seasonality (and even varies from day to day). It is usually the case that the amount of MSW collected at the peak time is twice as much as the monthly average MSW collected. This is more so if agricultural residues or yard wastes for two to three months are incorporated into MSW from cities. In the case of GeneSyst, waste supplies were not stored and the tipping fee receiving basin was to be emptied every 24 hours and cleaned (Titmas 2004), so the initial capital investment would be affected by peak capacity of plant. Thus, the initial survey must specify the seasonal MSW stream and identify the duration of peak periods.[39]

Third, the analysis was based on the best available technology. However, different technology can be applied to MSW classification, hydrolysis, fermentation, and distillation step. Yield of product and cost-effectiveness would be inconsistent among firms of a like nature. Thus, the result of my analysis is not necessarily the case with other firms. The profitability analysis with alternative technology should be conducted to make comparisons of cost effectiveness and technological efficiency.

Fourth, the result of the financial feasibility analysis above held plant size constant. Capital cost was based on GeneSyst's estimate of a 500 TPD plant, and it was used as a baseline. How benefits and costs change in response to plant size is not yet known. I do recommend making a model in which capital cost is a function of plant size. By doing so, sensitivity of profitability with changing plant size becomes clear.

Fifth, the analysis did not shed light on social cost. To gain public acceptance smoothly, social perspective should be incorporated into the analysis. For social cost-benefit analysis, environmental impact should be known. To estimate the value of environmental impact is challenging area, though, and it would be more evident how a MSW-ethanol plant is sustainable and environmentally beneficial approach compared to landfilling and incineration.

Finally, an initial survey is vital for the success of a MSW-ethanol plant. I recommend reviewing data periodically to improve accuracy. Additionally, keeping records of daily MSW streams and ex-post profitability analysis will generate more data

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[39] On the island of Malta, the peak endures for five months when the population triples (Titmas 2004).

for firms, public sectors, and researchers. This will result in deriving more appropriate supply and profit functions.

APPENDICES

APPENDIX A

Table A.1 Summary of Tipping Fee and Waste Volume by Region and Facility Type.

	MSW damping landfill		*Transfer Station*		*Waste-To-Energy facility*	
Region/State	daily volume (tons/day)	avg tip fee ($/ton)	daily volume (tons/day)	avg tip fee ($/ton)	daily volume (tons/day)	avg tip fee ($/ton)
Pacific Total	**153,010**	**$34.60**	**71,320**	**$45.21**	**7,340**	**$58.79**
Alaska	1,760	$46.41	80	$93.59	160	$140.91
California	120,860	$34.12	51,920	$40.46	3,430	$37.46
Hawaii	2,450	$60.59	450	$81.29	1,440	$81.27
Oregon	12,000	$31.71	7,410	$24.18	620	$64.96
Washington	15,940	$35.10	11,460	$78.60	1,690	$72.88
Mountain Total	**177,030**	**$20.48**	**33,700**	**$25.98**	**1,300**	**$42.15**
Arizona	20,030	$24.49	11,080	$29.45	-	-
Colorado	24,540	$19.59	4,450	$27.74	30	$25.00
Idaho	7,790	$19.45	1,220	$47.74	-	-
Montana	2,430	$20.27	480	$41.39	50	$60.00
Nevada	8,330	$14.59	2,650	$22.13	-	-
New Mexico	10,420	$18.37	2,630	$12.92	-	-
Oklahoma	13,070	$22.05	1,250	$22.23	1,130	$42.00
Texas	77,570	$19.79	8,200	$21.67	80	$41.71
Utah	11,030	$25.06	1,240	$24.76	10	$25.00
Wyoming	1,820	$22.17	500	$37.91	-	-
Midwest Total	**265,180**	**$31.67**	**79,090**	**$30.72**	**13,280**	$48.98
Illinois	60,100	$33.64	21,740	$28.03	1,200	**$59.00**
Indiana	25,340	$28.41	8,280	$27.18	1,920	$25.96
Iowa	8,720	$33.14	1,100	$40.25	180	$45.00
Kansas	8,930	$29.31	3,020	$31.12	-	-
Michigan	58,910	$31.95	6,480	$33.52	4,280	$54.76
Minnesota	7,420	$46.86	6,950	$44.65	5,280	$50.41
Missouri	16,250	$31.68	5,470	$28.93	-	-
Nebraska	8,170	$24.82	1,170	$34.70	-	-
North Dakota	1,930	$25.79	660	$34.55	-	-
Ohio	47,840	$28.60	18,290	$27.16	-	-
South Dakota	1,800	$25.65	230	$51.30	-	-
Wisconsin	19,770	$35.06	5,700	$35.00	420	$50.36
Southern Total	**258,590**	**$30.48**	**71,970**	**$35.82**	**29,060**	**$51.98**
Alabama	19,780	$25.70	1,930	$34.06	690	$39.90
Arkansas	8,250	$24.85	2,670	$24.32	70	$18.28
Dist of Columbia	-	-	5,200	$53.37	-	-
Florida	38,560	$36.89	17,820	$41.19	17,700	$57.48
Georgia	21,830	$28.86	8,750	$33.66	100	$60.00
Kentucky	18,600	$30.64	2,420	$36.42	-	-
Louisiana	13,790	$25.14	2,840	$30.84	-	-
Mississippi	10,740	$24.35	2,010	$32.03		-
North Carolina	21,110	$30.86	7,940	$38.99	400	$34.00
South Carolina	20,320	$32.60	2,790	$28.91	620	$59.50
Tennessee	34,590	$23.31	4,550	$25.64	460	$16.45
Virginia	45,270	$35.70	12,240	$28.78	9,020	$44.37
West Virginia	5,750	$35.17	810	$51.42	-	-
Northeast Total	**150,530**	**$53.56**	**77,740**	**$57.88**	**52,930**	**$62.55**
Connecticut	670	$43.82	3,270	$68.36	7,270	$61.06

Delaware	6,180	$55.38	980	$58.46	-	
Maine	730	$45.97	390	$34.85	2,600	$71.38
Maryland	8,720	$48.47	4,740	$31.18	2,490	$65.17
Massachusetts	7,210	$51.93	12,880	$58.56	10,150	$68.20
New Hampshire	4,680	$74.80	1,460	$71.21	770	$84.77
New Jersey	13,350	$49.68	11,400	$72.27	7,780	$64.06
New York	23,200	$47.36	24,710	$50.92	11,480	$58.23
Pennsylvania	81,450	$55.14	14,400	$63.38	10,380	$57.22
Rhode Island	3,610	$57.76	800	$73.54	-	-
Vermont	730	$66.97	2,710	$53.76	10	$42.83
United States	**1,004,340**	**$33.12**	**333,820**	**$40.76**	**103,910**	**$57.34**

Source: Chartwell Information, 2003

Table A.2: Summary of 745 Landfill Data[40]

	All	Type of facility			Region					Volume of MSW		
		LF	WTE	TS	Pacific	Western	Mid-west	South	North-east	Small	Medium	Large
N	745	524	63	154	102	98	184	203	158	25	368	352
Mean	38.2	33.7	60.2	43.9	42.7	22.0	31.2	33.8	59.1	43.5	36.7	39.4
STDV	21.5	16.6	19.4	26.5	23.5	7.8	14.6	16.1	22.9	21.3	23.6	19.0
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	180.0	104.0	100.0	130.0	180.0	50.0	73.0	91.3	130.0	92.0	180.0	110.0

Source: Chartwell Information, 2003

Table A.2 summarizes 745 landfill data listed in Solid Waste Digest. Of all data, average tipping fee is $38.17[41]. Note that the standard deviation is $21.51. This indicates that tipping fees are widely distributed. Firstly, landfill is sorted by type of facility. LF indicates ordinal MSW dumping landfill, WTE is Waste-to-Energy facility including incinerators, and TS is transfer station including MRF. Second, data is sorted by region by referring Table A.1. Third, data is sorted by daily volume of MSW. If daily volume is 101-500 TPD, it is small. Similarly 501-1000 daily volume is called medium, and exceeding 1000 TPD is coded as big. Note that there are 42 landfills that accept MSW without any charge, while maximum value tipping fee data is up to $180 per MSW ton.

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[40] Some of landfill tipping fee data is described as dollar per cubic yard. This is converted to dollar per ton based on assumption that 1 ton of waste is equal to 3 Cu.Yd. of waste. This assumption is used by some local government which require landfill operator to report waste volume by cubic yard.

[41] National average tipping fee by Solid Waste Digest is $36.00 per ton. Mean value of listed 745 data is slightly higher because Chartwell Institution (publishing Solid Waste Digest) estimates national average with including additional unlisted landfill data.

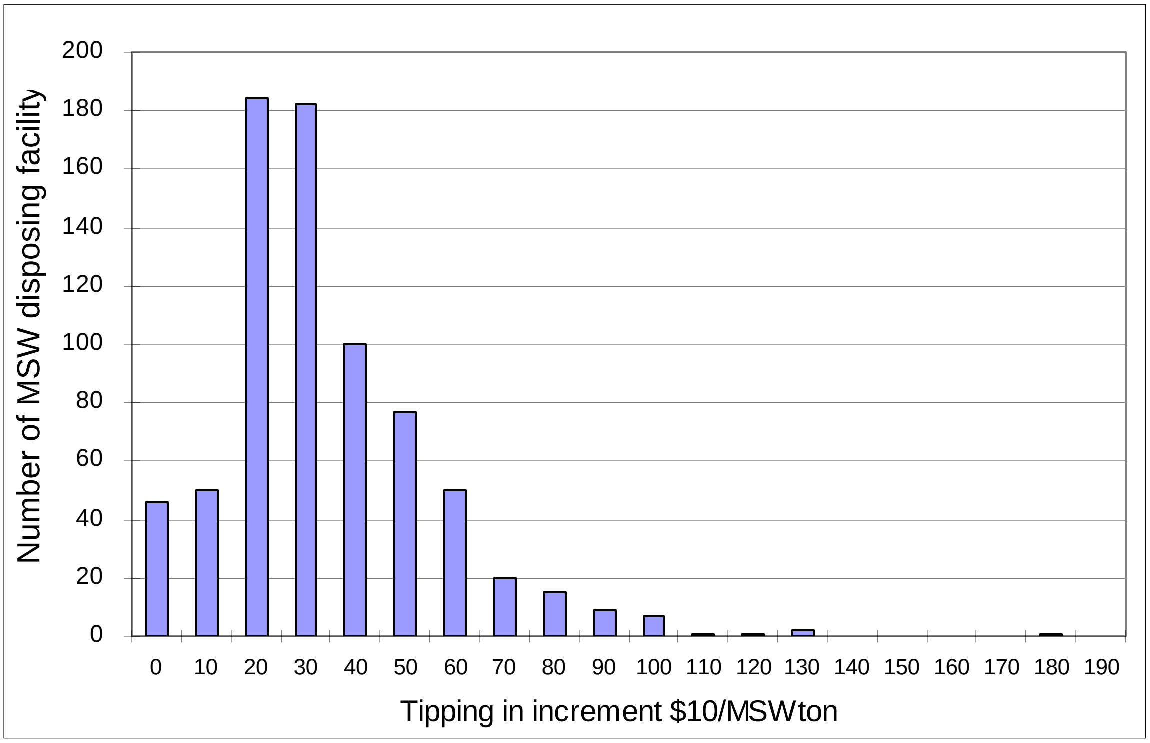

Figure A.1 Distribution of Tipping Fee Charged by MSW Disposing Facility
Source: Chartwell Information, 2003

Regression Analysis

Econometric analysis can be carried out with cross-sectional landfill data of Solid Waste Digest. Linear regression is useful tool to identify the factor affecting tipping fee price while controlling statistically for the effects of several explanatory variables. We utilize ordinary least square (OLS) for regression. The model specified is as follows;

$$
\begin{aligned}
Tip_i = {} & \beta_0 + \beta_1 WTE_i + \beta_2 TS_i + \beta_3 Mount_i + \beta_4 Mid_i \\
& + \beta_5 Sou_i + \beta_6 Nor_i + \beta_7 small_i + \beta_8 big_i + u_i
\end{aligned}
$$

where,

Tip_i = Tipping fee ($/MSW ton) charged by landfill i,

WTE_i = Dummy variable, coding 1 if landfill i is WTE facility or incinerators

TS_i = Dummy variable, coding 1 if landfill i is transfer station or other kinds of processing facility

$Mount_i$ = Dummy variable, coding 1 if landfill i is located in Mountain region

Mid_i = Dummy variable, coding 1 if landfill i is located in Midwest region

Sou_i = Dummy variable, coding 1 if landfill i is located in South region

Nor_i = Dummy variable, coding 1 if landfill i is located in Northeast region

$small_i$ = Dummy variable, coding 1 if daily MSW stream of landfill i is less than 500t

big_i = Dummy variable, coding 1 if daily MSW stream of landfill i is greater than 1000t

u_i = Random error term for landfill i

The first two explanatory dummy variables are incorporated into the model to see the effect of type of waste-disposing facility on tipping fee. Base case is ordinal MSW landfill. The second four dummy variables are used to indicate the effect of regional difference on tipping fee. Note that the dummy variable indicating Pacific region is the base case. Finally, the last two dummy variables are to analyze the effect of daily waste volume on tipping fee. If daily the volume MSW stream run into facility is less than 500t per day, we call it small volume. If daily volume is between 500t and 1000t, it is medium size. If volume exceeds 1000t per day, it is called big volume. Base case is medium.

Table A.3 OLS Regression Results

Variable	Coefficient	Std. Error	t-statistics	p-value
WTE	17.332	2.369	7.316	0.000
TS	6.148	1.625	3.783	0.000
Mountain	-18.892	2.489	-7.590	0.000
Midwest	-10.544	2.135	-4.938	0.000
South	-8.512	2.111	-4.032	0.000
Northeast	14.219	2.213	6.425	0.000
small_volume	-1.772	3.595	-0.493	0.622
large_volume	0.133	1.326	0.100	0.920
Intercept	39.828	1.983	20.086	0.000

N=745, R-square=0.37

The regression results reported in Table appendix 4.3 show that both type of facilities and regions have significant effects on tipping fee. Both WTE and TS charges higher tipping fee than ordinary MSW dumping landfill. F-statistics of these two dummy variables is 30.18 (p-value is 0.00), thus there is strong statistical evidence that tipping fee varies by type of facilities. F-statistics of regional four dummy variables is 68.61. Regional dummy variables are proxy to “population density indicators” or “landfill scarcity indicators”. For instance, Northeast region is heavily populated and has scarce landfill site, while in Mountain regions, population is scattered and landfill sites are abundant.

On the other hand, daily MSW volume shows no statistical relation with tipping fee. F-statistics of two dummy variables is only 0.14 (p-value is 0.87). In conclusion, tipping fee is not dependent on facility size but more affected by regional effect and type of facility.

APPENDIX B

Table B.1 MSW Generation, Recycling, Landfilled by State in the U.S. in 2003[42]

	MSW generated (1000t)	Population	**MSW per capita (ton)**	MSW recycled (1000t)	MSW to WTE (1000t)	MSW landfilled (1000t)	MSW recycled (%)	MSW to WTE (%)	MSW landfilled (%)	Number of MSW landfill	Number of WTE plants	Landfill capacity (1000t)	Capacity / landfilled (year)	Imported MSW (1000t)	Exported MSW (1000t)
West							**38%**	**3%**	**59%**						
Alaska	n/a	643,786	**n/a**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
California	54,430	35,116,033	**1.550**	21,902	887	31,640	40.2%	1.6%	58.1%	161	3	410,501	8	26	616
Hawaii	1,706	1,244,898	**1.370**	430	417	859	25.2%	24.4%	50.4%	9	1	n/a	n/a	n/a	n/a
Nevada	3,366	2,173,491	**1.548**	532	0	2,834	15.8%	0.0%	84.2%	23	0	60,742	18	534	0
Oregon	4,735	3,521,515	**1.345**	1,987	201	2,547	42.0%	4.3%	53.8%	30	1	n/a	n/a	1,626	19
Washington	8,667	6,068,996	**1.428**	2,960	489	5,218	34.1%	5.6%	60.2%	21	4	180,003	21	173	1,146
Mountain							**9%**	**1%**	**90%**						
Arizona	6,012	5,456,453	**1.102**	1,053	0	4,959	17.5%	0.0%	82.5%	41	0	n/a	n/a	383	10
Colorado	5,051	4,506,542	**1.121**	142	0	4,909	2.8%	0.0%	97.2%	65	0	n/a	n/a	n/a	n/a
Idaho	1,090	1,341,131	**0.813**	92	0	998	8.4%	0.0%	91.6%	29	0	n/a	n/a	n/a	n/a
Montana	n/a	909,453	**n/a**	n/a	n/a	n/a	n/a	n/a	n/a	30	0	32,727	n/a	n/a	n/a
New Mexico	2,095	1,855,059	**1.129**	135	0	1,960	6.5%	0.0%	93.5%	35	0	190,966	91	378	0
Utah	2,471	2,316,256	**1.067**	118	120	2,234	4.8%	4.9%	90.4%	38	1	n/a	n/a	139	n/a
Wyoming	694	498,703	**1.391**	12	0	682	1.7%	0.0%	98.3%	53	0	n/a	n/a	n/a	n/a
Midwest							**25%**	**<1%**	**75%**						
Arkansas	3,838	2,710,079	**1.416**	1,392	56	2,390	36.3%	1.5%	62.3%	24	2	n/a	n/a	168	370
Iowa	3,416	2,936,760	**1.163**	1,426	34	1,956	41.7%	1.0%	57.3%	59	1	40,183	12	403	128
Kansas	4,698	2,715,884	**1.730**	540	0	4,158	11.5%	0.0%	88.5%	51	0	n/a	n/a	663	n/a
Missouri	7,257	5,672,579	**1.279**	2,823	20	4,413	38.9%	0.3%	60.8%	24	0	41,433	6	11	1,993
Nebraska	2,395	1,729,180	**1.385**	369	0	2,026	15.4%	0.0%	84.6%	24	0	n/a	n/a	n/a	n/a
North Dakota	639	634,110	**1.007**	60	0	579	9.4%	0.0%	90.6%	14	0	n/a	n/a	101	10
Okalahoma	4,489	3,493,714	**1.285**	45	0	4,444	1.0%	0.0%	99.0%	40	1	n/a	n/a	n/a	n/a
South Dakota	518	761,063	**0.681**	15	0	503	3.0%	0.0%	97.0%	15	0	16,758	32	n/a	n/a
Texas	28,532	21,779,893	**1.310**	7,107	0	21,425	24.9%	0.0%	75.1%	175	2	970,000	34	66	n/a
Great Lakes							**27%**	**5%**	**68%**						
Illinois	15,951	12,600,620	**1.266**	5,191	0	10,760	32.5%	0.0%	67.5%	51	0	212,394	13	5,801	n/a
Indiana	9,542	6,159,068	**1.549**	3,340	648	5,555	35.0%	6.8%	58.2%	35	1	52,232	5	1,574	n/a
Michigan	16,916	10,050,446	**1.683**	2,550	1,183	13,182	15.1%	7.0%	77.9%	52	4	143,939	9	3,831	n/a
Minnesota	5,044	5,019,720	**1.005**	2,301	1,266	1,477	45.6%	25.1%	29.3%	21	15	18,700	4	n/a	636
Ohio	16,211	11,421,267	**1.419**	3,808	0	12,403	23.5%	0.0%	76.5%	44	0	124,080	8	1,978	987
Wisconsin	5,593	5,441,196	**1.028**	1,378	188	4,027	24.6%	3.4%	72.0%	42	2	30,440	5	1,407	n/a

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[42] Data of Oregon and Maryland was corrected by *BioCycle* itself three months after “The State of Garbage in America” for 2003 is issued. Data of Oregon and Maryland is taken from “Corrections to State of Garbage of Garbage” (*BioCycle* 2004).

South							**19%**	**12%**	**69%**						
Alabama	n/a	4,486,508	**n/a**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Florida	19,707	16,713,149	**1.179**	4,722	5,564	9,421	24.0%	28.2%	47.8%	100	13	n/a	n/a	n/a	n/a
Georgia	11,214	8,560,310	**1.310**	929	52	10,234	8.3%	0.5%	91.3%	60	1	135,349	12	963	n/a
Kentucky	5,466	4,092,891	**1.335**	625	2	4,838	11.4%	0.0%	88.5%	25	1	36,364	7	n/a	247
Louisiana	4,953	4,482,646	**1.105**	402	0	4,551	8.1%	0.0%	91.9%	24	0	n/a	n/a	n/a	n/a
Mississippi	2,918	2,871,782	**1.016**	10	0	2,908	0.3%	0.0%	99.7%	17	0	n/a	n/a	538	n/a
North Carolina	8,981	8,320,146	**1.079**	992	121	7,869	11.0%	1.3%	87.6%	41	1	100,000	11	n/a	882
South Carolina	5,973	4,107,183	**1.454**	1,698	231	4,044	28.4%	3.9%	67.7%	19	4	109,534	18	955	508
Tennessee	7,366	5,797,289	**1.271**	1,943	150	5,273	26.4%	2.0%	71.6%	34	1	n/a	n/a	n/a	549
Virginia	10,878	7,293,542	**1.491**	3,161	2,152	5,565	29.1%	19.8%	51.2%	67	5	251,810	23	4,509	n/a
Mid Atlantic							**28%**	**14%**	**58%**						
Delaware	1,069	807,385	**1.324**	218	0	851	20.4%	0.0%	79.6%	3	0	20,000	19	n/a	n/a
Maryland	7,103	5,458,137	**1.301**	2,456	1,376	3,270	34.6%	19.4%	46.0%	20	3	n/a	n/a	457	1,943
New Jersey	10,606	8,590,300	**1.235**	4,015	962	5,630	37.9%	9.1%	53.1%	12	5	40,000	4	576	3,500
New York	24,775	19,157,532	**1.293**	7,384	4,248	13,143	29.8%	17.1%	53.1%	26	10	90,000	4	568	5,400
Pennsylvania	12,676	12,335,091	**1.028**	3,399	2,095	7,182	26.8%	16.5%	56.7%	49	6	298,586	24	10,000	3,000
West Virginia	1,755	1,801,873	**0.974**	120	0	1,634	6.9%	0.0%	93.1%	18	0	5,674	3	204	432
New England							**27%**	**34%**	**39%**						
Connecticut	4,734	3,460,503	**1.368**	888	2,130	1,716	18.8%	45.0%	36.2%	2	6	n/a	n/a	64	366
Maine	1,327	1,294,464	**1.025**	650	448	229	49.0%	33.8%	17.2%	8	4	3,030	2	219	78
Massachusetts	8,307	6,427,801	**1.292**	2,584	3,128	2,596	31.1%	37.6%	31.3%	19	7	n/a	n/a	186	1,687
New Hampshire	1,215	1,275,056	**0.953**	288	206	721	23.7%	17.0%	59.4%	10	2	15,000	12	746	33
Rhode Island	1,249	1,069,725	**1.167**	160	0	1,089	12.8%	0.0%	87.2%	2	0	n/a	n/a	n/a	n/a
Vermont	612	616,592	**0.992**	183	56	373	29.8%	9.2%	60.9%	5	0	1,454	2	7	124
United States	**368,240**	**287,797,800**	**1.310**	**98,675**	**28,480**	**242,227**	**26.7%**	**7.7%**	**65.6%**	**1,767**					

Source: Kaufman *et al*., 2004

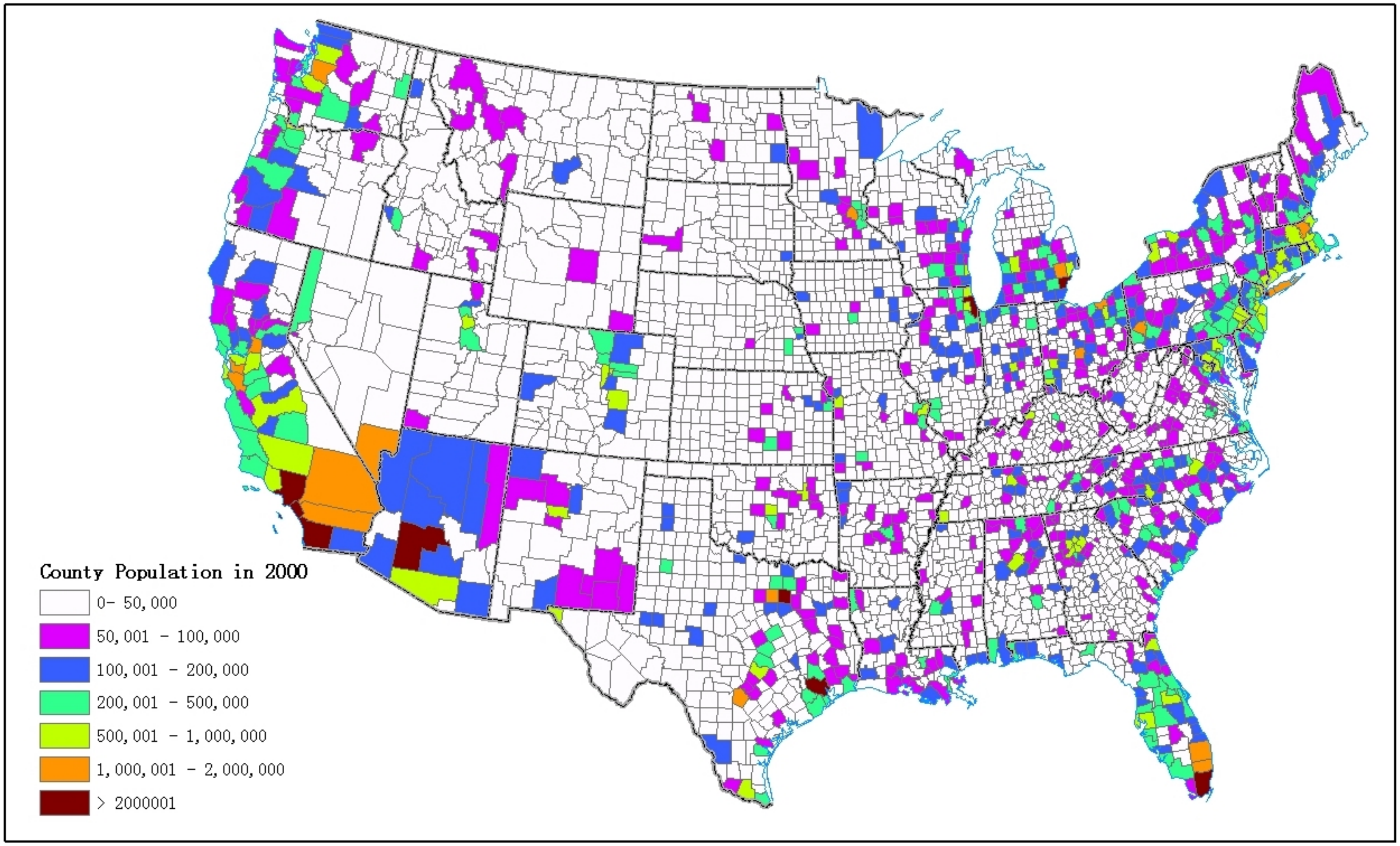

Figure B.1 Distribution of the U.S. Population in 2000
Source: U.S. Census Bureau, 2002

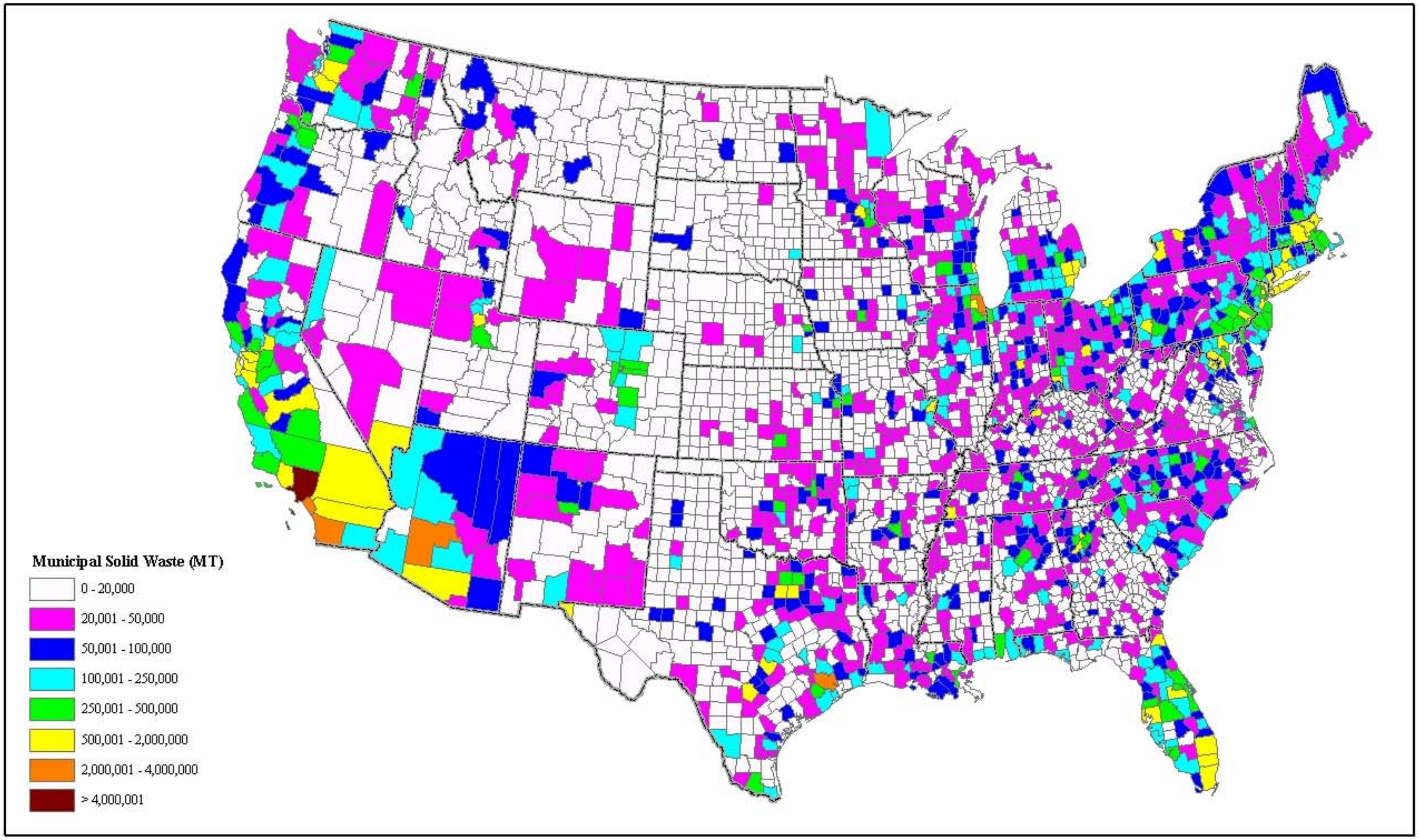

Figure B.2 Distribution of MSW in the U.S. in 2000

Source: County population data taken by U.S. Census Bureau (2002). State average MSW generation data taken by Goldstein and Madtes (2001)

Table B.2 MSW Density of Top 20 U.S. Populated Metropolitan Area

Metropolitan Area	Population (million)	Area (square mile)	Population density (tons/ square mile)	State average MSW generation (tons/year)	State average MSW generation (lbs/day)	Annual MSW generation (1000 tons /year)	Daily MSW generation (1000 tons /day)	MSW density (tons/square mile	MSW within 10 radius (tons/100π square mile)	Minimum radius supplying 500 TPD (mile)
New York--Northern New Jersey--Long Island	21.200	10,166	2,085	1.293	7.1	27,411	75.10	7.39	2,321	4.64
Los Angeles--Riverside--Orange County	16.374	33,966	482	1.550	8.5	25,379	69.53	2.05	643	8.82
Chicago--Gary--Kenosha	9.158	6,931	1,321	1.266	6.9	11,593	31.76	4.58	1,440	5.89
Washington--Baltimore	7.608	9,578	794	1.301	7.1	9,898	27.12	2.83	889	7.50
San Francisco--Oakland--San Jose	7.039	7,369	955	1.550	8.5	10,911	29.89	4.06	1,274	6.26
Philadelphia--Wilmington--Atlantic City	6.188	5,936	1,043	1.028	5.6	6,362	17.43	2.94	922	7.36
Boston--Worcester--Lawrence	5.819	6,450	902	1.292	7.1	7,518	20.60	3.19	1,003	7.06
Detroit--Ann Arbor--Flint	5.456	6,566	831	1.683	9.2	9,183	25.16	3.83	1,204	6.44
Dallas--Fort Worth	5.222	9,105	574	1.310	7.2	6,841	18.74	2.06	647	8.79
Houston--Galveston--Brazoria	4.670	7,707	606	1.310	7.2	6,117	16.76	2.17	683	8.55
Atlanta	4.112	6,126	671	1.310	7.2	5,387	14.76	2.41	757	8.13
Miami--Fort Lauderdale	3.876	3,154	1,229	1.179	6.5	4,570	12.52	3.97	1,247	6.33
Seattle--Tacoma--Bremerton	3.555	7,224	492	1.428	7.8	5,076	13.91	1.93	605	9.09
Phoenix--Mesa	3.252	14,574	223	1.102	6.0	3,584	9.82	0.67	212	15.37
Minneapolis--St. Paul	2.969	6,064	490	1.005	5.5	2,984	8.17	1.35	423	10.87
Cleveland--Akron	2.946	3,613	815	1.419	7.8	4,180	11.45	3.17	996	7.09
San Diego	2.814	4,205	669	1.550	8.5	4,361	11.95	2.84	893	7.48
St. Louis	2.604	6,393	407	1.279	7.0	3,330	9.12	1.43	448	10.56
Denver--Boulder--Greeley	2.582	8,496	304	1.121	6.1	2,894	7.93	0.93	293	13.06
Tampa--St. Petersburg--Clearwater	2.450	2,555	959	1.179	6.5	2,889	7.91	3.10	973	7.17

Data: Metropolitan population and area data is taken by U.S. Census Bureau. State average MSW generation data is taken by Kaufman *et al*. (2001)

APPENDIX C

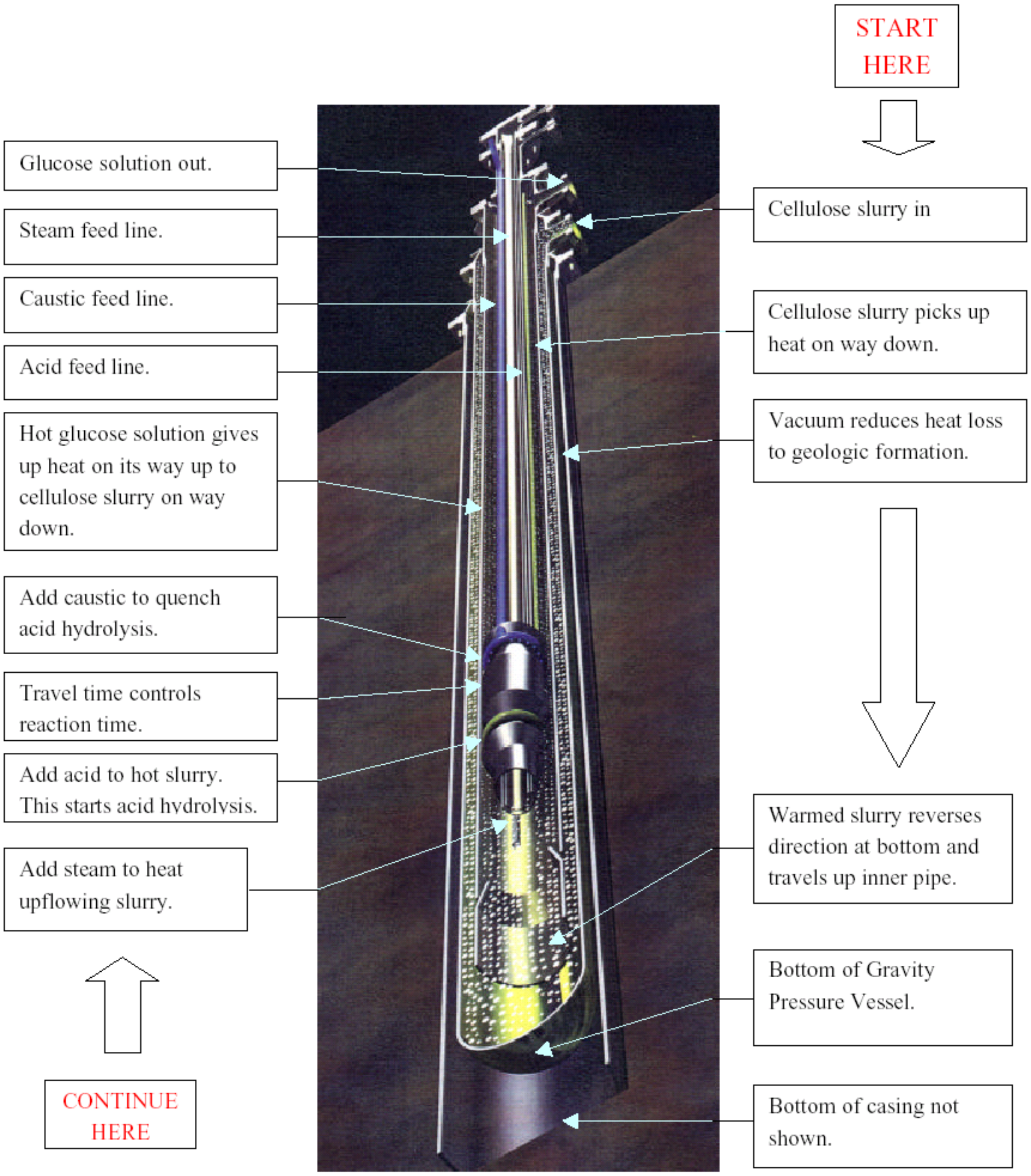

Figure C.1 Cellulose Conversion by GPV
Source: GeneSyst, 2004

APPENDIX D

Table D.1 Revenue Schedule of a 500 TPD MSW-Ethanol Plant at the Base Case (U.S. Thousands Dollar)

Year	MSW volume (T/day)	MSW volume (T/year)	***Ethanol sales***	***Recovered material sales***			***Chemical By-product sales***				**Total revenue**
				Aluminum sales	Ferrous sales	Plastic sales	Furfural sales	Yeast sales	Gypsum sales	CO2 sales	
0	0	0	0	0	0	-	0	0	0	0	0
1	500	156,000	5,070	983	262	-	390	346	9	117	7,177
2	510	159,120	5,171	1,002	267	-	796	706	9	119	8,072
3	520	162,302	5,275	1,023	273	-	812	721	9	122	8,233
4	531	165,548	5,380	1,043	278	-	828	735	9	124	8,398
5	541	168,859	5,488	1,064	284	-	844	750	10	127	8,566
6	552	172,237	5,598	1,085	289	-	861	765	10	129	8,737
7	563	175,681	5,710	1,107	295	-	878	780	10	132	8,912
8	574	179,195	5,824	1,129	301	-	896	796	10	134	9,090
9	586	182,779	5,940	1,152	307	-	914	812	10	137	9,272
10	598	186,434	6,059	1,175	313	-	932	828	11	140	9,457
11	609	190,163	6,180	1,198	319	-	951	844	11	143	9,646
12	622	193,966	6,304	1,222	326	-	970	861	11	145	9,839
13	634	197,846	6,430	1,246	332	-	989	878	11	148	10,036
14	647	201,803	6,559	1,271	339	-	1,009	896	11	151	10,237
15	660	205,839	6,690	1,297	346	-	1,029	914	12	154	10,441
16	673	209,955	6,824	1,323	353	-	1,050	932	12	157	10,650
17	686	214,155	6,960	1,349	360	-	1,071	951	12	161	10,863
18	700	218,438	7,099	1,376	367	-	1,092	970	12	164	11,081
19	714	222,806	7,241	1,404	374	-	1,114	989	13	167	11,302
20	728	227,263	7,386	1,432	382	-	1,136	1,009	13	170	11,528

Table D.2 Cost Schedule of a 500 TPD MSW-Ethanol Plant at the Base Case (U.S. Thousands Dollar)

Year	MSW volume (T/day)	MSW volume (T/year)	***Capital Cost***	***Feedstock cost***	***Total operation cost***		***General Administration Overhead***					**Total cost**
					MSW Classification cost	Plant operation cost	Admini-stration cost	Insurance cost	Loyalty cost	Contractual cost	Training cost	
0	0	0	(30,000)	0	0	0	0	0	0	0	0	(30,000)
1	500	156,000	0	5,054	(600)	(1,794)	(246)	(80)	(367)	(50)	(150)	1,767
2	510	159,120	0	5,155	(612)	(1,830)	(246)	(80)	(397)	(75)	(50)	1,866
3	520	162,302	0	5,259	(624)	(1,866)	(246)	(80)	(405)	(100)	(50)	1,887
4	531	165,548	0	5,364	(637)	(1,904)	(246)	(80)	(413)	(125)	(50)	1,909
5	541	168,859	(402)	5,471	(649)	(1,942)	(246)	(80)	(421)	(150)	(50)	1,531
6	552	172,237	0	5,580	(662)	(1,981)	(246)	(80)	(430)	(175)	(50)	1,957
7	563	175,681	0	5,692	(676)	(2,020)	(246)	(80)	(438)	(200)	(50)	1,982
8	574	179,195	0	5,806	(689)	(2,061)	(246)	(80)	(447)	(225)	(50)	2,008
9	586	182,779	0	5,922	(703)	(2,102)	(246)	(80)	(456)	(250)	(50)	2,035
10	598	186,434	(704)	6,040	(717)	(2,144)	(246)	(80)	(465)	(275)	(50)	1,360
11	609	190,163	0	6,161	(731)	(2,187)	(246)	(80)	(474)	(300)	(50)	2,093
12	622	193,966	0	6,285	(746)	(2,231)	(246)	(80)	(484)	(325)	(50)	2,123
13	634	197,846	0	6,410	(761)	(2,275)	(246)	(80)	(493)	(350)	(50)	2,155
14	647	201,803	0	6,538	(776)	(2,321)	(246)	(80)	(503)	(375)	(50)	2,187
15	660	205,839	(402)	6,669	(792)	(2,367)	(246)	(80)	(513)	(400)	(50)	1,819
16	673	209,955	0	6,803	(808)	(2,414)	(246)	(80)	(524)	(425)	(50)	2,256
17	686	214,155	0	6,939	(824)	(2,463)	(246)	(80)	(534)	(450)	(50)	2,292
18	700	218,438	0	7,077	(840)	(2,512)	(246)	(80)	(545)	(475)	(50)	2,329
19	714	222,806	0	7,219	(857)	(2,562)	(246)	(80)	(556)	(500)	(50)	2,368
20	728	227,263	0	7,363	(874)	(2,614)	(246)	(80)	(567)	(525)	(50)	2,408

Table D.3 Cash Flow of a 500 TPD MSW-Ethanol Plant under Different Tax Program Scenario (U.S. Thousands Dollar)

T	Year	**EBITDA**	**Annual depreciation**	Debt Schedule			Tax description			**Scenario 1** =No tax incentive		**Scenario 2** =Tax program ends in Year 2		**Scenario 3** = Tax program lasts by Year 15	
				Interest payment	Principal payment	Remaining Principal	Federal tax (32%)	State tax (8.5%)	Local Tax ($50,000 a year)	Tax imposed	**Cash flow**	Tax imposed	**Cash flow**	Tax imposed	**Cash flow**
0	2005	**(30,000)**	**0**	**0**	0	(30,000)	0	0	0	0	**(30,000)**	0	**(30,000)**	0	**(30,000)**
1	2006	**8,944**	**(1,634)**	**(2,100)**	(732)	(29,268)	(1,668)	(443)	(50)	(2,160)	**6,784**	(493)	**8,452**	(493)	**8,452**
2	2007	**9,937**	**(1,634)**	**(2,049)**	(783)	(28,485)	(2,002)	(532)	(50)	(2,583)	**7,354**	(582)	**9,356**	(582)	**9,356**
3	2008	**10,120**	**(1,634)**	**(1,994)**	(838)	(27,647)	(2,078)	(552)	(50)	(2,680)	**7,441**	(2,680)	**7,441**	(602)	**9,518**
4	2009	**10,307**	**(1,634)**	**(1,935)**	(896)	(26,751)	(2,156)	(573)	(50)	(2,779)	**7,528**	(2,779)	**7,528**	(623)	**9,684**
5	2010	**10,096**	**(1,634)**	**(1,873)**	(959)	(25,792)	(2,237)	(594)	(50)	(2,882)	**7,214**	(2,882)	**7,214**	(644)	**9,452**
6	2011	**10,694**	**(1,634)**	**(1,805)**	(1,026)	(24,765)	(2,322)	(617)	(50)	(2,988)	**7,706**	(2,988)	**7,706**	(667)	**10,027**
7	2012	**10,894**	**(1,634)**	**(1,734)**	(1,098)	(23,667)	(2,408)	(640)	(50)	(3,098)	**7,795**	(3,098)	**7,795**	(690)	**10,204**
8	2013	**11,098**	**(1,634)**	**(1,657)**	(1,175)	(22,492)	(2,499)	(664)	(50)	(3,212)	**7,886**	(3,212)	**7,886**	(714)	**10,384**
9	2014	**11,307**	**(1,634)**	**(1,574)**	(1,257)	(21,235)	(2,592)	(688)	(50)	(3,330)	**7,977**	(3,330)	**7,977**	(738)	**10,569**
10	2015	**10,817**	**(1,634)**	**(1,486)**	(1,345)	(19,889)	(2,688)	(714)	(50)	(3,452)	**7,365**	(3,452)	**7,365**	(764)	**10,053**
11	2016	**11,739**	**(1,374)**	**(1,392)**	(1,440)	(18,450)	(2,871)	(763)	(50)	(3,684)	**8,055**	(3,684)	**8,055**	(813)	**10,926**
12	2017	**11,962**	**(1,374)**	**(1,291)**	(1,540)	(16,909)	(2,975)	(790)	(50)	(3,815)	**8,147**	(3,815)	**8,147**	(857)	**11,105**
13	2018	**12,191**	**(1,374)**	**(1,184)**	(1,648)	(15,261)	(3,083)	(819)	(50)	(3,952)	**8,239**	(3,952)	**8,239**	(934)	**11,256**
14	2019	**12,424**	**(1,374)**	**(1,068)**	(1,763)	(13,498)	(3,194)	(848)	(50)	(4,093)	**8,331**	(4,093)	**8,331**	(1,015)	**11,409**
15	2020	**12,260**	**(1,374)**	**(945)**	(1,887)	(11,611)	(3,310)	(879)	(50)	(4,239)	**8,021**	(4,239)	**8,021**	(1,100)	**11,160**
16	2021	**12,906**	**(1,374)**	**(813)**	(2,019)	(9,592)	(3,430)	(911)	(50)	(4,392)	**8,515**	(4,392)	**8,515**	(4,392)	**8,515**
17	2022	**13,155**	**(1,374)**	**(671)**	(2,160)	(7,432)	(3,555)	(944)	(50)	(4,550)	**8,606**	(4,550)	**8,606**	(4,550)	**8,606**
18	2023	**13,410**	**(1,374)**	**(520)**	(2,312)	(5,120)	(3,685)	(979)	(50)	(4,714)	**8,696**	(4,714)	**8,696**	(4,714)	**8,696**
19	2024	**13,670**	**(1,374)**	**(358)**	(2,473)	(2,647)	(3,820)	(1,015)	(50)	(4,885)	**8,785**	(4,885)	**8,785**	(4,885)	**8,785**
20	2025	**13,936**	**(1,374)**	**(185)**	(2,647)	0	(3,961)	(1,052)	(50)	(5,063)	**8,873**	(5,063)	**8,873**	(5,063)	**8,873**
		33.4%								*IRR =*	***24.5%***	*IRR =*	***26.8%***	*IRR =*	***31.4%***
		87,474								*NPV =*	***52,291***	*NPV =*	***55,597***	*NPV =*	***74,072***
		10.4								*B/C =*	***2.2***	*B/C =*	***2.4***	*B/C =*	***4.3***

Table D.4 IRR Sensitivity with Changing Ethanol Price and Tipping Fee (EBITDA)

			Ethanol price ($/gallon) ±10% change																				
			-100%	-90%	-80%	-70%	-60%	-50%	-40%	-30%	-20%	-10%	**0%**	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
			0.00	0.13	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.17	**1.30**	1.43	1.56	1.69	1.82	1.95	2.08	2.21	2.34	2.47	2.60
Tipping fee (%/ton) ±10% change	-100%	0.00	-	-	-4.5%	-0.3%	3.0%	5.7%	8.1%	10.3%	12.4%	14.4%	16.3%	18.1%	19.9%	21.7%	23.4%	25.1%	26.8%	28.5%	30.2%	31.8%	33.5%
	-90%	3.60	-	-4.6%	-0.3%	3.0%	5.7%	8.1%	10.3%	12.4%	14.4%	16.3%	18.1%	19.9%	21.7%	23.4%	25.1%	26.8%	28.5%	30.2%	31.8%	33.5%	35.1%
	-80%	7.20	-4.6%	-0.3%	2.9%	5.7%	8.1%	10.3%	12.4%	14.4%	16.3%	18.1%	19.9%	21.7%	23.4%	25.1%	26.8%	28.5%	30.2%	31.8%	33.5%	35.1%	36.8%
	-70%	10.80	-0.3%	2.9%	5.7%	8.1%	10.3%	12.4%	14.3%	16.2%	18.1%	19.9%	21.7%	23.4%	25.1%	26.8%	28.5%	30.2%	31.8%	33.5%	35.1%	36.8%	38.4%
	-60%	14.40	2.9%	5.7%	8.1%	10.3%	12.4%	14.3%	16.2%	18.1%	19.9%	21.6%	23.4%	25.1%	26.8%	28.5%	30.2%	31.8%	33.5%	35.1%	36.8%	38.4%	40.1%
	-50%	18.00	5.6%	8.1%	10.3%	12.4%	14.3%	16.2%	18.1%	19.9%	21.6%	23.4%	25.1%	26.8%	28.5%	30.2%	31.8%	33.5%	35.1%	36.8%	38.4%	40.1%	41.7%
	-40%	21.60	8.1%	10.3%	12.4%	14.3%	16.2%	18.1%	19.9%	21.6%	23.4%	25.1%	26.8%	28.5%	30.1%	31.8%	33.5%	35.1%	36.8%	38.4%	40.0%	41.7%	43.3%
	-30%	25.20	10.3%	12.3%	14.3%	16.2%	18.1%	19.9%	21.6%	23.4%	25.1%	26.8%	28.5%	30.1%	31.8%	33.5%	35.1%	36.8%	38.4%	40.0%	41.7%	43.3%	44.9%
	-20%	28.80	12.3%	14.3%	16.2%	18.1%	19.9%	21.6%	23.4%	25.1%	26.8%	28.5%	30.1%	31.8%	33.5%	35.1%	36.8%	38.4%	40.0%	41.7%	43.3%	44.9%	46.6%
	-10%	32.40	14.3%	16.2%	18.1%	19.9%	21.6%	23.4%	25.1%	26.8%	28.5%	30.1%	31.8%	33.5%	35.1%	36.7%	38.4%	40.0%	41.7%	43.3%	44.9%	46.6%	48.2%
	0%	**36.00**	16.2%	18.1%	19.9%	21.6%	23.4%	25.1%	26.8%	28.5%	30.1%	31.8%	**33.4%**	35.1%	36.7%	38.4%	40.0%	41.7%	43.3%	44.9%	46.6%	48.2%	49.8%
	10%	39.60	18.0%	19.8%	21.6%	23.3%	25.1%	26.8%	28.4%	30.1%	31.8%	33.4%	35.1%	36.7%	38.4%	40.0%	41.7%	43.3%	44.9%	46.6%	48.2%	49.8%	51.4%
	20%	43.20	19.8%	21.6%	23.3%	25.1%	26.8%	28.4%	30.1%	31.8%	33.4%	35.1%	36.7%	38.4%	40.0%	41.7%	43.3%	44.9%	46.6%	48.2%	49.8%	51.4%	53.1%
	30%	46.80	21.6%	23.3%	25.1%	26.8%	28.4%	30.1%	31.8%	33.4%	35.1%	36.7%	38.4%	40.0%	41.6%	43.3%	44.9%	46.5%	48.2%	49.8%	51.4%	53.1%	54.7%
	40%	50.40	23.3%	25.0%	26.7%	28.4%	30.1%	31.8%	33.4%	35.1%	36.7%	38.4%	40.0%	41.6%	43.3%	44.9%	46.5%	48.2%	49.8%	51.4%	53.1%	54.7%	56.3%
	50%	54.00	25.0%	26.7%	28.4%	30.1%	31.8%	33.4%	35.1%	36.7%	38.4%	40.0%	41.6%	43.3%	44.9%	46.5%	48.2%	49.8%	51.4%	53.1%	54.7%	56.3%	57.9%
	60%	57.60	26.7%	28.4%	30.1%	31.8%	33.4%	35.1%	36.7%	38.4%	40.0%	41.6%	43.3%	44.9%	46.5%	48.2%	49.8%	51.4%	53.1%	54.7%	56.3%	57.9%	59.6%
	70%	61.20	28.4%	30.1%	31.8%	33.4%	35.1%	36.7%	38.4%	40.0%	41.6%	43.3%	44.9%	46.5%	48.2%	49.8%	51.4%	53.0%	54.7%	56.3%	57.9%	59.6%	61.2%
	80%	64.80	30.1%	31.7%	33.4%	35.1%	36.7%	38.3%	40.0%	41.6%	43.3%	44.9%	46.5%	48.2%	49.8%	51.4%	53.0%	54.7%	56.3%	57.9%	59.6%	61.2%	62.8%
	90%	68.40	31.7%	33.4%	35.1%	36.7%	38.3%	40.0%	41.6%	43.3%	44.9%	46.5%	48.1%	49.8%	51.4%	53.0%	54.7%	56.3%	57.9%	59.6%	61.2%	62.8%	64.4%
	100%	72.00	33.4%	35.0%	36.7%	38.3%	40.0%	41.6%	43.2%	44.9%	46.5%	48.1%	49.8%	51.4%	53.0%	54.7%	56.3%	57.9%	59.5%	61.2%	62.8%	64.4%	66.1%

Table D.5 IRR Sensitivity with Changing Ethanol Price and Tipping Fee (After Tax; No Tax Incentive case)

			Ethanol price ($/gallon) ±10% change																				
			-100%	-90%	-80%	-70%	-60%	-50%	-40%	-30%	-20%	-10%	**0%**	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
			0.00	0.13	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.17	**1.30**	1.43	1.56	1.69	1.82	1.95	2.08	2.21	2.34	2.47	2.60
Tipping fee (%/ton) ±10% change	-100%	0.0	-	-	-	-	-	-	-	-	-	-2.2%	2.1%	5.3%	8.1%	10.5%	12.8%	14.9%	17.0%	18.9%	20.8%	22.7%	24.6%
	-90%	3.6	-	-	-	-	-	-	-	-	-2.2%	2.1%	5.3%	8.1%	10.5%	12.8%	14.9%	17.0%	18.9%	20.8%	22.7%	24.5%	26.4%
	-80%	7.2	-	-	-	-	-	-	-	-2.2%	2.0%	5.3%	8.0%	10.5%	12.8%	14.9%	17.0%	18.9%	20.8%	22.7%	24.5%	26.4%	28.1%
	-70%	10.8	-	-	-	-	-	-	-2.2%	2.0%	5.3%	8.0%	10.5%	12.8%	14.9%	16.9%	18.9%	20.8%	22.7%	24.5%	26.3%	28.1%	29.9%
	-60%	14.4	-	-	-	-	-	-2.3%	2.0%	5.3%	8.0%	10.5%	12.8%	14.9%	16.9%	18.9%	20.8%	22.7%	24.5%	26.3%	28.1%	29.9%	31.7%
	-50%	18.0	-	-	-	-	-2.3%	2.0%	5.3%	8.0%	10.5%	12.8%	14.9%	16.9%	18.9%	20.8%	22.7%	24.5%	26.3%	28.1%	29.9%	31.7%	33.4%
	-40%	21.6	-	-	-	-2.3%	2.0%	5.3%	8.0%	10.5%	12.8%	14.9%	16.9%	18.9%	20.8%	22.7%	24.5%	26.3%	28.1%	29.9%	31.7%	33.4%	35.1%
	-30%	25.2	-	-	-2.3%	2.0%	5.2%	8.0%	10.5%	12.7%	14.9%	16.9%	18.9%	20.8%	22.7%	24.5%	26.3%	28.1%	29.9%	31.6%	33.4%	35.1%	36.9%
	-20%	28.8	-	-2.3%	2.0%	5.2%	8.0%	10.5%	12.7%	14.9%	16.9%	18.9%	20.8%	22.7%	24.5%	26.3%	28.1%	29.9%	31.6%	33.4%	35.1%	36.9%	38.6%
	-10%	32.4	-2.3%	2.0%	5.2%	8.0%	10.5%	12.7%	14.9%	16.9%	18.9%	20.8%	22.7%	24.5%	26.3%	28.1%	29.9%	31.6%	33.4%	35.1%	36.8%	38.6%	40.3%
	0%	**36.0**	2.0%	5.2%	8.0%	10.5%	12.7%	14.9%	16.9%	18.9%	20.8%	22.7%	**24.5%**	26.3%	28.1%	29.9%	31.6%	33.4%	35.1%	36.8%	38.6%	40.3%	42.0%
	10%	39.6	5.2%	8.0%	10.4%	12.7%	14.9%	16.9%	18.9%	20.8%	22.7%	24.5%	26.3%	28.1%	29.9%	31.6%	33.4%	35.1%	36.8%	38.6%	40.3%	42.0%	43.7%
	20%	43.2	8.0%	10.4%	12.7%	14.9%	16.9%	18.9%	20.8%	22.6%	24.5%	26.3%	28.1%	29.9%	31.6%	33.4%	35.1%	36.8%	38.6%	40.3%	42.0%	43.7%	45.4%
	30%	46.8	10.4%	12.7%	14.8%	16.9%	18.9%	20.8%	22.6%	24.5%	26.3%	28.1%	29.9%	31.6%	33.4%	35.1%	36.8%	38.6%	40.3%	42.0%	43.7%	45.4%	47.1%
	40%	50.4	12.7%	14.8%	16.9%	18.9%	20.8%	22.6%	24.5%	26.3%	28.1%	29.8%	31.6%	33.4%	35.1%	36.8%	38.5%	40.3%	42.0%	43.7%	45.4%	47.1%	48.8%
	50%	54.0	14.8%	16.9%	18.8%	20.8%	22.6%	24.5%	26.3%	28.1%	29.8%	31.6%	33.3%	35.1%	36.8%	38.5%	40.3%	42.0%	43.7%	45.4%	47.1%	48.8%	50.5%
	60%	57.6	16.9%	18.8%	20.8%	22.6%	24.5%	26.3%	28.1%	29.8%	31.6%	33.3%	35.1%	36.8%	38.5%	40.3%	42.0%	43.7%	45.4%	47.1%	48.8%	50.5%	52.2%
	70%	61.2	18.8%	20.7%	22.6%	24.5%	26.3%	28.1%	29.8%	31.6%	33.3%	35.1%	36.8%	38.5%	40.2%	42.0%	43.7%	45.4%	47.1%	48.8%	50.5%	52.2%	53.9%
	80%	64.8	20.7%	22.6%	24.5%	26.3%	28.1%	29.8%	31.6%	33.3%	35.1%	36.8%	38.5%	40.2%	42.0%	43.7%	45.4%	47.1%	48.8%	50.5%	52.2%	53.9%	55.6%
	90%	68.4	22.6%	24.4%	26.3%	28.0%	29.8%	31.6%	33.3%	35.1%	36.8%	38.5%	40.2%	42.0%	43.7%	45.4%	47.1%	48.8%	50.5%	52.2%	53.9%	55.6%	57.3%
	100%	72.0	24.4%	26.3%	28.0%	29.8%	31.6%	33.3%	35.1%	36.8%	38.5%	40.2%	41.9%	43.7%	45.4%	47.1%	48.8%	50.5%	52.2%	53.9%	55.6%	57.3%	59.0%

Table D.6 IRR Sensitivity with Changing Ethanol Price and Tipping Fee (After Tax; Tax Incentives Ends in Year 15)

			Ethanol price ($/gallon) ±10% change																			
			-100%	-90%	-80%	-70%	-60%	-50%	-40%	-30%	-20%	-10%	**0%**	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
			0.00	0.13	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.17	**1.30**	1.43	1.56	1.69	1.82	1.95	2.08	2.21	2.34	2.47	2.60
Tipping fee ($/ton) +10% change	-100%	0.0	-	-	-	-	-	-	-3.3%	3.0%	6.7%	9.6%	12.1%	14.4%	16.5%	18.5%	20.5%	22.4%	24.3%	26.1%	27.9%	29.7%	31.4%
	-90%	3.6	-	-	-	-	-	-3.3%	3.0%	6.6%	9.5%	12.1%	14.4%	16.5%	18.5%	20.5%	22.4%	24.3%	26.1%	27.9%	29.6%	31.4%	33.1%
	-80%	7.2	-	-	-	-	-3.4%	3.0%	6.6%	9.5%	12.1%	14.4%	16.5%	18.5%	20.5%	22.4%	24.3%	26.1%	27.9%	29.6%	31.4%	33.1%	34.9%
	-70%	10.8	-	-	-	-3.4%	3.0%	6.6%	9.5%	12.1%	14.3%	16.5%	18.5%	20.5%	22.4%	24.2%	26.1%	27.9%	29.6%	31.4%	33.1%	34.9%	36.6%
	-60%	14.4	-	-	-3.4%	2.9%	6.6%	9.5%	12.0%	14.3%	16.5%	18.5%	20.5%	22.4%	24.2%	26.1%	27.9%	29.6%	31.4%	33.1%	34.9%	36.6%	38.3%
	-50%	18.0	-	-3.5%	2.9%	6.6%	9.5%	12.0%	14.3%	16.5%	18.5%	20.5%	22.4%	24.2%	26.1%	27.9%	29.6%	31.4%	33.1%	34.9%	36.6%	38.3%	40.0%
	-40%	21.6	-3.5%	2.9%	6.6%	9.5%	12.0%	14.3%	16.5%	18.5%	20.5%	22.4%	24.2%	26.1%	27.8%	29.6%	31.4%	33.1%	34.8%	36.6%	38.3%	40.0%	41.7%
	-30%	25.2	2.9%	6.6%	9.5%	12.0%	14.3%	16.5%	18.5%	20.5%	22.4%	24.2%	26.0%	27.8%	29.6%	31.4%	33.1%	34.8%	36.6%	38.3%	40.0%	41.7%	43.4%
	-20%	28.8	6.6%	9.5%	12.0%	14.3%	16.5%	18.5%	20.5%	22.4%	24.2%	26.0%	27.8%	29.6%	31.4%	33.1%	34.8%	36.6%	38.3%	40.0%	41.7%	43.4%	45.1%
	-10%	32.4	9.5%	12.0%	14.3%	16.5%	18.5%	20.5%	22.4%	24.2%	26.0%	27.8%	29.6%	31.4%	33.1%	34.8%	36.6%	38.3%	40.0%	41.7%	43.4%	45.1%	46.8%
	0%	**36.0**	12.0%	14.3%	16.4%	18.5%	20.4%	22.4%	24.2%	26.0%	27.8%	29.6%	**31.4%**	33.1%	34.8%	36.5%	38.3%	40.0%	41.7%	43.4%	45.1%	46.8%	48.4%
	10%	39.6	14.3%	16.4%	18.5%	20.4%	22.3%	24.2%	26.0%	27.8%	29.6%	31.3%	33.1%	34.8%	36.5%	38.3%	40.0%	41.7%	43.4%	45.1%	46.8%	48.4%	50.1%
	20%	43.2	16.4%	18.5%	20.4%	22.3%	24.2%	26.0%	27.8%	29.6%	31.3%	33.1%	34.8%	36.5%	38.2%	40.0%	41.7%	43.4%	45.1%	46.7%	48.4%	50.1%	51.8%
	30%	46.8	18.5%	20.4%	22.3%	24.2%	26.0%	27.8%	29.6%	31.3%	33.1%	34.8%	36.5%	38.2%	40.0%	41.7%	43.4%	45.0%	46.7%	48.4%	50.1%	51.8%	53.5%
	40%	50.4	20.4%	22.3%	24.2%	26.0%	27.8%	29.6%	31.3%	33.1%	34.8%	36.5%	38.2%	39.9%	41.6%	43.3%	45.0%	46.7%	48.4%	50.1%	51.8%	53.5%	55.2%
	50%	54.0	22.3%	24.2%	26.0%	27.8%	29.6%	31.3%	33.1%	34.8%	36.5%	38.2%	39.9%	41.6%	43.3%	45.0%	46.7%	48.4%	50.1%	51.8%	53.5%	55.2%	56.9%
	60%	57.6	24.2%	26.0%	27.8%	29.6%	31.3%	33.1%	34.8%	36.5%	38.2%	39.9%	41.6%	43.3%	45.0%	46.7%	48.4%	50.1%	51.8%	53.5%	55.2%	56.8%	58.5%
	70%	61.2	26.0%	27.8%	29.6%	31.3%	33.1%	34.8%	36.5%	38.2%	39.9%	41.6%	43.3%	45.0%	46.7%	48.4%	50.1%	51.8%	53.5%	55.2%	56.8%	58.5%	60.2%
	80%	64.8	27.8%	29.6%	31.3%	33.1%	34.8%	36.5%	38.2%	39.9%	41.6%	43.3%	45.0%	46.7%	48.4%	50.1%	51.8%	53.5%	55.2%	56.8%	58.5%	60.2%	61.9%
	90%	68.4	29.5%	31.3%	33.0%	34.8%	36.5%	38.2%	39.9%	41.6%	43.3%	45.0%	46.7%	48.4%	50.1%	51.8%	53.5%	55.1%	56.8%	58.5%	60.2%	61.9%	63.6%
	100%	72.0	31.3%	33.0%	34.8%	36.5%	38.2%	39.9%	41.6%	43.3%	45.0%	46.7%	48.4%	50.1%	51.8%	53.5%	55.1%	56.8%	58.5%	60.2%	61.9%	63.6%	65.2%

Table D.7 NPV Sensitivity with Changing Ethanol Price and Tipping Fee (EBITDA; U.S. Million Dollar)

			Ethanol price ($/gallon) ±10% change																				
			-100%	-90%	-80%	-70%	-60%	-50%	-40%	-30%	-20%	-10%	**0%**	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
			0.00	0.13	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.17	**1.30**	1.43	1.56	1.69	1.82	1.95	2.08	2.21	2.34	2.47	2.60
Tipping fee ($/ton) ±10% change	-100%	0.0	(33.52)	(27.46)	(21.40)	(15.34)	(9.28)	(3.22)	2.84	8.90	14.95	21.01	27.07	33.13	39.19	45.25	51.31	57.37	63.43	69.48	75.54	81.60	87.66
	-90%	3.6	(27.48)	(21.42)	(15.36)	(9.30)	(3.24)	2.82	8.88	14.94	20.99	27.05	33.11	39.17	45.23	51.29	57.35	63.41	69.47	75.52	81.58	87.64	93.70
	-80%	7.2	(21.44)	(15.38)	(9.32)	(3.26)	2.80	8.86	14.92	20.98	27.03	33.09	39.15	45.21	51.27	57.33	63.39	69.45	75.51	81.56	87.62	93.68	99.74
	-70%	10.8	(15.40)	(9.34)	(3.28)	2.78	8.84	14.90	20.96	27.02	33.08	39.13	45.19	51.25	57.31	63.37	69.43	75.49	81.55	87.60	93.66	99.72	105.78
	-60%	14.4	(9.36)	(3.30)	2.76	8.82	14.88	20.94	27.00	33.06	39.12	45.17	51.23	57.29	63.35	69.41	75.47	81.53	87.59	93.65	99.70	105.76	111.82
	-50%	18.0	(3.32)	2.74	8.80	14.86	20.92	26.98	33.04	39.10	45.16	51.21	57.27	63.33	69.39	75.45	81.51	87.57	93.63	99.69	105.74	111.80	117.86
	-40%	21.6	2.72	8.78	14.84	20.90	26.96	33.02	39.08	45.14	51.20	57.25	63.31	69.37	75.43	81.49	87.55	93.61	99.67	105.73	111.78	117.84	123.90
	-30%	25.2	8.76	14.82	20.88	26.94	33.00	39.06	45.12	51.18	57.24	63.29	69.35	75.41	81.47	87.53	93.59	99.65	105.71	111.77	117.82	123.88	129.94
	-20%	28.8	14.81	20.86	26.92	32.98	39.04	45.10	51.16	57.22	63.28	69.34	75.39	81.45	87.51	93.57	99.63	105.69	111.75	117.81	123.87	129.92	135.98
	-10%	32.4	20.85	26.90	32.96	39.02	45.08	51.14	57.20	63.26	69.32	75.38	81.43	87.49	93.55	99.61	105.67	111.73	117.79	123.85	129.91	135.96	142.02
	0%	**36.0**	26.89	32.94	39.00	45.06	51.12	57.18	63.24	69.30	75.36	81.42	**87.47**	93.53	99.59	105.65	111.71	117.77	123.83	129.89	135.95	142.00	148.06
	10%	39.6	32.93	38.98	45.04	51.10	57.16	63.22	69.28	75.34	81.40	87.46	93.51	99.57	105.63	111.69	117.75	123.81	129.87	135.93	141.99	148.04	154.10
	20%	43.2	38.97	45.02	51.08	57.14	63.20	69.26	75.32	81.38	87.44	93.50	99.55	105.61	111.67	117.73	123.79	129.85	135.91	141.97	148.03	154.08	160.14
	30%	46.8	45.01	51.07	57.12	63.18	69.24	75.30	81.36	87.42	93.48	99.54	105.60	111.65	117.71	123.77	129.83	135.89	141.95	148.01	154.07	160.13	166.18
	40%	50.4	51.05	57.11	63.16	69.22	75.28	81.34	87.40	93.46	99.52	105.58	111.64	117.69	123.75	129.81	135.87	141.93	147.99	154.05	160.11	166.17	172.22
	50%	54.0	57.09	63.15	69.20	75.26	81.32	87.38	93.44	99.50	105.56	111.62	117.68	123.73	129.79	135.85	141.91	147.97	154.03	160.09	166.15	172.21	178.26
	60%	57.6	63.13	69.19	75.24	81.30	87.36	93.42	99.48	105.54	111.60	117.66	123.72	129.77	135.83	141.89	147.95	154.01	160.07	166.13	172.19	178.25	184.30
	70%	61.2	69.17	75.23	81.29	87.34	93.40	99.46	105.52	111.58	117.64	123.70	129.76	135.81	141.87	147.93	153.99	160.05	166.11	172.17	178.23	184.29	190.34
	80%	64.8	75.21	81.27	87.33	93.38	99.44	105.50	111.56	117.62	123.68	129.74	135.80	141.86	147.91	153.97	160.03	166.09	172.15	178.21	184.27	190.33	196.39
	90%	68.4	81.25	87.31	93.37	99.42	105.48	111.54	117.60	123.66	129.72	135.78	141.84	147.90	153.95	160.01	166.07	172.13	178.19	184.25	190.31	196.37	202.43
	100%	72.0	87.29	93.35	99.41	105.46	111.52	117.58	123.64	129.70	135.76	141.82	147.88	153.94	159.99	166.05	172.11	178.17	184.23	190.29	196.35	202.41	208.47

Table D.8 NPV Sensitivity with Changing Ethanol Price and Tipping Fee (Scenario 1; U.S. Million Dollar)

			Ethanol price ($/gallon) ±10% change																				
			-100%	-90%	-80%	-70%	-60%	-50%	-40%	-30%	-20%	-10%	**0%**	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
			0.00	0.13		0.39	0.52	0.65	0.78	0.91	1.04	1.17	**1.30**	1.43	1.56	1.69	1.82	1.95	2.08	2.21	2.34	2.47	2.60
Tipping fee ($/ton) ±10% change	-100%	0.0	(72.44)	(66.20)	(59.95)	(53.70)	(47.46)	(41.21)	(34.96)	(28.72)	(22.47)	(16.23)	(9.98)	(3.73)	2.51	8.76	15.01	21.25	27.50	33.74	39.99	46.24	52.48
	-90%	3.6	(66.22)	(59.97)	(53.72)	(47.48)	(41.23)	(34.98)	(28.74)	(22.49)	(16.25)	(10.00)	(3.75)	2.49	8.74	14.99	21.23	27.48	33.72	39.97	46.22	52.46	58.71
	-80%	7.2	(59.99)	(53.74)	(47.50)	(41.25)	(35.00)	(28.76)	(22.51)	(16.26)	(10.02)	(3.77)	2.47	8.72	14.97	21.21	27.46	33.71	39.95	46.20	52.44	58.69	64.94
	-70%	10.8	(53.76)	(47.52)	(41.27)	(35.02)	(28.78)	(22.53)	(16.28)	(10.04)	(3.79)	2.46	8.70	14.95	21.19	27.44	33.69	39.93	46.18	52.43	58.67	64.92	71.16
	-60%	14.4	(47.53)	(41.29)	(35.04)	(28.80)	(22.55)	(16.30)	(10.06)	(3.81)	2.44	8.68	14.93	21.17	27.42	33.67	39.91	46.16	52.41	58.65	64.90	71.14	77.39
	-50%	18.0	(41.31)	(35.06)	(28.81)	(22.57)	(16.32)	(10.08)	(3.83)	2.42	8.66	14.91	21.16	27.40	33.65	39.89	46.14	52.39	58.63	64.88	71.13	77.37	83.62
	-40%	21.6	(35.08)	(28.83)	(22.59)	(16.34)	(10.10)	(3.85)	2.40	8.64	14.89	21.14	27.38	33.63	39.87	46.12	52.37	58.61	64.86	71.11	77.35	83.60	89.85
	-30%	25.2	(28.85)	(22.61)	(16.36)	(10.11)	(3.87)	2.38	8.62	14.87	21.12	27.36	33.61	39.86	46.10	52.35	58.59	64.84	71.09	77.33	83.58	89.83	96.07
	-20%	28.8	(22.63)	(16.38)	(10.13)	(3.89)	2.36	8.61	14.85	21.10	27.34	33.59	39.84	46.08	52.33	58.58	64.82	71.07	77.31	83.56	89.81	96.05	102.30
	-10%	32.4	(16.40)	(10.15)	(3.91)	2.34	8.59	14.83	21.08	27.32	33.57	39.82	46.06	52.31	58.56	64.80	71.05	77.29	83.54	89.79	96.03	102.28	108.53
	0%	**36.0**	(10.17)	(3.93)	2.32	8.57	14.81	21.06	27.31	33.55	39.80	46.04	**52.29**	58.54	64.78	71.03	77.28	83.52	89.77	96.01	102.26	108.51	114.75
	10%	39.6	(3.94)	2.30	8.55	14.79	21.04	27.29	33.53	39.78	46.03	52.27	58.52	64.76	71.01	77.26	83.50	89.75	96.00	102.24	108.49	114.73	120.98
	20%	43.2	2.28	8.53	14.77	21.02	27.27	33.51	39.76	46.01	52.25	58.50	64.74	70.99	77.24	83.48	89.73	95.98	102.22	108.47	114.71	120.96	127.21
	30%	46.8	8.51	14.76	21.00	27.25	33.49	39.74	45.99	52.23	58.48	64.73	70.97	77.22	83.46	89.71	95.96	102.20	108.45	114.70	120.94	127.19	133.43
	40%	50.4	14.74	20.98	27.23	33.47	39.72	45.97	52.21	58.46	64.71	70.95	77.20	83.45	89.69	95.94	102.18	108.43	114.68	120.92	127.17	133.42	139.66
	50%	54.0	20.96	27.21	33.46	39.70	45.95	52.19	58.44	64.69	70.93	77.18	83.43	89.67	95.92	102.16	108.41	114.66	120.90	127.15	133.40	139.64	145.89
	60%	57.6	27.19	33.44	39.68	45.93	52.18	58.42	64.67	70.91	77.16	83.41	89.65	95.90	102.15	108.39	114.64	120.88	127.13	133.38	139.62	145.87	152.12
	70%	61.2	33.42	39.66	45.91	52.16	58.40	64.65	70.89	77.14	83.39	89.63	95.88	102.13	108.37	114.62	120.87	127.11	133.36	139.60	145.85	152.10	158.34
	80%	64.8	39.64	45.89	52.14	58.38	64.63	70.88	77.12	83.37	89.61	95.86	102.11	108.35	114.60	120.85	127.09	133.34	139.58	145.83	152.08	158.32	164.57
	90%	68.4	45.87	52.12	58.36	64.61	70.86	77.10	83.35	89.60	95.84	102.09	108.33	114.58	120.83	127.07	133.32	139.57	145.81	152.06	158.30	164.55	170.80
	100%	72.0	52.10	58.34	64.59	70.84	77.08	83.33	89.58	95.82	102.07	108.31	114.56	120.81	127.05	133.30	139.55	145.79	152.04	158.29	164.53	170.78	177.02

Table D.9 NPV Sensitivity with Changing Ethanol Price and Tipping Fee (Scenario 3; U.S. Million Dollar)

			Ethanol price ($/gallon) ±10% change																				
			-100%	-90%	-80%	-70%	-60%	-50%	-40%	-30%	-20%	-10%	**0%**	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
			0.00	0.13	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.17	**1.30**	1.43	1.56	1.69	1.82	1.95	2.08	2.21	2.34	2.47	2.60
Tipping fee ($/ton) ±10% change	-100%	0.0	(50.66)	(44.42)	(38.17)	(31.92)	(25.68)	(19.43)	(13.18)	(6.94)	(0.69)	5.55	11.80	18.05	24.29	30.54	36.79	43.03	49.28	55.53	61.77	68.02	74.26
	-90%	3.6	(44.43)	(38.19)	(31.94)	(25.70)	(19.45)	(13.20)	(6.96)	(0.71)	5.54	11.78	18.03	24.27	30.52	36.77	43.01	49.26	55.51	61.75	68.00	74.24	80.49
	-80%	7.2	(38.21)	(31.96)	(25.71)	(19.47)	(13.22)	(6.98)	(0.73)	5.52	11.76	18.01	24.26	30.50	36.75	42.99	49.24	55.49	61.73	67.98	74.23	80.47	86.72
	-70%	10.8	(31.98)	(25.73)	(19.49)	(13.24)	(7.00)	(0.75)	5.50	11.74	17.99	24.24	30.48	36.73	42.97	49.22	55.47	61.71	67.96	74.21	80.45	86.70	92.95
	-60%	14.4	(25.75)	(19.51)	(13.26)	(7.01)	(0.77)	5.48	11.72	17.97	24.22	30.46	36.71	42.96	49.20	55.45	61.69	67.94	74.19	80.43	86.68	92.93	99.17
	-50%	18.0	(19.53)	(13.28)	(7.03)	(0.79)	5.46	11.71	17.95	24.20	30.44	36.69	42.94	49.18	55.43	61.68	67.92	74.17	80.41	86.66	92.91	99.15	105.40
	-40%	21.6	(13.30)	(7.05)	(0.81)	5.44	11.69	17.93	24.18	30.42	36.67	42.92	49.16	55.41	61.66	67.90	74.15	80.39	86.64	92.89	99.13	105.38	111.63
	-30%	25.2	(7.07)	(0.83)	5.42	11.67	17.91	24.16	30.41	36.65	42.90	49.14	55.39	61.64	67.88	74.13	80.38	86.62	92.87	99.11	105.36	111.61	117.85
	-20%	28.8	(0.85)	5.40	11.65	17.89	24.14	30.39	36.63	42.88	49.13	55.37	61.62	67.86	74.11	80.36	86.60	92.85	99.10	105.34	111.59	117.83	124.08
	-10%	32.4	5.38	11.63	17.87	24.12	30.37	36.61	42.86	49.11	55.35	61.60	67.84	74.09	80.34	86.58	92.83	99.08	105.32	111.57	117.81	124.06	130.31
	0%	**36.0**	11.61	17.86	24.10	30.35	36.59	42.84	49.09	55.33	61.58	67.83	**74.07**	80.32	86.56	92.81	99.06	105.30	111.55	117.80	124.04	130.29	136.53
	10%	39.6	17.84	24.08	30.33	36.57	42.82	49.07	55.31	61.56	67.81	74.05	80.30	86.55	92.79	99.04	105.28	111.53	117.78	124.02	130.27	136.52	142.76
	20%	43.2	24.06	30.31	36.56	42.80	49.05	55.29	61.54	67.79	74.03	80.28	86.53	92.77	99.02	105.26	111.51	117.76	124.00	130.25	136.50	142.74	148.99
	30%	46.8	30.29	36.54	42.78	49.03	55.28	61.52	67.77	74.01	80.26	86.51	92.75	99.00	105.25	111.49	117.74	123.98	130.23	136.48	142.72	148.97	155.22
	40%	50.4	36.52	42.76	49.01	55.26	61.50	67.75	73.99	80.24	86.49	92.73	98.98	105.23	111.47	117.72	123.97	130.21	136.46	142.70	148.95	155.20	161.44
	50%	54.0	42.74	48.99	55.24	61.48	67.73	73.98	80.22	86.47	92.71	98.96	105.21	111.45	117.70	123.95	130.19	136.44	142.68	148.93	155.18	161.42	167.67
	60%	57.6	48.97	55.22	61.46	67.71	73.96	80.20	86.45	92.70	98.94	105.19	111.43	117.68	123.93	130.17	136.42	142.67	148.91	155.16	161.40	167.65	173.90
	70%	61.2	55.20	61.44	67.69	73.94	80.18	86.43	92.68	98.92	105.17	111.41	117.66	123.91	130.15	136.40	142.65	148.89	155.14	161.39	167.63	173.88	180.12
	80%	64.8	61.43	67.67	73.92	80.16	86.41	92.66	98.90	105.15	111.40	117.64	123.89	130.13	136.38	142.63	148.87	155.12	161.37	167.61	173.86	180.10	186.35
	90%	68.4	67.65	73.90	80.15	86.39	92.64	98.88	105.13	111.38	117.62	123.87	130.12	136.36	142.61	148.85	155.10	161.35	167.59	173.84	180.09	186.33	192.58
	100%	72.0	73.88	80.13	86.37	92.62	98.86	105.11	111.36	117.60	123.85	130.10	136.34	142.59	148.83	155.08	161.33	167.57	173.82	180.07	186.31	192.56	198.80

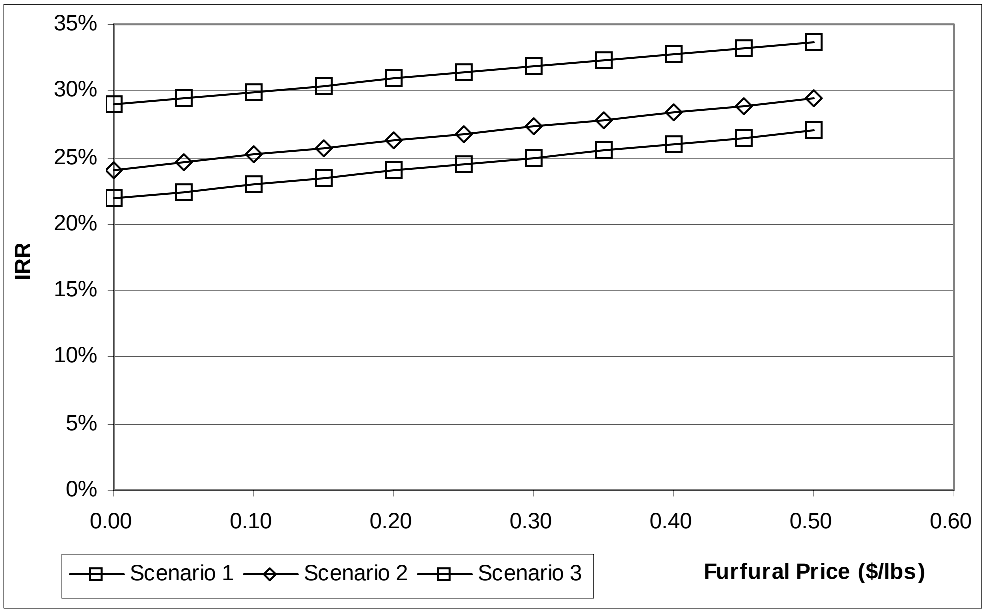

Figure D.1 Effect of Furfural Price on IRR

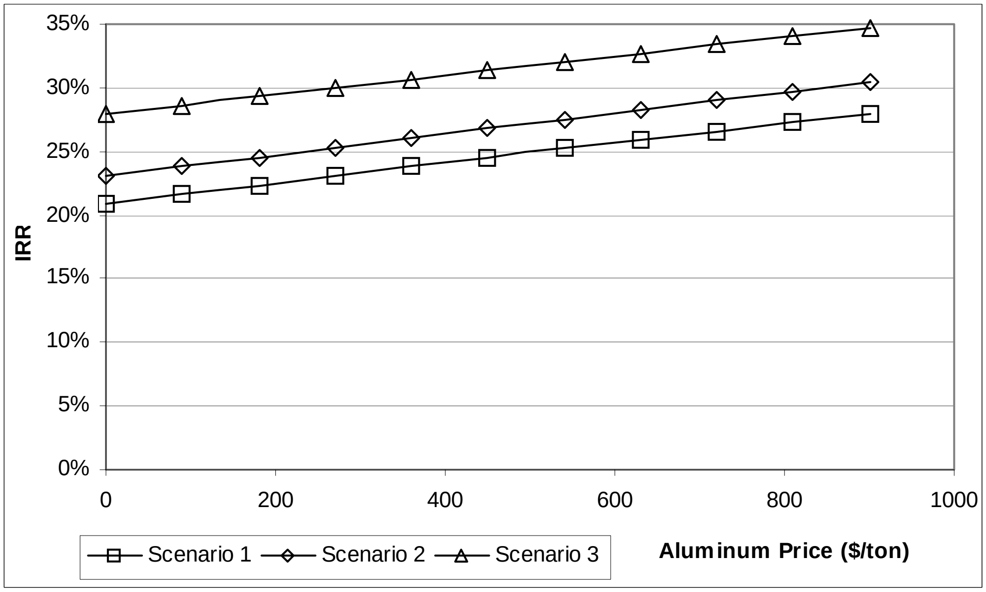

Figure D.2 Effect of Aluminum Price on IRR

APPENDIX E

Table E.1 Time Line of MSW-Ethanol Project of PMO in the City of Middletown, NY

Date	Event
February 1994	Pencor, a Baltimore development agency, says it wants to build a recycling and manufacturing plant in Middletown.
December 1994	Pencor Orange Corp. proposes designing, building and operating a waste-ethanol facility in Middletown. The proposal is in reply to a city request for a company to handle its MSW.
January 1995	Pencor is named joins with Masada OxyNol Inc., a subsidiary of Masada Resource Group, to form Pencor-Masada OxyNol LLC. (PMO).
January 1996	The city's Common Council gives then-city Public Works Commissioner authority to solicit trash from neighbors to make a plant viable. The goal is 700 TPD. Middletown generates 50 TPD. The promise of a long-term, fixed price on tipping fees is attractive to many communities.
September 1997	Middletown officially signs on to the project as a customer. Five other Orange County communities already are signed on to deliver their trash to PMO.
August 1998	Orange County lawmakers reject PMO's offer to take county garbage.
March 1999	25 municipalities or garbage districts sign up to pay PMO to haul and process garbage. The city Planning Board approves PMO's plan to build on a former city landfill.
December 1999	Nearly 500 people cram a public hearing on the PMO's proposal. Many are concerned about the potential for the plant to pollute the city's south end.
July 2001	Middletown asks Kroll Associates, an international risk management firm, to review PMO.
November 2001	Kroll requests documents from PMO. PMO provides some material but refuses or fails to turn over much of the requested information.
October 2002	After reading the Kroll report, the Common Council agrees to spend $50,000 to hire a Long Island law firm that specializes in complex contracts and limiting risk.
November 2003	The common Council receives a copy of the final draft of a contract between the city and PMO. Thy mayor says all questions raised by the Kroll report have been satisfied.
December 8th 2003	The Common Council votes on whether to authorize the mayor to sign a contract with PMO. Finally Mayor is allowed to make a contract with PMO.

Source: Times Herald-Record 2004

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