Fuels from Municipal Waste

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Abstract Autoclaving (pressure cooking) municipal solid waste (MSW), and sieving the sterile product produces separable organic material, a substantial fraction of the original waste. This fraction contains most of the biodegradable material in MSW and can be treated to produce ethanol, a methane-rich gas, and other valuable components. The biodegradable material need not be put in a landfill but can be processed to make fuels such as ethanol and methane. This reduces release of greenhouse gases (GHGs) from a landfill. After removing missed recyclables, on average 40% of the original waste, landfill diversion can be increased from 20% up to 80% in volume. The remaining waste, now mainly free of gas producing material, can be put in a landfill, thus reducing hauling costs and extending the lifetime of the landfill. Research on many aspects of this treatment protocol is needed to estimate the economic potential.

Introduction There is a growing realization that climate change may be due to increasing amounts of GHGs released by human activities. One of the most potent of the GHGs is methane, readily formed in a landfill by anaerobic decomposition of organic matter, much of which is of anthropogenic origin. When organic matter, containing carbon compounds from plant and animal sources, combines with bacteria and archaea in the absence of oxygen, a temperature greater than 50° F, and greater than 40% water, methane forms readily (CDC, 2001, Chapt. 5). Carbon dioxide is usually blamed as the major culprit in climate change because there is so much produced from burning fossil fuels. However methane, kilogram for kilogram, has a Global Warming Potential (GWP) more than 20 times stronger than carbon dioxide at preventing heat from escaping into outer space, (USEPA, 2006a).

The largest source of methane in the US is from the digestive processes of domestic ruminant animals, (cattle, sheep, goats, etc.) and close behind, is from landfills where we put our waste (USEPA, 2009). In properly sealed landfills some of the methane is captured, but there are many landfills where the gases are not captured. Moreover, in very dry climates such as southern Nevada, there is insufficient water in the landfills to produce methane at a rate that can profitably be captured. MSW, sewage sludge (SSl) and street sweepings (SSw) all go to landfills. But, in some locations there may be other ways of processing waste to capture these potential sources of fuels without impacting the food supply, as would, for example, cultivating plants for biofuel.

It is helpful to look at waste: how it is collected, what is in it (USEPA, 2006b), and how it is disposed of. There are different ways in different places, so we will describe current practice in general, and then present our own locale as needing a different approach. Many sealed landfills are now equipped to recover landfill gas (CDC, 2001, Chapt. 5). Various kinds of piping arrangements have been devised in order to collect the gas and burn the methane and a few other organic materials to reduce their impact on the climate. One problem with this approach is that landfill gas is of variable composition. There are four different phases of the decomposition process that may last up to 12-15 years in locations with ample rainfall per year. (CDC, 2001, Chapt. 2). Useful concentrations of methane are not obtained until the process is well into the third phase and then the methane content of the landfill gas seldom reaches more than 50% (USEPA, 2009).

Clark County, NV needs a different approach to waste disposal because our average yearly rainfall is about 4". That is not enough water to enable a sealed landfill to evolve methane at a useable rate. (CDC, 2001, Chapt. 2) We generate much MSW, SSw, and SSl. The county has a population estimated at 1.8 million and is home to the two largest cities in the state, Las Vegas and Henderson, and the 4th largest city, North Las Vegas. There are also some densely populated unincorporated townships and there is a large population of visitors. A major waste hauler has a long term contract for trash pick up. The trash, averaging 8,400 tons per day, is picked up twice a week in residential neighborhoods. The trucks take the waste to one of three regional transfer stations where it is off-loaded to large semi rigs for transportation to the landfill that is about 30 miles distant. The solid waste has a large paper content, more than 40%. A previous landfill, not properly piped to collect landfill gas, was much closer and is now closed. A separate voluntary recycle pickup occurs every two weeks in residential neighborhoods and the participation is much lower than the national average; 21.6% (State of Nevada, 2009) vs 51.6 % (US EPA, 2007).

Residents are supposed to sort the recyclables into paper, cans, plastics, and glass. Recycling is not generally provided for apartment complexes. Much of the food waste from the hotels and casinos goes to a local hog farm.

Wastewater is handled in different ways. Las Vegas, Clark County, and Henderson all have treatment plants in close proximity to one another and the extensively treated wastewater goes into Lake Mead. It is important to note that these facilities are close to major highways, a rail line, and electric power lines that offer the feasibility of feeding co-generation electricity into the grid. The Las Vegas treatment plant digests its sludge anaerobically and uses the methane produced to power some of its operations. The nearby Clark County Regional Water Reclamation Project generates an average 450 tons per day of dewatered sludge in the form of a crumbly solid that is 70-75% water. This too is trucked to the landfill. The Henderson plant generates 90 tons of sludge per day and that also goes to the landfill. Combining this sludge with MSW in the autoclave could replace some of the water that otherwise has to be added. During the anaerobic stage, adding sludge results in a significant increase in methane production for use in a co-generation plant that can generate electricity. Sludge, when dried, contains double digit percentages of grease and fat, protein, cellulose (paper), and silica, and single digit percents of iron, phosphorus, and nitrogen (Vassilev et al., 1999). This shows that there is a substantial amount of material that is organic and also contains appreciable amounts of plant nutrients.

Treatment of solid waste A Nevada corporation, Comprehensive Resources, Recovery & Reuse (CR3) , has patented technology for treatment and separation processes and has a demonstration installation at a recently closed regional landfill near Salinas, CA. CR3 has granted us permission to treat some sample mixes of wastes at this facility (Anderson, 2009). Four of the five authors of this white paper witnessed a demonstration of this technology early in 2009. (None of the authors has a financial interest in CR3 .)

The processing unit is an autoclave with a capacity of about two tons (Figure 1). The device resembles a ready-mix concrete truck body. It rotates and can be tipped up or down on a plane vertically perpendicular to the axis of rotation. The inside of the autoclave has a helical metal "knife" that reduces the volume and stirs the contents when the autoclave is rotating. The waste is loaded by tipping a dumpster load of trash on to a conveyor that discharges the material into the maw of the autoclave as it is tipped somewhat backward (Figure 2). After the loading is complete, the maw is closed and the air in the free space is evacuated and replaced by hot water and steam. The autoclave is raised to a temperature of about 270^{o} F (132^{o} Celsius); rotation is begun and the contents are "pressure cooked" for 30 minutes. The pressure is approximately 1.7 times atmospheric pressure. The rotation is then stopped, the hot water is transferred to a holding tank (Figure 3), and the pressure is dropped rapidly to about 7/10 of atmospheric pressure This processing accomplishes several desirable ends:

- The waste material is sterilized and contains no active pathogens;
- The rapid pressure drop allows a phenomenon known as a modified "steam explosion" to occur. For example, the hot water can penetrate plant material and when the water turns to steam as the pressure drops, a separation of cellulose and lignin occurs, somewhat like what happens when wood chips are treated to form paper pulp;
- The overall volume of the waste is reduced substantially;
- The size of some of the waste material is reduced to make more fines for separation.

After uncovering the autoclave the vessel is tipped slightly downward and the treated waste is sorted into different sizes by a rotating screen that has 1/2" and 2" meshes and an open end (Figure 4). Wheeled carts under each segment of the sieve collect the materials that drop through the meshes or come out the open end. The material that passes through the 1/2" mesh contains more than 90% of the material that degrades to GHGs in a landfill and constitutes about 50% of the volume of the waste (Anderson, 2009). The materials falling through the 2" screen can be landfilled and have very small potential for gas generation. What comes out of the open end of the screen contains substantial recyclable material (Figure 5).

Treatment for recovery of fuel CR3 cooperates with scientists at the US Department of Agriculture USDA laboratories in Albany, CA and UC-Davis in studying ways to convert the cellulosic and hemicellulosic material in the fines (1/2") of autoclaved solid waste in the USDA laboratories. Enzymes have been identified that convert these materials to sugars that can be fermented to make ethanol that can be used for motor fuel (Zheng et al., 2007). The importance of this finding is that the ethanol is produced from waste and not from food sources such as corn and sugar. [The USDA-Albany Laboratory has given our group permission to use their technology for cellulose breakdown and fermentation of the resulting sugar (Orts, 2009).] The autoclaving and sieving will have to be done at the Salinas facility. Our team intends to prepare mixtures of MSW, SWs, and SSl in Las Vegas and ship the mixtures to Salinas for processing and sieving. The material passing the 1/2" screen will be returned for processing in Las Vegas to determine how much ethanol, methane, and char can be produced from a given amount of the biodegradable material. At the Salinas facility a member of our team will make measurements of the amount of energy required to operate the autoclaving process. It is also the case that the addition of food waste and/or dewatered sewage sludge mixed with solid waste will be an added source of methane by anaerobic degradation. Some preliminary findings indicate that this methane is consistently about 70% pure and most of the rest is carbon dioxide. Landfill gas collected at appropriately sealed and piped landfills in the US is of variable composition, usually not more than 50% methane, and thus not an excellent fuel source (CDC, 2001, Chapt. 2). Moreover, in arid climates, a sealed landfill may take several decades to stop producing GHGs. Thus, separating most of the biodegradable material from waste by autoclaving and sieving may:

- Provide the energy required to run the process;
- Make ethanol for motor fuel without impinging on the food supply;
- Enable a large reduction in emission of methane by a landfill, one of the worst GHGs;
- Reduce the volume of material taken to a landfill by up to 75%;
- Reduce up to ¾ of the round trips of waste hauled to a landfill, thus lessening the consumption of diesel fuel and lessening both traffic congestion and air pollution;
- Convert some of the carbonaceous material in waste to char, which is a soil amendment and a known way to sequester carbon.

Conclusions From the standpoint of what autoclaving and sieving can accomplish, this method of treating solid waste and sewage sludge may be an attractive alternative to the way most waste is handled in the United States. For this to be a workable solution, however, it must be shown to be economically viable. To learn this, it will be necessary to process various combinations of MSW, SSw, and SSl to see how much of the useful products (mainly ethanol, methane, and char) (Van Zwieten et al., 2007; Vassilev et al., 1999) can be made, and to find out how the cost of this kind of processing compares with the cost of the way waste is now handled. A comprehensive comparison is needed of both ways of treating waste, landfilling or autoclaving, that also takes into account the environmental costs and benefits as well as the worth of fuels and char produced.

There is a rather narrow window of opportunity for this research because the owner, CR3, of the autoclaving facility in Salinas, CA will have to close down the facility in a little more than a year because the regional landfill is now closed.

Research will provide the answers to whether this way of processing municipal waste has enough promise to attract investment for the equipment needed to process municipal waste in a way much different than landfilling. Will it reduce GHGs, provide fuels in substantial quantities made from non-food sources, extend the life of landfills, and reduce traffic congestion by reducing trash hauling to landfills? Encouraging signs include the following:

- The value of paper, cardboard and other recyclables is highly variable and, in slow economic times, paper and cardboard are nearly worthless (The Bulletin Oct. 22, 2009); biofuels derived from cellulosic material will likely have an average greater value that will rise with time;

- The supply of sewage sludge, a source of methane, will be plentiful; this fuel is likely to provide all of the energy required to run the treatment process and may generate excess electricity that can be sold;

- GHGs from landfills will be greatly reduced; the carbon footprint will be reduced; what this is worth isn't known at present, but if carbon taxes are imposed, the landfill owner will benefit;

- Future landfills would last up to four times as long and income from tipping fees may be significantly reduced unless the tipping fee is raised.

The question of carbon taxes is open, thus an estimate of carbon credits or debits is not calculable at this time. The House of Representatives has passed a bill but the Senate has not, as of this writing. The US Chamber of Commerce has lobbied against passage, but large electric utilities in California and Texas have resigned from the Chamber in protest. We observe, however, that the proposed treatment of all Clark County, NV waste by the described process would greatly reduce the carbon footprint of the waste hauler and probably the County.

It is time to give autoclaving, sorting, and generation of fuels a closer look. Clark County, NV is a highly favorable location for testing the technology and estimating its economic viability.

References

For extensive information about solid waste management, See Environmental Protection Agency (USEPA) (2007) Facts and Figures http://www.epa.gov/osw/nonhaz/municipal/msw99.htm

Anderson, Joseph (2009) President of CR3, Letter of Support and conversations

The Bulletin, (Oct. 22, 2009) Recyclables: Demand drops - could our rates rise, then? http://www.bendbulletin.com/apps/pbcs.dll/article?AID=/20081221/NEWS0107/812210420/-1/rss

Centers for Disease Control (CDC) (2001) Landfill Gas Primer, Chapt. 2: Landfill Gas Basics, Figure 2.1 http://www.atsdr.cdc.gov/hac/landfill/html/ch2.html

CDC (2001) Landfill Gas Primer, Chapt. 5: Landfill Gas Control Measures http://www.atsdr.cdc.gov/hac/landfill/html/ch5.html

Orts, W. J. (2009) Research Leader, USDA-ARS, WRRC, BCE, Letter of Support

State of Nevada, Nevada Division of Environmental Protection, (2009), Recycling & Waste Reduction Report. http://nevadarecycles.gov/doc/2009_biennial_report.htm#7 [The figure is for total recycled material in 2006, not just paper & paperboard.]

USEPA (2009) Landfill Methane Outreach Program (LMOP) http://www.epa.gov/lmop/overview.htm

USEPA (2009) Methane: Sources and Emissions http://www.epa.gov/methane/sources.html

USEPA (2006a) Methane: Science. http://www.epa.gov/methane/scientific.html

USEPA (2006b) Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, 3rd Edition. Chapt. 6: Landfilling http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html

USEPA (2007) Municipal Solid Waste Generation, Recycling, and Disposal in the United States, Figure 3 http://www.epa.gov/osw/nonhaz/municipal/pubs/msw06.pdf

Van Zwieten, L., Kimber, S., Morris, K., Chan, Y. Y., Downie, A., Rust, J., Joseph, S., Cowie, A. (2009) Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility, *Plant Soil,* DOI 10.1007/s11104-009-0050-x

Vassilev, S.V., C. Braekman-Danheux and P. Laurent, (1999), Characterization of refuse-derived char from municipal solid waste. 1. Phase-mineral and chemical composition, *Fuel Processing Technology* **59** pp. 95–134

Zheng, Y., P. Zhongli, R. Zhang, J. Labavitch, D. Wang, S. Teter, and B. Jenkins. (2007) Evaluation of different biomass materials as feedstock for fermentable sugar production. *Applied Chemistry and Biotechnology*, **136140** pp. 423-435

Figure 1

The Autoclave in the background; holding tank for water.

Figure 2
The autoclave being loaded with waste

Figure 3

The autoclave opened "after cooking." Note hot water vapor escaping and the conveyor that is transporting treated waste to the rotating sieve

Figure 4

The sorting sieve. The brush prevents clogging of the mesh.

Figure 5

Sieving of the waste in progress. Note the larger objects coming out the open end.