**Proceedings of the 18th Annual North American Waste-to-Energy Conference**
**NAWTEC18**
**May 11-13, 2010, Orlando, Florida, USA**

# NAWTEC18-3540

# POTENTIAL FOR ENERGY-FROM-WASTE CARBON OFFSETS IN NORTH AMERICA

**Michael Van Brunt**
Covanta Energy Corporation
Fairfield, New Jersey, USA

**Brian Bahor**
Covanta Energy Corporation
Fairfield, New Jersey, USA

## ABSTRACT

A carbon offset program is likely to be part of any future federal cap-and-trade program and is included in both the U.S. House of Representatives passed *American Clean Energy and Security Act of 2009* and the Kerry-Boxer Senate draft greenhouse gas legislation. Internationally, Energy-from-Waste (EfW) facilities in emerging economies are eligible for carbon offset credits under the Clean Development Mechanism of the Kyoto Protocol. These carbon offset credits can be purchased by developed countries, such as those in Western Europe, to help comply with their obligations under the Kyoto Protocol. Although a similar mandatory market does not yet exist in the United States, there is a growing voluntary market in carbon offsets and a set of standards designed to provide some order to this market. One of the key players in the voluntary market is the Voluntary Carbon Standard (VCS). Project types, such as EfW, that are eligible for credits under the Clean Development Mechanism are also eligible to generate voluntary carbon credits under the VCS. This paper reviews the current methodology for calculating offsets from EfW projects. The current methodology is very conservative, severely restricts the accounting for avoided landfill methane, and significantly underestimates greenhouse gas savings relative to life cycle assessments performed on waste management practices. The current methodology for offsets is compared and contrasted with a more realistic methodology more in line with life cycle assessment calculations. A review of the potential for EfW offsets under evolving state and federal programs and precedents for offsets generated based on avoided landfill methane is also completed.

**Keywords:** energy-from-waste, greenhouse gas, methane, landfill gas, carbon offsets

## INTRODUCTION

Energy-from-Waste (EfW) is an internationally recognized source of greenhouse gas mitigation, avoiding approximately one ton of greenhouse gas emissions for every ton of municipal solid waste processed, based on average United States landfills and fossil-based grid electrical generation [1].

EfW facilities achieve net GHG emission reductions primarily through four greenhouse gas related processes:

1. Avoidance of landfill methane emissions from waste, including factoring-in methane capture, that would have been landfilled in the absence of the EfW facility;
2. Avoidance of carbon dioxide ($CO_2$) emissions from fossil-fuel fired power plants on the local grid resulting from the EfW facility generating renewable electrical power or steam;
3. Avoidance of extraction and manufacturing $CO_2$ due to ferrous and non-ferrous (aluminum) metal recovery and recycling at EfW facilities relative to the production of these materials from virgin inputs; and

4. Avoidance of GHG emissions from the transportation of MSW to distant landfills.

Methane generation from degradable organic waste can largely be avoided by adopting MSW management approaches including EfW [2]. The proximate one hour EfW combustion process eliminates 100% of the potential of MSW to generate methane in a landfill for 100 years or more. The Intergovernmental Panel on Climate Change (IPCC) has identified MSW combustion with energy recovery as a key GHG emission mitigation technology due to its avoidance of landfill methane [3].

EfW's ability to mitigate GHG emissions has been effectively demonstrated. The European Union, in the 1999 Landfill Directive, took aggressive steps to reduce landfill methane emissions by restricting the amount of biodegradable waste sent to landfills [4]. Early implementation of this directive has already resulted in reductions of GHG emissions. Effective waste management and energy recovery through incineration has been an important contributor to this trend [5]. The European Environment Agency expects GHG emissions from MSW management to drop considerably by 2020 with increasing use of incineration with energy recovery and recycling [6].

When combined with recycling in a comprehensive integrated waste management approach, EfW can help achieve significant reductions in GHG emissions on a global scale. Recent analysis has demonstrated that allocating MSW to recycling, waste to energy and landfilling in descending order in lieu of existing 'business-as-usual' practices with each option using modern technology and best practices, the system would reduce greenhouse gas emissions by more than 1 Gt C $year^{-1}$ by 2050 [7].

## CAP & TRADE PROGRAMS

To date, all of the significant proposals for federal climate change legislation, including the *American Clean Energy and Security Act of 2009* passed by the U.S. House of Representatives, have included a cap-and-trade program. Under a cap-and-trade program, organizations are required to secure allowances to emit greenhouse gas emissions, typically measured in terms of carbon dioxide equivalents ($CO_2e$). Allowances may be either auctioned off or allocated by the issuing authority. Over time, the authority issues fewer and fewer allowances, leading to a corresponding reduction in greenhouse gas emissions.

Invariably, the cap does not apply to all sectors of the economy or all potential greenhouse gas sources or sinks. To incentivize emissions reductions in uncapped sectors, many of the cap-and-trade programs under consideration turn to offsets. A robust offsets program is endorsed by many organizations as a way to encourage innovation and to more fully cover all of the potential sources and sinks of greenhouse gas emissions. The magnitude of GHG reductions achieved is still driven by the cap; however, reductions can be achieved outside of the capped sector. Furthermore, given the level of conservatism often applied to offsets, the level of reductions achieved through the incorporation of an offsets program may actually exceed those that would have been achieved in the absence of offsets.

With the incorporation of offsets into a cap-and-trade program, regulated entities, or those under the emissions cap, have another mechanism to meet their allowance obligation. Instead of purchasing or securing allowances, the entity may choose to fulfill part of its obligation through the purchase of offsets.

Voluntary and regulated offset programs alike have established a series of standards and principles to promote the rigor of their program. Common amongst the programs is an adherence to a basic set of principles. Under these principles, offset credits must be real, measureable, additional, permanent, verifiable, and unique [8-10]. These principles are summarized as follows:

*Real* All of the GHG emissions reductions and removals must have actually taken place due to the offset project and shall be conservatively calculated. Unintended increases of GHG emissions occurring as a result of the project, termed "leakage" must be taken into consideration.

*Measurable* GHG emission reductions must be quantifiable using appropriate and recognized methodologies. Reductions shall be calculated against an emissions "baseline" that quantifies the emissions that would have existed in the absence of the project.

*Additional* GHG emission reductions achieved by a project must be in addition to what would have likely happened under a "business as usual" scenario under which the project was not completed. To varying degrees, most programs require demonstration that the project is in itself not "business as usual." In the most extreme case, some programs require that a demonstration that the project would not have occurred without the monetary benefit of carbon offset revenues.

*Permanent* GHG emission reductions must not be temporary or reversible within a reasonable timeframe. If there is a potential for reversal, as exists with forest carbon sequestration which is subject to future fire risk, adequate safeguards must be in place to ensure that the reductions are replaced or otherwise compensated.

*Verifiable* All GHG emission reductions must be verified by an external third party.

*Unique* All GHG reductions must be only be counted once and can only be associated with one offset project.

To date, the most notable mandatory cap-and-trade programs in place are the European Union Emission Trading Scheme (EU-ETS) and the Regional Greenhouse Gas Initiative (RGGI). The EU-ETS was established by directive in 2003 as a cap-and-trade program to help meet the European Union's commitments under the Kyoto Protocol. The program commenced operation in 2005 and quickly emerged as the largest multi-country and multi-sector GHG emission trading scheme in the world. Covering nearly 15,000 facilities in 25 countries emitting roughly half of Europe's GHG emissions, the program included combustion facilities, oil refineries, coke ovens, iron and steel plants, and factories making cement, glass, lime, brick, ceramics, and pulp and paper [11]. EfW facilities were specifically exempted from the program [12]. Carbon offsets generated through the Clean Development Mechanism (CDM) of the Kyoto Protocol can be used to meet individual country goals [13].

On January 1, 2008, RGGI became the first mandatory cap-and-trade program in the United States, covering fossil fuel fired electrical power plants with nameplate capacities 25 MW or greater. Consisting of ten New England and Mid-Atlantic states (Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Rhode Island, and Vermont), the program first aims to stabilize GHG emissions from power plants by 2014, and then to reduce emissions by 2.5% annually over the period from 2015 to 2018. GHG allowances are largely auctioned with revenues generally directed towards investment for energy efficiency and renewable energy programs [14]. EfW facilities, regardless of size, are not covered by the program.

Several other regional programs are in development in the United States. The Western Climate Initiative (WCI) is a regional cap-and-trade program covering eleven states and Canadian provinces, currently under development. Expected to be operational in 2015, the WCI will be nearly economy-wide, covering electricity generation, industry, transportation, and residential and commercial fuel use. A carbon offsets program will be incorporated into the final program [15].

Furthest along of those in development, is the California cap-and-trade program, a primary component of the implementation of Assembly Bill 32, the Global Warming Solutions Act, passed in 2006. A preliminary draft of the cap-and-trade regulation was issued by the California Air Resources Board (CARB) in November 2009. Final regulation must be in place by January 1, 2011 and the program must be in place by 2012. The cap-and-trade program will include an offsets program. The existing Climate Action Reserve (CAR), currently a voluntary program, is widely expected to at least heavily influence the mandatory cap-and-trade program. Many are betting that current CAR projects will be eligible under the future mandatory program.

## CLEAN DEVELOPMENT MECHANISM

Established by the Kyoto Protocol, the Clean Development Mechanism (CDM) allows emission-reduction projects in developing countries to generate carbon offsets termed certified emission reduction (CER) credits. These CERs can be used by industrialized countries to meet part of their emission reduction targets under the Kyoto Protocol. The purpose of the CDM is to encourage sustainable development and emission reductions in emerging countries and to provide flexibility to developed countries in meeting their Kyoto targets.

Each project must qualify through a rigorous and public validation and registration process, which is overseen by the CDM Executive Board, which reports to the countries that ratified the Kyoto Protocol.

Given that the CDM operates under the Kyoto Protocol, there is considerable uncertainty regarding the future of the program beyond 2012, the final year of the Kyoto Protocol. This uncertainty has been exacerbated by the impasse at the 2009 United Nations Climate Change Conference in Copenhagen.

## EXISITING CDM METHODOLOGY

One of the methodologies under the CDM is AM0025 "Avoided emissions from organic waste through alternative waste treatment processes" [16]. This methodology is applicable to a wide variety of landfill methane avoidance projects, including the "incineration of fresh waste for energy generation, electricity, and/or heat." As recognized by the methodology, EfW facilities actively avoid methane emissions by diverting organic waste from disposal at a landfill, where methane emissions are caused by anaerobic process, and avoid fossil $CO_2$ emissions by displacing electricity through the utilization of heat generated in the combustion process. The methodology recognizes that waste is a mixture of biogenic and fossil-based components and requires that emissions from the combustion of fossil-based wastes are included as project emissions. The GHGs covered by the methodology include dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$).

As with all CDM methodologies, emissions reductions are calculated as the difference between the GHG emissions of the project (the project emissions) and the emissions that would have occurred in the absence of the project (the baseline emissions). The baseline emissions are generally calculated assuming that the waste would have been handled in a landfill. A summary of the greenhouse gases and emission sources included in the methodology is presented in Table 1.

**Table 1. GHG Emissions and Sources in CDM Methodology**

| | Source | Gases |
|---|---|---|
| Baseline | Emissions from the decomposition of waste at the landfill site | $CH_4$ |
| Baseline | Emissions from electricity generation | $CO_2$ |
| Project Activity | On-site fossil fuel combustion (auxiliary fuel) | $CO_2$, $CH_4$, $N_2O$ |
| Project Activity | Emissions from the combustion of waste | fossil $CO_2$, $CH_4$, $N_2O$ |

A critical component is the calculation of avoided landfill methane emissions. These emissions under the baseline scenario are calculated using the multi-phase first order decay model from CDM methodological tool, “Tool to determine methane emissions avoided from disposal of waste as a solid waste disposal site.”

The CDM methodological tool normally provides for year by year crediting, however, there does not appear to be an express requirement that the calculation be performed on a year-by-year basis. The CDM Executive Board has concluded, that for the calculation of avoided methane emissions from biogenic waste that would have been disposed in a landfill [17]:

“(a) Only those emissions in the baseline that would have occurred over the crediting period should be considered in estimating the emissions reduction; and

(b) In particular, the first order decay (FOD) model shall be used in estimating the baseline methane emissions for projects avoiding emission from biogenic waste that would have been disposed either in landfills or left to decay in an uncontrolled manner. which would have resulted in methane emissions.”

The equation below has been modified from the version in the methodological tool to account for ten years of avoided landfill methane at once, instead of a year by year calculation. This revised equation is fundamentally equivalent to the methodological tool as it relies on the first order decay model, and it does not allow for estimating the emission reduction beyond the crediting period, consistent with the CDM Executive Board conclusion.

$$BE_{CH4,SWDS} = \varphi \cdot GWP_{CH4} \cdot (1 - OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF \cdot \sum_{x=1}^{y} \sum_{j} (1 - f_x) \cdot W_j \cdot DOC_j \cdot e^{-k_j \cdot (x-1)} \cdot \left(1 - e^{-k_j}\right)$$

Where:

| | | |
|---|---|---|
| $BE_{CH4,SWDS}$ | = | Baseline emissions from the solid waste disposal site (landfill) |
| $\varphi$ | = | Model correction factor to account for model uncertainties (0.9) |
| $GWP_{CH4}$ | = | Global Warming Potential (GWP) of methane |
| $OX$ | = | Oxidation factor, reflecting the amount of methane from the landfill that is oxidized in the soil or other material covering the waste |
| $F$ | = | Fraction of methane in landfill gas (volume fraction) |
| $DOC_f$ | = | Fraction of degradable organic carbon (DOC) that can decompose |
| $MCF$ | = | Methane correction factor (1.0 for sanitary anaerobic landfills) |
| $W_j$ | = | Amount of waste type $j$ prevented from disposal in the landfill (tonnes) |
| $DOC_j$ | = | Fraction of degradable organic carbon (by weight) in the waste type $j$ |
| $k_j$ | = | First order decay rate for the waste type j ( / year) |
| $j$ | = | Waste type category (index) |
| $x$ | = | Year of crediting period |
| $y$ | = | Years for which avoided methane emissions can be credited (10 years) |

The CDM methodology places significant limits on the potential offsets generated by EfW facilities generally in an effort to be conservative. However, this conservatism has in effect, yielded a methodology that reflects only a minor portion of the mitigation afforded by EfW.

**Limit on Avoided Methane**

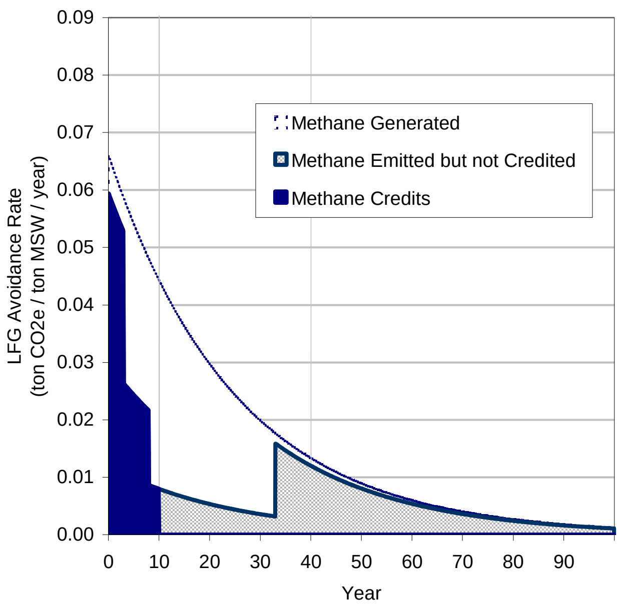
EfW facilities permanently destroy all of the methane generation potential during the combustion process. There is absolutely no risk of future GHG emissions once the process is completed. In contrast, under the baseline scenario, landfills emit methane for up to 100 years, or more, depending on the rate of decay. Furthermore, the collection and subsequent destruction of the methane generated, although required by regulation for large landfills, is subject to proper operation and maintenance of systems for long periods of time.

Although EfW facilities permanently destroy all of the methane generation potential, the emissions reduction is not calculated beyond the project crediting period of ten years.

This results in a very conservative estimate of the total methane avoided by an EfW facility.

Figure 1 depicts the impact of the 10 Year limit on avoided methane for the potential to generate carbon offsets where the avoided landfill is assumed to collect and destroy methane at an efficiency of up to 80% for 30 years. Depending on the rate of methane evolution from the landfill, limiting crediting to a 10 year period misses over 50% of the methane emitted from the landfill, significantly under-representing the GHG mitigation achieved by EfW.

**Figure 1. Impact of 10 Year Limit on Avoided Methane**




### Exclusion of Ferrous & Non-Ferrous Recycling

Virtually all facilities in the U.S. recover ferrous metals from the ash, with many facilities recovering non-ferrous metals consisting predominately of aluminum. Recovery of these materials that would have otherwise been landfilled avoids greenhouse gas emissions associated with the production of ferrous and non-ferrous metals from raw materials and ores. Metals recovery for recycling is recognized as a GHG mitigation process; however, it is not included in AM 0025.

### Selection of Global Warming Potential

Given that the CDM methodologies exist within the context of the Kyoto Protocol, the global warming potentials (GWPs) in place under the Kyoto Protocol, despite being significantly outdated, are the ones applied.

The GWPs chosen have a significant impact on the calculation of GHG emissions reductions. For example, the 100 year GWP of methane used by the CDM methodology, originally published in the IPCC 2$^{nd}$ Assessment Report in 1995, is 21. After two subsequent revisions, the first in 2001, and then in 2007, the IPCC now concludes that the GWP of methane is 25, a nearly 20% increase from 1995 value [18]. Furthermore, recent research published in *Science* by a team of Columbia and NASA scientists has found that, when aerosol effects are included, the 100 year GWP for methane is 34, 62% higher than the value reported by IPCC in 1995 [19].

There is hope, although still some debate, that a post-Kyoto agreement will rely on current figures for GWPs. Both the European Union and Australia have already recommended that a post – Kyoto agreement reflect should include updated GWPs. Furthermore, the *American Clean Energy and Security Act of 2009* passed by the U.S. House of Representatives uses the GWPs of the IPCC Fourth Assessment Report (AR4).

### Exclusion of Upstream Grid Electricity GHG Emissions

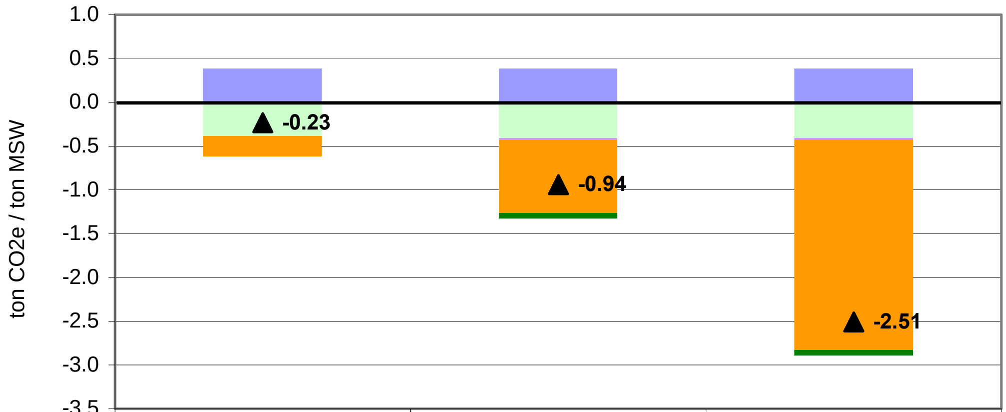
The generation of electricity using traditional fossil fuel emissions not only results in emissions from the generation plant itself, but upstream emissions associated with the extraction, processing, and transportation of fossil fuels. While only a fraction of the emissions from the combustion of fossil fuels, projects that reduce our reliance on fossil generated electricity decrease these upstream emissions as well. The CDM methodology does not account for upstream emissions.

### Exclusion of Transportation Emissions

EfW facilities may also offer significant reductions in GHG emissions from the avoidance of long haul transportation. EfW facilities are often built relatively close to the sources of waste generation. In contrast, in many areas of the country, particularly in the northeast, waste is transported hundreds of miles to landfills.

Taken together, the factors, limits, and assumptions above significantly limit the potential offsets generated by EfW. Figure 2 presents a hypothetical calculation comparing offset credits calculated using the existing CDM methodology and a more realistic methodology that better reflects the actual mitigation achieved by EfW. In this example, the net offset under the CDM methodology is approximately 0.2 tons $CO_2$e / ton MSW processed. Under a more realistic protocol which considers ferrous and non-ferrous recycling, the full 100 years of landfill methane avoidance, the avoided upstream grid electricity emissions, and the current methane GWP, the net offset is closer to 0.9 tons $CO_2$e / ton MSW.

**Figure 2. Comparison of Potential Offset Credits Under the CDM Methodology and a More Realistic Methodology**




| | CDM Methodology | Realistic Methodology 100yr GWP = 25 | Realisitic Methodology 20yr GWP = 72 |
|---|---|---|---|
| CO2 from combustion | 0.39 | 0.39 | 0.39 |
| Fe and non-Fe Recovery | 0.00 | -0.06 | -0.06 |
| Avoided Landfill CH4 (1st 10 Years) | -0.23 | -0.28 | -0.80 |
| Avoided Landfill CH4 (Yrs 11-100) | 0.00 | -0.55 | -1.60 |
| Avoided Grid Elec (Upstream) | 0.00 | -0.02 | -0.02 |
| Avoided Grid Electricity | -0.38 | -0.41 | -0.41 |
| ▲Net Offset | -0.23 | -0.94 | -2.51 |

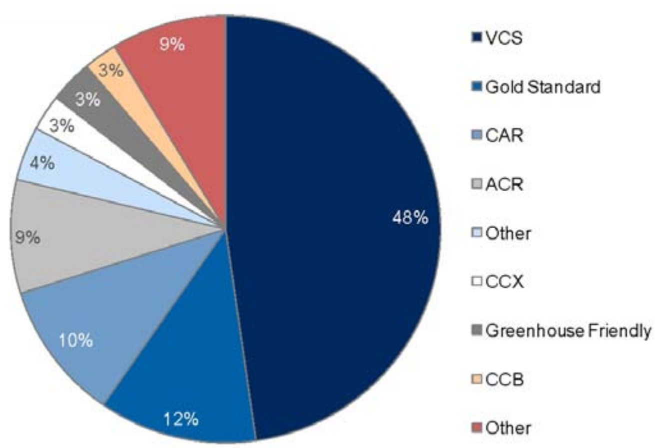
For comparison purposes, Figure 2 also includes the results of a more realistic protocol using the current 20 year global warming potential of 72. The 100 year GWP is the current convention; however, the IPCC has indicated that a 20-year index is relevant for policy aimed at preventing potentially abrupt, non-linear climate responses in the near term.

## VOLUNTARY CARBON STANDARD

In the absence of a regulatory cap-and-trade system in the U.S., a voluntary offsets market has taken hold and is growing. Participants in the voluntary market generally have two objectives in mind: 1) to secure a stream of offsets that can be used in a future mandatory cap-and-trade program, and 2) to reduce the organization's carbon footprint for product or other organizational changes. The first objective, in particular, requires a robust voluntary offsets program that stands a good chance of being incorporated into a mandatory cap-and-trade program.

One of the key players in the voluntary market is the Voluntary Carbon Standard (VCS). Nearly half of the voluntary credits generated in 2008 were verified to the VCS [20]. Project types, such as EfW, that are eligible for credits under the CDM are also eligible to generate voluntary carbon credits under the VCS if they meet certain "additionality" tests. Additionality refers to the premise that any project getting carbon credits must be something beyond "business as usual" practices. For EfW, one of the tests is to demonstrate that it is not required by regulation and that it is not the lowest tip fee option available. A project must also have commenced operation since 2007. The calculation of carbon offsets generated must also be done in line with an existing CDM methodology.

**Figure 3. 2008 Voluntary Carbon Market Standard Utilization**




*Source:* [20]

Based on its acceptance of CDM methodologies, the VCS could be an excellent vehicle for the generation of carbon offset credits from EfW.

## OTHER VOLUNTARY PROGRAMS

As noted in Figure 3, there a variety a variety of voluntary carbon offset standards in addition to VCS. Several of these standards have offset methodologies constructed around the concept of methane avoidance from landfills. While these methodologies do not include EfW specifically, they set an important foundation for the concept of quantifying one of the key benefits of EfW technology.

The Chicago Climate Exchange (CCX) developed a methodology in 2009 that provides for offset credits from composting of organic wastes that would have otherwise been landfilled. The protocol is limited to the avoided methane because composting operations do not generate electricity and therefore cannot offset carbon emissions from grid connected electrical generation. Waste types are limited to food wastes, yard wastes, and wastewater biosolids. The methodology assumes that composted wastes, in the absence of the project, would have otherwise been sent to a landfill equipped with landfill gas collection and destruction. The methodology assumes that the methane collection efficiency is 0% for the first three years of waste in a landfill, and 75% for years four through ten. Avoided methane emissions are calculated using the First Order Decay Model (FOD) consistent with the CDM methodology.

The Climate Action Reserve (CAR) finalized its Organic Waste Digestion Project Protocol in October of 2009. This protocol covers anaerobic digestion projects that process eligible organic wastes that would otherwise would have gone to uncontrolled anaerobic storage, treatment and disposal systems such as solid waste landfills [21]. CAR is currently developing a compost project protocol of its own with its adoption expected in June of 2010. Both protocols generate offset credits strictly through avoided landfill methane.

The most inclusive of the avoided landfill methane protocols is Alberta's Aerobic Composting Protocol, which includes the organic portion of municipal solid waste [22]. Alberta's compost offset protocol falls within the Specified Gas Emitters Regulation, which, when finalized, will require certain large emitters to reduce their GHG emissions either through direct reductions or purchase of carbon offsets.

## DISCUSSION & CONCLUSION

Significant precedent exists for the generation of carbon offsets by avoiding methane generation in landfills. Three separate programs in North America, including CCX, CAR, and the Alberta offsets program recognize, or plan to recognize, the greenhouse gases avoided by composting. One program, CAR, recognizes the landfill methane avoided through anaerobic digestion of certain organic wastes. Each of these sets a strong precedent for generating carbon offsets from EfW, another mechanism that effectively avoids all of the methane generation from the MSW processed.

EfW is already specifically recognized by the CDM of the Kyoto Protocol. Under methodology AM0025, EfW facilities can generate carbon offsets from projects in emerging countries. In fact, projects have already been registered in China and India. These offsets can in turn be used by developed countries to meet their obligations under the Kyoto Protocol. Carbon offsets in developed countries, including the United States, can potentially be generated using the CDM methodology through the VCS.

Challenges remain for generating credits from EfW facilities. Program rules which restrict the age of facilities eligible to generate credits eliminate most EfW facilities in the U.S. from generating offset credits under existing programs. Only a few capital expansions of existing facilities may be eligible.

Furthermore, certain assumptions significantly restrict the potential to generate offset credits, resulting in offset calculations that under-report the mitigation achieved by EfW. For example, the CDM methodology as well as existing methane avoidance protocols written for the CCX, CAR, and Alberta programs significantly restrict the amount of avoided methane eligible for credits. Although landfills typically generate methane for 100 years or more, these protocols only recognize the first 10 years of avoided landfill methane. This, coupled with use of an outdated methane global warming potential, and the exclusion of ferrous and non-ferrous metals recovery, seriously limit the potential for EfW to generate credits. Although these limits are often established to ensure conservatism, they have become so conservative as to be inaccurate.

In most areas of the country, average tip fees for EfW generally exceed those for landfilling. Given that they were not always the cheapest option, exisiting EfW facilities that were often constructed due to the recognition that their ability to reduce GHG emissions and recover energy from waste makes them a more sustainable solution for the waste remaining after recycling. Proper accounting for the greenhouse gas emission reductions achieved by EfW, realized in the form of carbon offset credits, can help level the playing field for EfW, making the environmentally preferable means of post recycled MSW waste management, more economically attractive.

## REFERENCES


[1] B. Bahor, M. Van Brunt, K. Weitz, A. Szurgot, "Life Cycle Assessment of Waste Management Greenhouse Gas Emissions Using Municipal Waste Combustor Data" *Journal of Environmental Engineering*, in press (available at http://dx.doi.org/10.1061/(ASCE)EE.1943-7870.0000189).

[2] IPCC. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter10.pdf

[3] IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[4] EU (European Union) (1999) Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. *Official Journal of the European Communities*. L182, **42**, 1–19.

[5] European Environment Agency. Annual European Community greenhouse gas inventory 1990-2005 and inventory report 2007, May 27, 2007. http://www.eea.europa.eu/publications/technical_report_2007_7

[6] European Environment Agency. EEEA Briefing, Better management of municipal waste will reduce greenhouse gas emissions. 2008. http://www.eea.europa.eu/publications/briefing_2008_1

[7] Bahor, B., M. Van Brunt, J. Stovall, K. Blue, 2009, Integrated Waste Management as a Climate Change Stabilization Wedge, *Waste Management & Research*, **27**¸ 839-849

[8] Climate Action Reserve, 2009, *Program Manual, February 23, 2009*

[9] VCS Association, 2008, *Voluntary Carbon Standard Program Guidelines 2007.1*

[10] World Business Council for Sustainable Development and World Resources Institute Greenhouse Gas Protocol, 2005, *The GHG Protocol for Project Accounting*, Switzerland & Washington.

[11] Europa, 2005, "Questions & Answers on Emissions Trading and National Allocation Plans" website accessed 1/15/2010.

[12] EU (European Union) (2003) Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. *Official Journal of the European Union*. L275, **46**, 32-46.

[13] EU (European Union) (2004) Directive 2004/101/EC of the European Parliament and of the Council of 27 October 2004 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of Kyoto Protocol's Project Mechanisms. *Official Journal of the European Union.* L338, **47**, 18-23.

[14] RGGI, Inc., 2009, *RGGI Fact Sheet*, New York. http://www.rggi.org/docs/RGGI_Executive%20Summary_4.22.09.pdf Accessed 1/15/2010.

[15] Western Climate Initiative, 2008, *Design Recommendations for the WCI Regional Cap-and-Trade Program.*

[16] CDM (Clean Development Mechanism) Executive Board, 2008, Approved Baseline and Monitoring Methodology AM0025 Avoided Emissions from Organic Waste Through Alternative Waste Treatment Processes, Version 11.

[17] United Nations Framework Convention on Climate Change. Executive Board of the Clean Development Mechanism, 23rd Meeting. Report. February 24, 2006 http://cdm.unfccc.int/EB/023/eb23rep.pdf

[18] IPCC (Intergovernmental Panel on Climate Change), 2007, Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., Tignor, M., & Miller, H. (eds.): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

[19] Shindell, Drew T., Greg Faluvegi, Dorothy M. Koch, Gavin A. Schmidt, Madine Unger, Susanne E. Bauer, Improved Attribution of Climate Forcing to Emissions, *Science*, **326**, 716-718.

[20] Ecosystem Marketplace & New Carbon Finance, 2009, *Fortifying the Foundation: State of the Voluntary Carbon Markets 2009*, New York & Washington, DC.

[21] Climate Action Reserve, 2009, *Organic Waste Digestion Project Protocol: Avoiding Methane Emissions from Anaerobic Digestion of Food Waste and/or Agro-Industrial Wastewater, Version 1.0*, Los Angeles

[22] Alberta Environment, 2008, *Quantification Protocol for Aerobic Composting Projects, Version 1.1*, Edmonton