Union of Concerned Scientists

FACT SHEET

Turning Trash into Low-Carbon Treasure

The Benefits and Implications of Waste-derived Power and Fuel

HIGHLIGHTS

Each year the United States generates more than 250 million tons of garbage and more than 9 trillion gallons of wastewater. If better managed, these waste resources could be used to significantly increase the production of clean, low-carbon energy. Through smart policies and infrastructure investments, the United States could produce the equivalent of nearly 4.5 billion gallons of gasoline—enough to power 10.4 million cars—out of its waste resources, cutting annual global warming emissions by more than 49 million metric tons. Given the economic and environmental impacts associated with using fossil fuels, the time is ripe to capitalize on the energy potential of waste and wastewater.

Municipal waste is a largely unrecognized biomass resource. Municipal solid waste (MSW), better known as trash, is made up of the everyday items discarded by the public, picked up by garbage companies, and either recycled, burned, or deposited in landfills across the country. Municipal wastewater comprises sewage and gray water (non-sewage waste water from sinks and baths) emanating from public drains, and is processed at a treatment facility before being released into the environment. Both of these waste resources can contain large amounts of carbon-rich organic matter—for example, food scraps are often discarded into the trash or added to wastewater via a garbage disposal—that, instead of being discarded, could generate clean, low-carbon fuel in every region of the country (see Figure 1, p. 2).

Each year, the United States generates more than 250 million tons of MSW (EPA 2014) and 9 trillion gallons of wastewater (EPA 2009). While there is certainly a need to reduce the amount of waste we generate in the first place, appropriate waste management strategies could maximize the potential to convert waste into fuel and minimize life cycle global warming emissions from both MSW and wastewater streams.

The Climate-Changing Potential of Trash

Although recycling rates have steadily increased over the past 30 years (see Figure 2, p. 4), nearly two-thirds of MSW still ends up in landfills today (EPA 2014). With more plastic, glass, and metal being diverted from the waste stream, the remaining fraction of landfill waste has become increasingly organic. Currently available data indicate that organic matter comprises more than 44 percent of landfilled

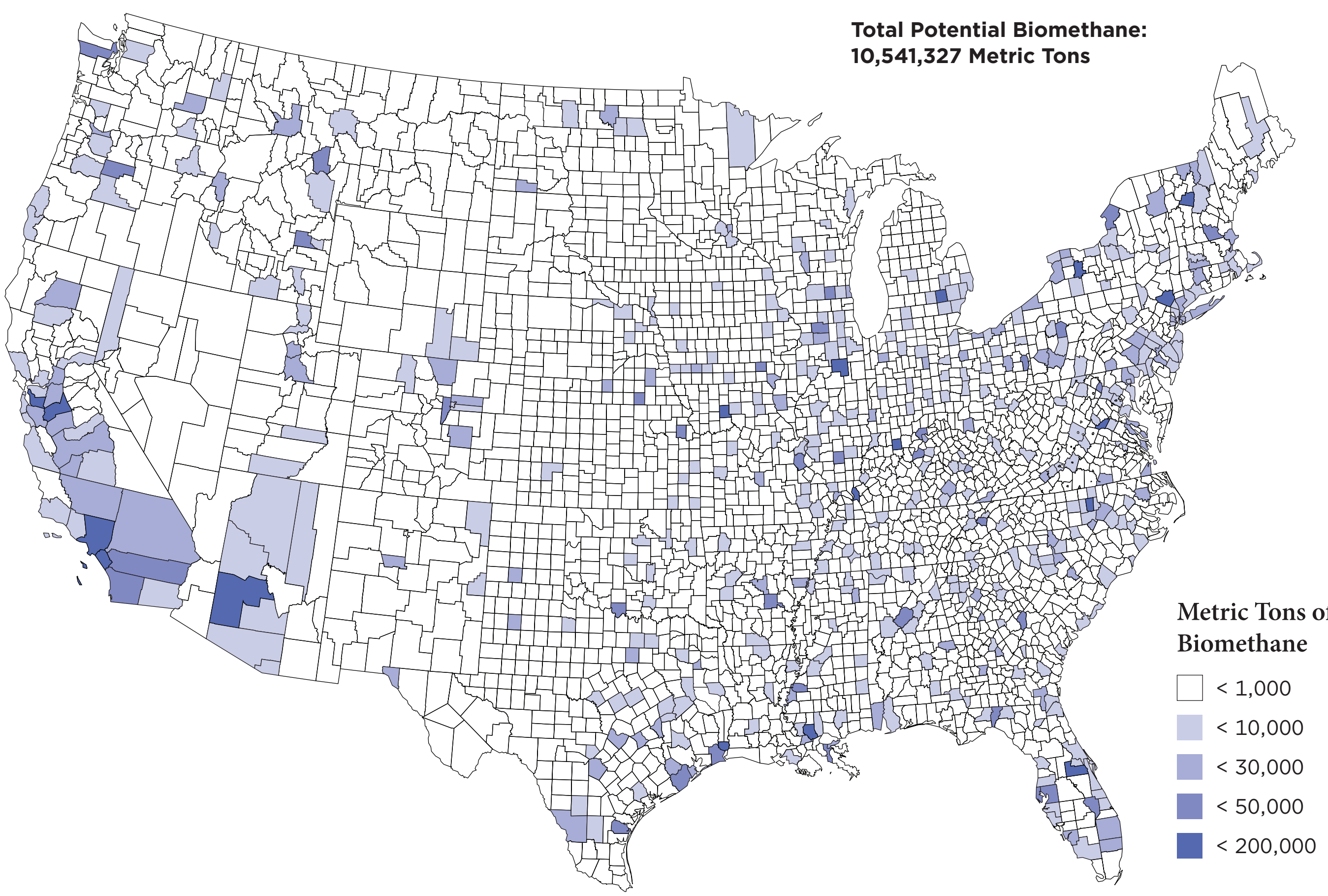
Better policies and practices could help divert carbon-rich organic material from landfills, where it decomposes and generates global warming emissions, and use it to generate clean, low-carbon fuel and electricity.

MSW; food waste is the largest single contributor to this total, accounting for nearly half (48 percent) of organic waste (EPA 2015a).

Organic materials naturally decompose under anaerobic conditions (conditions with little or no oxygen) to produce biogas, a mixture of carbon dioxide (CO_2) and methane—a global warming gas 28 to 36 times more potent than CO_2. (The decomposition process, known as anaerobic digestion, is described in more detail in Box 1.) Landfilling organic wastes can present a major environmental problem; landfills not only create conditions ripe for anaerobic decomposition but also lack the ability to adequately capture biogas, allowing it to escape to the atmosphere and exacerbate global warming.

Fortunately, methane is an energy-dense fuel that can be used for electricity, heating, and transportation. For example, U.S. waste-derived "biomethane" could produce nearly 4.5 billion gasoline-equivalent gallons of fuel annually—enough fuel for 10.4 million cars (EIA 2015a), or approximately 17,000 megawatts of electricity per year—enough to power 13.7 million homes (EIA 2015b). This could displace nearly 75 percent of the natural gas consumed by the transportation sector or 7 percent of the natural gas consumed by the electricity sector (EIA 2015c). And as the electric vehicle market continues to grow, biomethane-generated electricity could allow for truly zero-emission driving (see Box 2, p. 7).

FIGURE 1. Waste-derived Biomethane Potential across the United States



Every region of the country has the potential to generate fuel from local waste resources. The potential is greatest near large cities and other population centers that generate higher amounts of waste and wastewater. These areas also have the greatest demand for power and fuel.

SOURCE: NREL 2015.

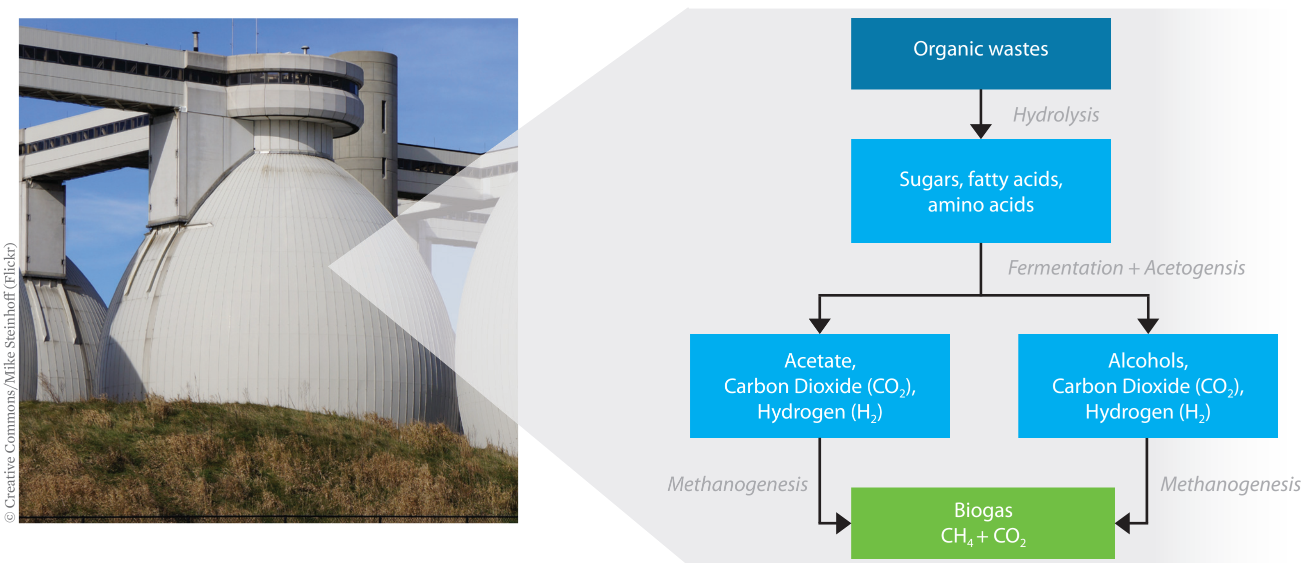
BOX 1.

How Is Biogas Produced?

Biogas is a mixture of gases, typically methane and carbon dioxide, produced during the anaerobic digestion of organic matter. Anaerobic digestion is a naturally occurring process in which microorganisms break down organic matter such as sugars, lipids, and proteins, creating biogas along with residual material called digestate. Digestate, which contains some unconverted organic matter along with inorganic nutrients such as nitrogen and phosphorus, is a valuable by-product that can be processed further by composting or directly applied to land as fertilizer.

The biochemical conversion processes that take place naturally within landfill systems are identical to those taking place in anaerobic digesters. Anaerobic digesters, however, are reactor systems engineered to optimize the conversion of organic waste to biogas, which makes for faster and more efficient fuel recovery and utilization.

© Creative Commons/Mike Steinhoff (Flickr)



Anaerobic digester systems are designed to optimize the conversion of organic waste into methane and carbon dioxide. The anaerobic digestion process comprises four major steps, each mediated by different types of microorganisms. Diagram adapted from Tchobanoglous, Burton, and Stensel 2003.

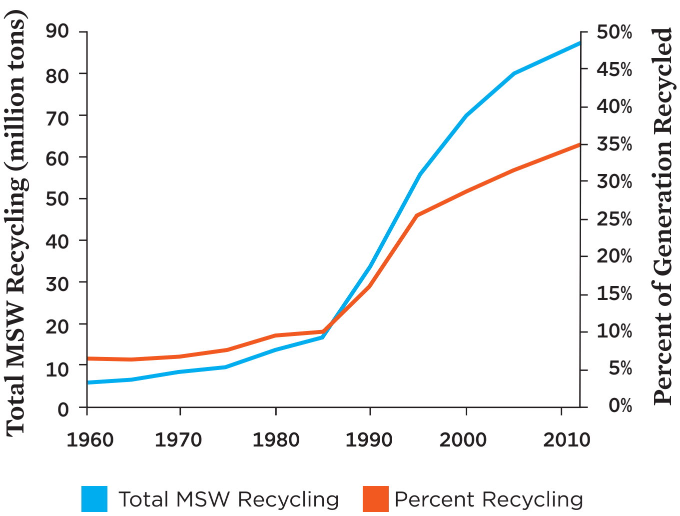
Wasteful Waste Treatment Infrastructure

The United States could be harvesting as much as 10.5 million metric tons of biomethane from MSW and municipal wastewater, but is currently harvesting less than 2 million metric tons (see Figure 3, p. 5)—less than 18 percent of the total potential. This is largely due to an outdated U.S. waste management system.

Although most U.S. landfills are collecting biogas, landfills were not initially conceived of with biogas recovery in mind. While recovery equipment has helped avoid some methane release that would have otherwise occurred over the last few decades, it is still inherently inefficient (Staley and Barlaz 2009). As a result, landfills have released and continue to release large amounts of fugitive methane—uncaptured or unburned methane—into the atmosphere. Since methane is a potent heat-trapping gas, fugitive emissions have a significant impact on our climate.

The Environmental Protection Agency (EPA) estimates that only a quarter of all methane generated in landfills is not captured by landfill gas collection systems (EPA 2015c); fugitive emissions vary widely from location to location (Spokas et al. 2006), and a recent report by the Intergovernmental Panel on Climate Change found that fugitive landfill gas emissions over the long term may be as high as 80 percent (Pachauri and Reisinger 2007). Until 1998 waste management was the second-largest source of U.S. methane emissions after

FIGURE 2. Changes in the U.S. Recycling Rate, 1960–2012



Over the past 50 years, the percentage of municipal solid waste recovered for recycling has increased from less than 7 percent to more than 34 percent, which represents more than a 14-fold increase in the amount of material being recycled over this time period. The remaining waste stream has become more concentrated in organic matter that, if recovered, could be used to produce renewable fuels.

SOURCE: EPA 2014.

the energy sector, and recent data indicate that waste management is currently the third-largest contributor of U.S. methane emissions after the energy and agricultural sectors (EIA 2011).

Numerous peer-reviewed studies have evaluated heat-trapping emissions reductions from organic management alternatives (Laurent et al. 2014), and the conclusions have been clear and consistent—landfilling of organic wastes generates more heat-trapping emissions, and has poorer overall environmental performance, than any other conventional waste-disposal approach, including anaerobic digestion, composting, and incineration. However, landfilling remains the primary management route for organic MSW in the United States.

Unlike MSW treatment in landfills, biomethane recovery from wastewater treatment facilities (WWTFs) is not limited by inefficient infrastructure, but rather a lack of relevant infrastructure all together. Less than 45 percent of WWTFs have anaerobic digesters, and among those that do, 90 percent end up flaring the excess biogas not used to heat the digesters (EPA CHP Partnership 2011).

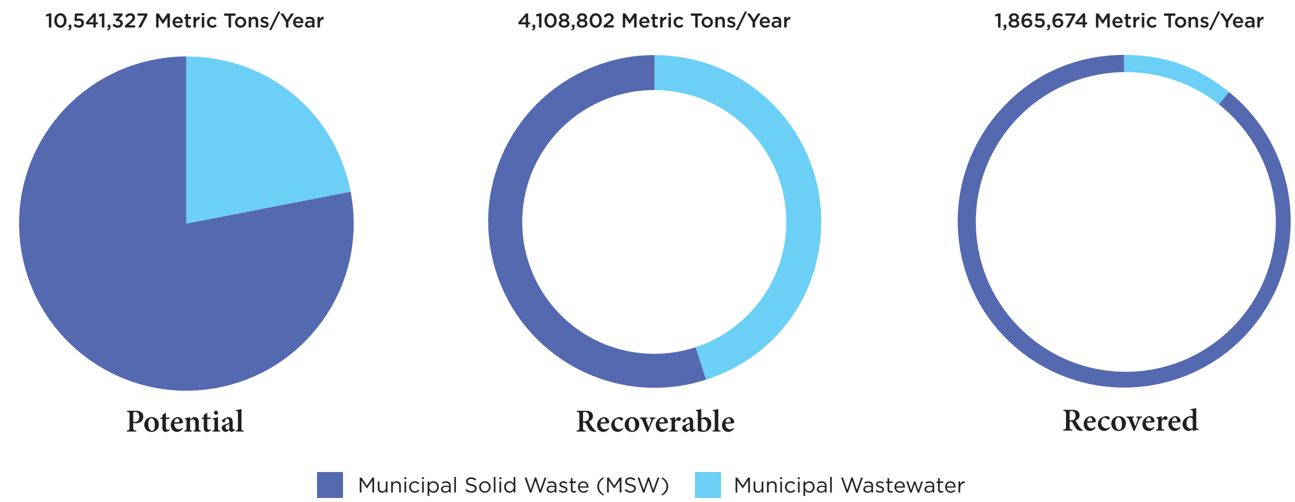
The decision to flare biogas at WWTFs (and landfills) is driven typically by economic and regulatory factors rather than environmental considerations. Direct combustion of biogas to generate electricity requires costly infrastructure, air permits, and, in some cases, unique gas cleanup equipment. Pipeline injection or direct production of compressed natural gas (CNG) or liquefied natural gas (LNG) requires biogas to be purified by removing CO_2, inert gases, and contaminants. Often the cost of these projects is hard to justify based solely on the market prices for electricity or natural gas, and cost-benefit analyses often do not take into account the economic benefit of avoided global warming emissions and reduced demand for fossil fuels.

Policy Options for Improving Waste Management Systems

Some of the hurdles described above may be overcome by enacting long-term, stable policies and regulatory frameworks that account for the full suite of environmental attributes associated with renewable waste–derived fuels. (Ayalon, Avnimelech, and Shechter 2001). Local, regional, and state governments are responsible for providing and/or overseeing services such as waste management, wastewater treatment, and energy delivery, as well as protecting communities from natural disasters aggravated by climate change and protecting ecosystems and the environment. A well-functioning waste system can meet all of these needs, providing benefits far in excess of the market price of a kilowatt-hour of electricity or a cubic foot of natural gas.

Waste-derived "biomethane" could produce approximately 17,000 megawatts of electricity per year—enough to power 13.7 million homes and displace 7 percent of the natural gas consumed by the electricity sector. Biomethane-generated electricity could also allow electric vehicles to achieve truly zero-emission driving.

FIGURE 3. Most U.S. Biomethane Potential Goes Unrealized



The United States could generate more than 10.5 million metric tons of biomethane from municipal solid waste and wastewater systems each year, but inefficient or missing infrastructure means only a fraction of this total—less than 2 million metric tons—is being recovered today.

Note: "Potential" total assumes that all organic waste material is converted to biogas optimally using anaerobic digestion. "Recovered" total represents the current annual estimated amount of biomethane used for energy production. "Recoverable" total represents the annual estimated amount of biomethane that could be recovered for energy using existing infrastructure, and equals the amount of biomethane that is currently flared plus the amount of biomethane that is currently recovered.

SOURCE: SAUR AND MILBRANDT 2014; NREL 2013.

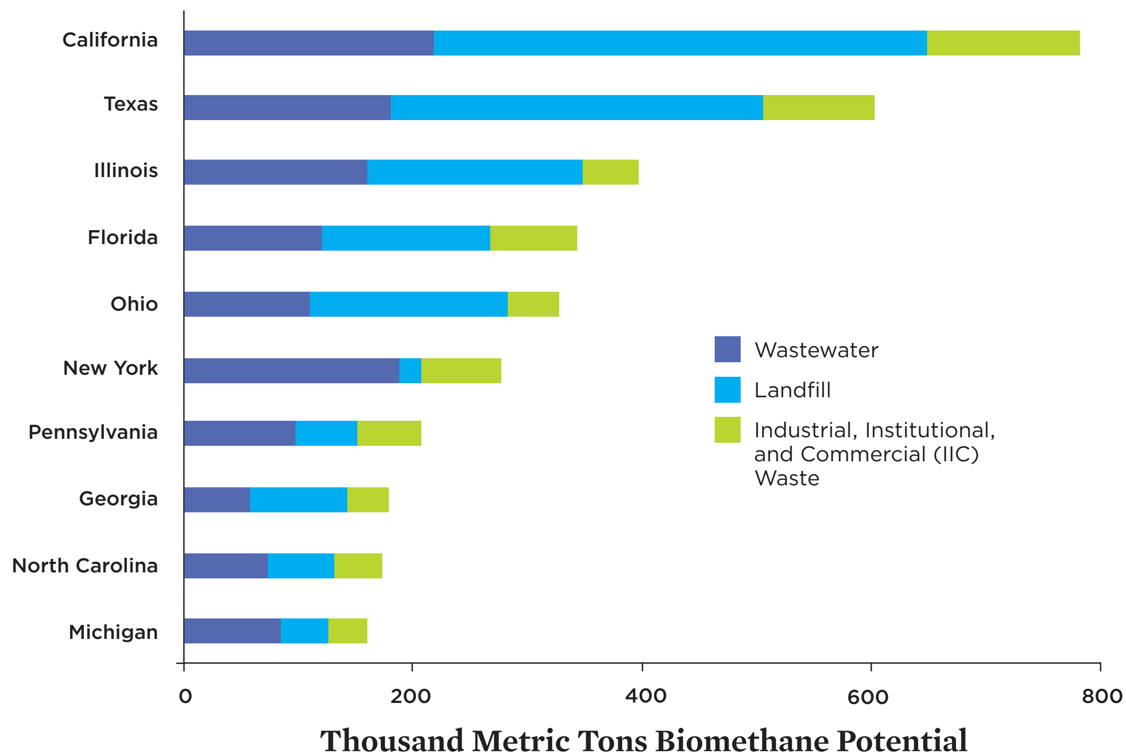
To achieve these goals, we need targeted policies premised on the recognition that organic wastes are valuable resources, and corresponding regulations that encourage efficient management practices to both maximize fuel production and minimize fugitive gas emissions (Levis et al. 2010). Additional incentives and credits for waste-derived fuels that appropriately value its energy content and environmental attributes can also help policy makers, municipalities, and businesses address the economic costs associated with establishing better waste management infrastructure.

A supportive policy environment could shift our waste management framework from disposal systems to reuse and renewable energy production systems. This new paradigm would prioritize separation of organic wastes (including food) for treatment outside of landfills, catalyzing the development of new systems to treat these diverted wastes and highlighting existing capacity for treatment (such as existing WWTF digesters). Some of these changes are already happening across the United States. For example:

- Massachusetts approved a measure in 2014 that requires convention centers, hospitals, universities, and other large producers of waste (greater than one ton per week) to separate organics from landfill-bound MSW for alternative management. While households and small businesses are currently exempt, this measure is still expected to reduce global warming emissions by approximately 71,250 metric tons per year, and isolate enough organic material to generate 44 tons of biomethane per year.
- The city of Oakland, CA, operates an organics diversion program and uses the organic waste to fuel co-digestion

Large producers of waste, such as convention centers and universities, could make a significant contribution to waste-based fuel production. In Massachusetts, these facilities are diverting enough organic waste from other trash to produce an estimated 44 tons of biomethane per year.

FIGURE 4. States with the Greatest Waste-derived Fuel Potential



To promote better waste management practices, states should consider the amounts and types of waste resources available locally, and use that data to shape policies, infrastructure, and incentive programs.

Note: IIC waste comprises primarily food waste.

SOURCE: NREL 2013

in its East Bay Municipal Utility District WWTF (Christian-Smith and Wisland 2015). Co-digestion—combining energy-rich organic materials, such as food waste, with wastewater sludge to increase biomethane production—has been identified as one of the best alternatives for organic waste management, effectively mitigating the harms of landfilling organic material while leveraging existing infrastructure to increase biomethane generation.

Identifying and pursuing synergies between MSW and wastewater systems will help maximize U.S. biomethane production.

The strategy being employed by Oakland highlights the potential technical synergy between MSW and wastewater systems. Identifying, prioritizing and actively pursuing these synergies will go a long way toward maximizing U.S. biomethane production.

In addition, policies and regulatory frameworks that promote greater waste-derived fuel production should be based on the types of local waste resources available. In New York, for example, more than 65 percent of the biomethane potential is attributed to wastewater and less than 5 percent to landfills (see Figure 4). By contrast, more than half (55 percent) of California's potential biomethane comes from landfills and less than 30 percent from wastewater. Thus, organic waste–diversion policies would be much more effective at reducing global warming emissions in California than New York, while measures to incentivize greater resource recovery from WWTFs would be more valuable in New York. And in states with high levels of IIC (industrial, institutional, and

BOX 2.

The Potential for Powering Electric Cars with Trash

Our perception of transportation fuel is changing. There are nearly 300,000 electric vehicles (EVs) on the road today, and when the electricity used to power these vehicles comes from clean resources, EVs can operate nearly emissions-free. Using waste-derived biogas to generate electricity is a win-win: by helping to displace fossil-based natural gas, it makes the electricity grid cleaner, and as more EVs and plug-in hybrid vehicles become available, a cleaner grid will offer a cleaner transportation sector as well.

In July 2014 the EPA acknowledged these benefits when it finalized its Pathways II rule making, designating biogas-derived electricity as both a renewable and cellulosic biofuel. This determination will allow biogas-derived electricity used in the transportation sector to receive biofuel credits called renewable identification numbers (RINs) under the Renewable Fuel Standard; one RIN is equivalent to one ethanol gallon equivalent of fuel, based on energy content. These RINs essentially represent the environmental attributes of biogas-derived electricity. Estimates indicate that roughly 90 million RINs could be generated annually from waste-derived biogas—about twice the amount generated from biogas-derived CNG and LNG—based on cumulative EV sales and average VMT (vehicle miles traveled) data in the United States.

Since RINs are only generated for biogas-derived electricity used in the transportation sector, the value of RINs can benefit the biogas industry and promote EV charging infrastructure; it may also be translated into a financial incentive for prospective EV buyers. The specific regulatory framework and value apportionment approach has not yet been fully established, but the work so far to finalize these details shows that the EPA is taking important steps to include more biofuels in the Renewable Fuel Standard. Currently, more than 90 percent of the waste-derived biogas collected for fuel is used to generate electricity (EPA 2015d). Although the amount of biogas-derived electricity is currently greater than demand for electricity by the transportation sector, the EPA's determination would support expanded electricity demand in the transportation sector.

© General Motors

As more EVs and plug-in hybrid vehicles come to market, a cleaner electricity grid—boosted by low-carbon, waste-derived fuel—will mean a cleaner transportation sector as well.

commercial) waste, which is primarily food waste, there are unique opportunities to isolate this material from landfill streams—where more than 97 percent of it currently goes—and process it into biofuels (Levis et al. 2010).

Not All Biogas Is Created Equal

How biogas is produced, and from which wastes it is generated, can substantially affect the lifecycle emissions of the resulting fuel. For example, landfill biogas has a greater carbon intensity than digester biogas because landfill systems are not as efficient at producing and capturing biogas, whereas digesters are specifically designed for that purpose. Additional carbon benefits are also conferred to digester biogas produced from organic material diverted from landfills to account for the avoided fugitive methane emissions from landfill systems. Consequently, several studies have shown that organics diversion and anaerobic digestion can result in negative lifecycle emissions (see Figure 5, p. 8) (Laurent et al. 2014; Yoshida, Gable, and Park 2012).

For the purposes of California's Low Carbon Fuel Standard, the state's Air Resources Board recently determined that biogas-derived CNG fuel was between 86 percent and 115 percent less carbon-intensive than diesel fuel (CARB 2015). Waste-derived fuels may have the greatest benefits for the transportation sector because transportation fuels have greater carbon intensities than the natural gas that would be displaced in the electricity sector. Moreover, as oil companies are forced to turn to new sources of oil that require more energy to extract and refine, petroleum-based fuels are becoming dirtier and more carbon-intensive, making the relative emissions-reduction benefits of waste-based fuel even more substantial (see Box 2).

The Case for Sustainable Waste Management

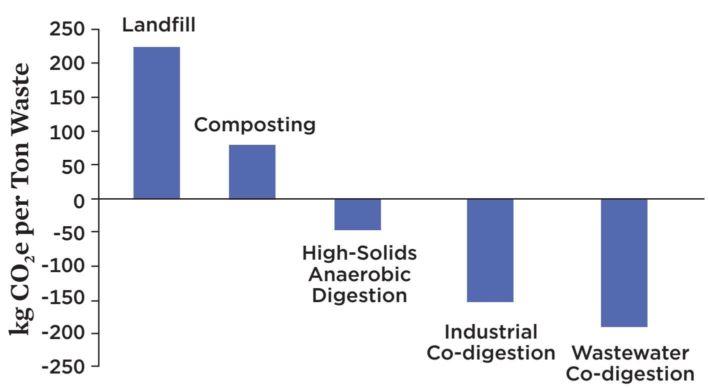
Municipal waste and wastewater are intrinsic by-products of our society and will continue to exist even with steadily improving systems for reducing, reusing, and recycling. Recognizing the potential harms that our current waste management systems and practices have on our climate and environment should catalyze the development of better, more efficient approaches to recovering and using energy from waste resources.

A sustainable waste management system would effectively isolate organic wastes at the source and keep these materials separate from other solid wastes. The isolated organic wastes would then be processed to generate renewable fuels that displace fossil fuels. Any organic material remaining after processing could be composted or alternatively stabilized to become fertilizer (which is typically derived from fossil sources) or other value-added products. And since organic material would be kept out of landfills, substantial global warming emissions would be avoided at the same time. Additionally, fertilizer produced from composted organic wastes may offer more financial and environmental benefits with fewer capital and operating costs.

Although the amount of energy that can be produced from waste resources is more than five times greater than what is currently being produced, it is important to remember that these resources are finite. Thus, policies to increase the production of waste-derived fuels must be coupled with efforts to significantly reduce the overall demand for fossil fuels.

[Policies to increase the production of waste-derived fuels must be coupled with efforts to significantly reduce the overall demand for fossil fuels.]

FIGURE 5. Life Cycle Emissions of Various Waste Management Options



Global warming emissions can be significantly reduced by diverting organic material from municipal solid waste that would otherwise go to landfills. Anaerobic digestion can even result in negative global warming emissions.

Note: Life cycle emissions can vary widely depending on the specific system configuration and actual alternative waste fates.

SOURCE: YOSHIDA, GABLE, AND PARK 2012.

David Babson *is a senior engineer in the Union of Concerned Scientists Clean Vehicles Program.*

REFERENCES

Ayalon, O., Y. Avnimelech, and M. Shechter. 2001 Solid waste treatment as a high-priority and low-cost alternative for greenhouse gas mitigation. *Environmental Management* 27(5).

California Air Resources Board (CARB). 2015. Table 6. Carbon intensity lookup table for gasoline and fuels that substitute for gasoline. Online at *www.arb.ca.gov/fuels/lcfs/lu_tables_11282012.pdf*, accessed June 11, 2015.

Christian-Smith, J., and L. Wisland. 2015. Clean energy opportunities in California's water sector. Cambridge, MA: Union of Concerned Scientists. Online at *www.ucsusa.org/CAwaterenergy*, accessed June 23, 2015.

Tchobanoglous, G., F. Burton, and H.D. Stensel. 2002. Wastewater engineering: Treatment and reuse. Metcalf & Eddy, contributor. Boston: McGraw-Hill.

Energy Information Administration (EIA). 2015a. Frequently asked questions: Gasoline. Washington, DC. Online at *www.eia.gov/tools/faqs*, accessed June 11, 2015.

Energy Information Administration (EIA). 2015b. Frequently asked questions: Electricity. Washington, DC. Online at *www.eia.gov/tools/faqs*, accessed June 11, 2015.

Energy Information Administration (EIA). 2015c. Natural gas consumption by end use. Washington, DC. Online at *www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_m.htm*, accessed June 11, 2015.

Energy Information Administration (EIA). 2011. Chapter 3. Methane emissions. In *U.S. Emissions of Greenhouse Gases in the United States 2009*. Washington, DC.

Environmental Protection Agency (EPA). 2015a. U.S. Advancing sustainable materials management: 2013 Fact Sheet: Assessing trends in material generation, Recycling and disposal in the United States. Washington, DC.

Environmental Protection Agency (EPA). 2015b. Understanding global warming potentials. Washington, DC. Online at *www.epa.gov/climatechange/ghgemissions/gwps.html*, accessed June 11, 2015.

Environmental Protection Agency (EPA). 2015c. LFG energy projects. Washington, DC. Online at *www.epa.gov/lmop/faq/lfg.html*, accessed June 11, 2015.

Environmental Protection Agency (EPA). 2015d. Basic information. Washington, DC. Online at *www.epa.gov/methane/lmop/basic-info/index.html*, accessed June 11, 2015.

Environmental Protection Agency (EPA). 2014. Municipal solid waste generation, recycling, and disposal in the United States: Facts and figures for 2012. EPA-530-F-14-001. Washington, DC.

Environmental Protection Agency (EPA). 2009. Clean Watersheds Needs Survey 2008 Data. EPA-832-R-10-002. Washington, DC.

Environmental Protection Agency (EPA) CHP Partnership. 2011. Opportunities for combined heat and power at wastewater treatment facilities: Market analysis and lessons from the field. Washington, DC.

Laurent, A., I. Bakas, J. Clavreul, A. Bernstad, M. Nieroa, E. Gentil, M.Z. Hauschild, and T.H. Christensen. 2014. Review of LCA studies of solid waste management systems—Part I: Lessons learned and perspectives. *Waste Management* 34(3):573–588.

Levis, J.W., M.A. Barlaz, N.J. Themelis, and P. Ulloa. 2010. Assessment of the state of food waste treatment in the United States and Canada. *Waste Management* 30(8-9):1486–1494.

National Renewable Energy Laboratory (NREL). 2015. The Biofuels Atlas. Golden, CO. Online at *https://maps.nrel.gov/biofuels-atlas*, accessed June 11, 2015.

National Renewable Energy Laboratory (NREL). 2013. Energy analysis: Biogas potential in the United States. NREL/FS-6A20-60178. Golden, CO.

Pachauri, R.K., and A. Reisinger. 2007. Chapter 10: Waste management. In *Climate change 2007: Working group III: Mitigation of climate change*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Saur, A., and A. Milbrandt. 2014. Renewable hydrogen potential from biogas in the United States. Golden, CO: National Renewable Energy Laboratory.

Spokas, K., J. Bogner, J.P. Chanton, M. Morcet, C. Aran, C. Graff, Y. Moreau-Le Golvan, and I. Hebe. 2006. Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems? *Waste Management* 26(5):516–525.

Staley, B., and M. Barlaz. 2009. Composition of municipal solid waste in the United States and implications for carbon sequestration and methane yield. *Journal of Environmental Engineering* 135(10):901–909.

Yoshida, H., J. Gable, and J. Park. 2012. Evaluation of organic waste diversion alternatives for greenhouse gas reduction. *Resources, Conservation and Recycling* 60(March):1–9.

Union of Concerned Scientists

FIND A FULLY REFERENCED VERSION ONLINE: **www.ucsusa.org/TrashtoTreasure**

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

NATIONAL HEADQUARTERS
Two Brattle Square
Cambridge, MA 02138-3780
Phone: (617) 547-5552
Fax: (617) 864-9405

WASHINGTON, DC, OFFICE
1825 K St. NW, Suite 800
Washington, DC 20006-1232
Phone: (202) 223-6133
Fax: (202) 223-6162

WEST COAST OFFICE
500 12th St., Suite 340
Oakland, CA 94607-4087
Phone: (510) 843-1872
Fax: (510) 843-3785

MIDWEST OFFICE
One N. LaSalle St., Suite 1904
Chicago, IL 60602-4064
Phone: (312) 578-1750
Fax: (312) 578-1751

PRINTED ON RECYCLED PAPER USING VEGETABLE-BASED INKS