Norwegian University of Science and Technology

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Assessment of resource potential for biogas feedstocks in New York's Hudson Valley

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Abstract

Biogas production has the potential to evolve into an environmentally beneficial and economically viable industry in New York State's (NYS) lower Hudson Valley. This form of renewable energy infrastructure is complementary to the state's climate change mitigation goals, and new low carbon fuel standards (LCFS) have created profitable incentives for the construction and operation of anaerobic digesters (AD). This study aims to identify, collect and collate quantitative and qualitative data on available biogas feedstocks inclusive of excess food waste, biosolids, animal manure, landfills, biocrops (crops grown specifically for AD), invasive species, and compost. The area of focus spans 10 counties, between New York City and Albany, which covers approximately 7,200 mi² (18,650 km²) and is home to over 2.3 million people; Columbia, Dutchess, Delaware, Greene, Orange, Rockland, Putnam, Sullivan, Ulster, and Westchester.

Data and research from global, national, state, regional, and county publications have served as the basis for these concluded results. Sources include the US Environmental Protection Agency (US EPA), the US Department of Agriculture (USDA), the US Department of Energy (US DOE), the NYS Pollution Prevention Institute (NYS2PI), the NYS Department of Environmental Conservation (NYS DEC), the NYS Energy Research and Development Authority (NYSERDA), the Cornell Waste Management Institute (CWMI), and several county solid waste management plans (SWMPs). This analysis identifies roughly 2,200 tons of excess food waste per week generated by the corporate sector and industry sources. It also examines food waste from an end-point perspective, inclusive of residential sources, that recognizes more than 6,500 tons per week processed by waste management facilities. Of the 165 wastewater treatment plants (WWTPs) in the region, only 18, or 11% utilize anaerobic digestion as a sewage sludge treatment method. This equates to about 50% of flows, or 109 million gallons per day (MGD), that may be able to be upgraded with anaerobic treatment technologies. In addition, there are at least 18 concentrated livestock feeding facilities where animal manure is collected in high quantities and could be applied to biogas production. The lower Hudson Valley has over 300 thousand acres of farmland, 60 thousand acres of land trust & conservancy groups, and 884 environmental clean-up sites that warrant further study for the implementation of biocrops. Also, the water chestnut is an aquatic invasive plant prevalent in 9 of the 10 counties which can be harvested as a feedstock. Finally, there are 19 composting facilities with food waste as a primary source where anaerobic digestion may be implemented as an intermediary process to effectively honor the food recovery hierarchy.

By mapping the availability of these bioresources, corporations and policy makers can now use this data as a foundation for designing and implementing an integrated bioenergy system throughout the region. Specific legislation, financial incentives, and waste programs can be enacted to optimize local resource valorization and guarantee consistent and predictable input and output flows. These efforts would aid the development of a production cycle that is characteristic of a localized circular economy; a system aimed to eliminate waste and promote the continual use of resources. Additional benefits include the creation of green jobs and the empowerment of environmental justice initiatives. All of these elements help drive a sustainable community.

Ultimately, biogas can be upgraded to renewable natural gas (RNG) and offset NYS's dependency on fossil fuels. Specifically, this technology could be applied to the state's transportation sector which is responsible for emissions 20% higher than 1990 levels and approximately 40% of the total annual quantity. In this way, biogas production can complement the aggressive goals of the Climate Leadership and Community Protection Act (CLCPA) which advocates an 85% reduction in greenhouse gas (GHG) emissions by 2050 (relative to 1990 levels), 100% carbon-free electricity by 2040, and 70% renewable energy by 2030. The lower Hudson Valley is positioned for a leadership role in these efforts, and can take advantage of relevant feedstocks to become a model for this renewable energy technology and system design throughout the state and the nation.

Acknowledgements

I am eternally grateful for the education and learning opportunities that have been presented to me at Norwegian University of Science and Technology (NTNU). The Industrial Ecology program along with the Department of Energy and Process Engineering have helped me develop a unique set of skills to examine local economies as an ecological construct. Mother nature provides us with remarkable models to learn from: Our job is to be inspired by her and incorporate these best practices into our everyday lives. We are responsible for the world we create, and our quality of success is grounded in the sustainability of our actions.

My advisor, Professor Francesco Cherubini, who is director of the Industrial Ecology department and who has served as lead author for the IPCC Special Report on Climate Change and Land, has helped guide me through this investigative research and inspired me to think in regards to global implications. His openness to exploratory discovery and personal creativity have permitted me to develop this work with passion and curiosity. My hope is that this lust for meaningful development reverberates with the reader and transcends to thoughtful and determined execution. There is no time like the present.

We are but small specks on this Earth, yet our everyday actions can echo across continents. My time away from home, especially during this difficult period of isolation, has provided me with an even greater admiration of my native region and a deeper appreciation for the resources that myself and others can so easily take for granted. Despite the separation, this work has deepened my feeling of connection to the Hudson Valley and the wonderful community in which I was raised. This compilation of research, information, and ideas involved countless phone calls, emails, and virtual meetings with many people across more than 100 different organizations. This included educational & research institutions, advocacy & activists groups, policy makers, state & federal associations, and international panels & corporations. I greatly cherish the time shared with each of these individuals, and I am gracious for their shared knowledge, expertise, and encouragement.

My heartfelt gratitude is extended to my friends and family at home and abroad who have encouraged and supported me throughout these endeavors. These connections are filled with the utmost love and sincerity which is interwoven and expressed throughout my everyday character and mindset. My life has been blessed with a variety of unique opportunities, and I have pride and passion combining my diverse interests in innovative and thought provoking ways. From entrepreneurship, to science, to technology, to farming, to music, to production, to theater, to entertainment, to performance, to teaching, to education, to travel, and to spirituality, I am enlightened by the people I work with, the collective absorption of knowledge, and the remarkable results that can emerge.

Trondheim has graced me with a wonderful foreign experience and provided me with many new ideas and perspectives that I am honored to return back to my community. I realized that to learn more about my home, I first needed to learn more about the world. NTNU has played a defining role in my life, and continues to unify my multifaceted interests in ways of which I could have never imagined. Everyday, I am amazed by the diversity of different schools of thought I am exposed to and the cultures from which they emanate. Each lesson requires an important path of due diligence and appreciation for the wisdom others have to offer.

Just as the Hudson Valley gave birth to the modern American environmental movement in the 1960s, we are again positioned to design a system of prosperity and sustainability to inspire the nation. With renewable energies as the primary focus for the future, we have the opportunity to consider new and innovative technologies that will propel and encourage others for generations to come. We can join together in one mission, and share promises of hope, love, and security for the future. May you be inspired.

"Kunnskap for en bedre verden" - "Knowledge for a better world" - NTNU

Table of abbreviations

ABC	|	American Biogas Council
AD	|	Anaerobic Digestion
CHP	|	Combined Heat & Power
CLCPA	|	Climate Leadership and Community Protection Act (Climate Act)
CNG	|	Compressed Natural Gas
CWMI	|	Cornell Waste Management Institute
EIA	|	Energy Information Administration
ESD	|	Empire State Development
FEWWN	|	Food-Energy-Water-Waste Nexus
GDP	|	Gross Domestic Product
GGDP	|	Green Gross Domestic Product
GHG	|	Greenhouse Gas Emissions
GIS	|	Golisano Institute of Sustainability
HTC	|	Hydrothermal Carbonization
HTL	|	Hydrothermal Liquefaction
IPCC	|	Intergovernmental Panel on Climate Change
ISWA	|	International Solid Waste Association
LCA	|	Life Cycle Assessment
LCFS	|	Low Carbon Fuel Standards
LNG	|	Liquified Natural Gas
MGD	|	Million Gallons per Day
MSW	|	Municipal Solid Waste
NOP	|	National Organics Program
NYC	|	New York City
NYCRR	|	New York State Codes, Rules, and Regulations
NYISO	|	New York Independent Systems Operator
NYS	|	New York State
NYSP2I	|	New York State Pollution Prevention Institute
NYS DEC	|	New York State Department of Environmental Conservation
NYS DOT	|	New York State Department of Transportation
NYSERDA	|	New York State Energy Research and Development Authority
POTW	|	Publicly Owned Treatment Work
RFS	|	Renewable Fuel Standard
RIT	|	Rochester Institute of Technology
RNG	|	Renewable Natural Gas
SWMP	|	Solid Waste Management Plan
UCRRA	|	Ulster County Resource Recovery Agency
USA (US)	|	United States of America
USDA	|	United States Department of Agriculture
US DOE	|	United States Department of Energy
US EIA	|	United States Energy Information Administration
US EPA	|	United States Environmental Protection Agency
WBA	|	World Biogas Association
WERF	|	Water Environment Research Foundation
WWRF	|	Wastewater Recovery Facility
WWTP	|	Wastewater Treatment Plant

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Introduction

Climate change mitigation strategies have become a focus of energy discussions in New York State (NYS) as representatives and activists make substantial efforts to reduce dependencies on fossil fuels and implement new sources of green energy. In 2019, the NYS Legislature passed the Climate Leadership and Community Protection Act (CLCPA, or Climate Act) which introduced an aggressive climate change mitigation agenda. The declared objectives include an 85% reduction in greenhouse gas (GHG) emissions by 2050 (relative to 1990 levels), 100% carbon-free electricity by 2040, 70% renewable energy by 2030, and a reduction in 22 million tons of carbon through energy efficiency and electrification.

New York Independent System Operator (NYISO) reports that nearly 90% of the energy produced in the upstate region north and west of the capital is already derived from carbon-free resources while in downstate regions, this portion only represents about 30% (NYISO, 2019). The Hudson Valley is within this downstate region and comprises a series of communities adjacent to the Hudson River that stretch over 100 miles (160 km) from Manhattan to the Capital District. This area covers approximately 7,200 mi² (18,650 km²) and is home to over 2.3 million people. In order to achieve the objectives set out by the CLCPA, innovation and investments are essential in this downstate region. Solutions must be scalable and well-integrated with transportation and utility networks that connect populations between Albany and New York City (NYC).

The technologies identified with the CLCPA initiatives are wind- and solar-power along with energy storage infrastructure. These policy declarations, however, make no mention nor inclusion of bioenergy even though this renewable technology makes up a significant portion of the state's power source and is recognized by the Intergovernmental Panel on Climate Change (IPCC) as a substantial component of the 1.5°C mitigation pathway (IPCC Chapter 2, 2018). Meanwhile, the US Energy Information Administration (US EIA) reports that bioenergy consumption in NYS was estimated to be 165.2 Trillion Btu of biomass in 2018. This figure represents about 4% of the state's total consumed energy and approximately 34% of the energy produced by renewable sources (excluding nuclear). In comparison, that same year, energy consumption in the form of natural gas was 1393.7 Trillion Btu, or 36.08% of the total consumption, and as a result of the Governor's fracking ban within NYS, it was mostly supplied by neighboring states and Canada. Due to the public's large dependency on this particular fossil fuel, organizations such as the US Environmental Protection Agency (US EPA) have encouraged the recovery and production of biogas, a type of bioenergy which can be upgraded to renewable natural gas (RNG) standards and replace compressed or liquified natural gas (CNG or LNG).

New York State Energy Research and Development Authority (NYSERDA) and the Water Environment Research Foundation (WERF) have formerly categorized biogas production as a technology with inadequate payback economics (NYSERDA Biogas Barriers, 2012). However, today, there are new programs such as the Federal Renewable Fuel Standard (RFS) and Low Carbon Fuel Standard (LCFS) from states such as California and Oregon, which allow New Yorkers to capitalize on biogas production opportunities, and access lucrative markets. According to the American Biogas Council (ABC), these programs can value RNG at 3 to 30 times more per MMBTU than natural gas produced from fossil fuels. By taking advantage of these alternative sources of funding and re-framed economics, these former barriers can be overcome to establish and implement a widespread production network. (See APPENDIX 1: Barriers and Mitigation Strategies for additional barriers and mitigation strategies published by NYSERDA and WERF in Biogas Barriers 2012.)

The northeastern US has 18% of the USA's population in 5% of the country's land area. This fact, combined with cold winters and many poorly insulated homes make high energy demand a distinctive feature of the region (Untapped Potential, 2014). The ABC estimates NYS production potential of biogas, also known as renewable methane, to be 52.3 billion cubic feet; an amount which could significantly offset demands for fossil fuels. This is equivalent to a combined 4,379 million kWh electricity and 2,706 million TU/h heat or 679.1 million gasoline gallon equivalents (gge). They claim this energy is similar to removing 5.16 million cars from the road and would generate 882 permanent jobs (ABC NYS Profile). National Grid, a natural gas provider in NYS, has set a precedent for accepting renewable methane via injection into their transmission pipelines. They have also published a report on the potential of RNG to be capable of providing 17% of overall demand (National Grid, 2010). Another NYS provider, Central Hudson Gas & Electric, may create a pilot program to offer customers the opportunity to buy RNG to help subsidize a transition. These are two corporations of many that recognize RNG as a viable alternative to natural gas that can aid decarbonization of the sector (NGA, 2019). Both companies expect this renewable fuel to play a significant role in their future operations.

This report seeks to assess the resource potential for biogas feedstocks for 10 counties in NYS's lower Hudson Valley; Columbia, Dutchess, Delaware, Greene, Orange, Rockland, Putnam, Sullivan, Ulster, and Westchester. By mapping the availability of these bioresources, corporations and policy makers can use this data as a foundation for designing and implementing an integrated bioenergy system throughout the region. Specific legislation, financial incentives, and waste programs can also be enacted to optimize local resource valorization and guarantee consistent and predictable input and output flows.

FIGURE 1: *The 10 assessed counties in NYS (yellow)*

Previous biogas feedstock studies have been conducted with respect to the entire state or specific counties. However, their scope of feedstocks was narrow. NYSERDA has produced several publications which mention opportunities for biogas production throughout NYS, but the feedstocks are limited to sewage sludge, animal manure, and sometimes food waste. Other reports, such as their "Biomass Power Guide," make reference to energy conversion potentials, yet, the majority of this content is focused on the implementation and scaling of bioenergy opportunities related to combustion for heat and power (CHP). In 2017, the Cornell Cooperative Extension prepared an "Organics Recycling Study for Dutchess County" (sponsored by NYSERDA) that examined related potential recycling technologies, locations for resource recovery, and waste-stream analysis. These feedstocks were also limited to sludge from wastewater treatment plants (WWTPs) and excess food waste. The project leaders determined that energy markets at that time were non-conducive for AD (Dutchess Organics, 2017) and there has been no further work. More recently, Westchester commissioned a food waste study which prescribed mid-term and long-term recommendations for co-digestion of food waste at an existing county wastewater recovery facility (WWRF) and/or their Wheelabrator waste-to-energy facility in Peekskill. Similar to studies before them, this analysis was also limited to excess food waste and biosolid feedstocks, yet a public-private partnership was suggested as a go-to-market strategy (Westchester Food Waste, 2020).

This independent assessment of resource potential for biogas feedstocks for the lower Hudson Valley, presented herein, goes beyond the work of these previous studies by widening the scope of biomass harvesting possibilities and examining the production components from a systems perspective. Data and research from global, national, state, regional, and county publications are used to extend these opportunities from excess food waste and biosolids to animal manure, biocrops, invasive species, landfills, and composting. The information is sourced from organizations inclusive of the US Environmental Protection Agency (US EPA), the U.S. Department of Agriculture (USDA), the US Department of Energy (US DOE), the NYS Pollution Prevention Institute (NYS2PI), the NYS Department of Environmental Conservation (NYS DEC), the NYS Energy Research and Development Board (NYSERDA), the Cornell Waste Management Institute (CWMI), and several county solid waste management plans (SWMPs). Through these elaborative efforts, additional benefits of biogas production are revealed that have a greater adherence to a production cycle that models that of a circular economy; a system aimed to eliminate waste and promote the continual use of resources. These qualities are best suited for a community that upholds a high commitment to sustainability.

A food-energy-water-waste nexus (FEWWN) is analogous to the interconnectedness of these sectors. Individual inputs and outputs should be viewed as cogs in a larger cycle where waste from one process is used by the following process. Segregation of these industries would otherwise result in enormous quantities of agricultural and organic waste which are not optimized and discarded. When these material flows are not assigned a future value, there are inherent ramifications to the environment - even when profit margins are not a driving force. The additional feedstocks presented in this work can help to overcome these shortcomings by reimagining an integrated system where opportunities for reuse and recycling are designed to mitigate true costs to the environment while benefiting the local economy. Green gross domestic product (GGDP), or the sum of nominal GDP and the value of all relevant ecosystem services (FEWWN, 2019) is the form of accounting that a multilayered biogas production system can offer the community. This perspective provides a foundation for more in-depth studies which focus on the aggregated benefits, avoided costs, and hedonic values. Thinking in this manner invokes a mindset for building with a long and lasting time horizon, and it inspires a holistic framework to conserve and maximize the region's resources. It is a form of operation which can best valorize the local resources of the Hudson Valley and positively influence the energy and environmental goals envisioned by the state, the country, and the world.

Background

Anaerobic digestion (AD) is the biological decomposition of organic materials in the absence of oxygen. The process is carried out by microorganisms that convert carbohydrates (glucose, fructose, and sucrose) to biogas. This gas product consists of approximately 55% methane (CH4), 45% carbon dioxide (CO2), and trace amounts of other gases like hydrogen sulfide (H2S) (Ulster SWMP, 2020). AD is typically implemented at organic waste management facilities, municipal solid waste (MSW) facilities, wastewater WWTPs, livestock farms, and landfills. Different feedstocks can be combined and processed simultaneously to enhance this process and help to maintain an internal environment conducive for microbial decomposition (EPA Wasted Food Report, 2018).

A variety of pre-treatment methods are necessary for efficient digestion. First, the feedstock must be separated from any inorganic fractions and undergo a mechanical shredding and mixing process. In wet AD systems, water is the primary input as the actual feedstock only accounts for about 15% of the input composition. After the biological process is complete, the extracted biogas can be combusted for electricity and heat cogeneration. For small operations, the biogas typically meets the power and heating demands of the facility. This onsite use is generally the most economical because the biogas achieves full market value.

The remaining slurry is separated into solid and liquids, usually with a screw press. In most cases, the liquid portion is neutralized and discharged to a nearby watershed, but it can also be used as fertilizer and refined to commercial standards for agriculture. The solids are preferably destined for beneficial use through composting and soil application. Otherwise, they are incinerated or landfilled. Additional advantages of this process include reductions in odor, pathogen content, and solid mass reduction (DEC Beyond Waste, 2010).

Excess food waste

Organic food waste is characterized by food scraps from households, restaurants, caterers, retail premises, and comparable waste from food processing plants. It excludes by-products of food production that never become waste (ISWA Global Assessment, 2020). The EPA has published a "Food Recovery Hierarchy," displayed in FIGURE 2, which conveys how this waste should be reutilized and prioritized to improve consumption efficiency and mitigate losses. After source reduction, food banks, and animal feed, excess food waste should be allocated to industrial uses. This includes fuel conversion technologies, such as AD, to recover useful energy.

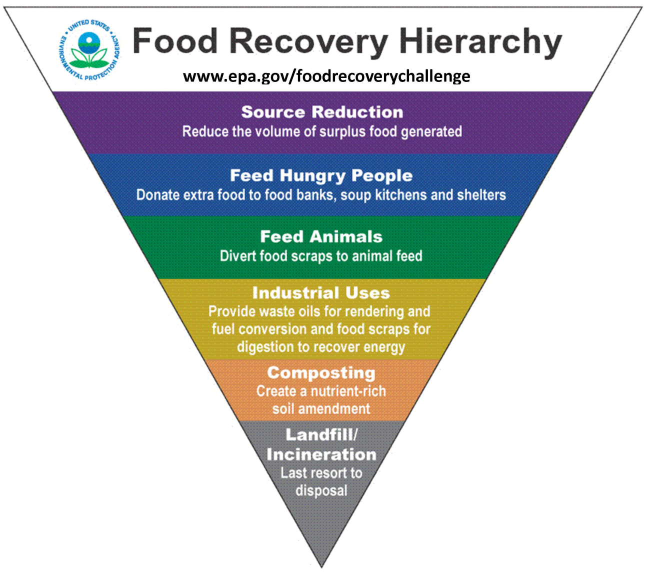


FIGURE 2: *The US EPA's food recovery hierarchy*

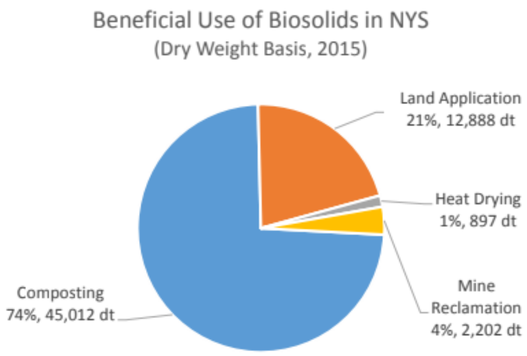
Food waste that is not diverted at the source of generation is combined with all other municipal solid waste (MSW). This collective waste stream includes many other non-organic materials generated by the residential, commercial, and institutional sectors. It excludes construction and demolition debris and biosolids except if they are commingled, according to NYS Codes, Rules, and Regulations (NYCRR) Part 360. Unless MSW waste is sorted by a specialized waste management facility, all of this material is landfilled or incinerated. These end uses are at the bottom of the hierarchy and therefore of last resort. According to county solid waste management plans (SWMPs), most of the waste that is generated in the lower Hudson Valley ends up in landfills located in the northwestern and western regions of the state. This implies several hours of hauling for loads to reach these destinations and a plethora of additional anthropogenic impacts to the environment.

Localized biogas production would eliminate a significant portion of this transport activity and conserve the food's inherent energy content and nutrients within our local economy and ecosystem. Many operations throughout the country are already diverting this valuable waste stream to capture its available energy. An EPA nationwide survey of 126 food waste-accepting AD estimated a total of 10.7 million tons of food waste were collected and processed through recovery facilities during 2016 (EPA Wasted Food Report, 2018). The Hudson Valley is well-positioned to contribute to these recovery efforts and implement relevant technologies at a variety of locations throughout the 10 counties.

Biosolids

Biosolids are the organic material byproduct of WWTPs. Their characteristics vary depending on the sources of wastewater and can be in solid or semi-solid form. AD is a widely utilized and accepted way of stabilizing this sludge material. The resulting biogas is attractive for RNG projects due to its high CH_4 content and extremely low N_2 and O_2 contents (EPA RNG, 2020). WWTPs tend to be publicly owned, and offer a prime opportunity for resource valorization where AD technology is not already implemented.

Biosolids may contain contaminants such as heavy metals and pathogens that may be detrimental to the environment if not properly controlled. In NYS, regulations with respect to the recycling of biosolids are currently defined and managed by both state and federal agencies (DEC Biosolid Facts). According to the 2018 Biosolids Report produced by the NYS DEC, about 16% of dry weight biosolids, or roughly 60,999 dry tons from publicly-owned treatment works (POTWs), or WWTPs, were directed to beneficial use in 2015; composting, land application, mine reclamation, and heat drying (NYS DEC Biosolids 2018). FIGURE 3 displays the beneficial use allocation for that year. Meanwhile, that same year, about 16% of biosolids were directed to incineration, and 68% were disposed of in landfills. FIGURE 4 shows the change in these proportions since 1988. Note that a significant decrease in beneficial uses occurred around 2010 due to the closure of over 15 facilities. A biogas network with a variety of feedstocks may offer additional opportunities to apply a larger portion of this nutrient rich material to beneficial uses and repair the positive trend that NYS used to be on track with.



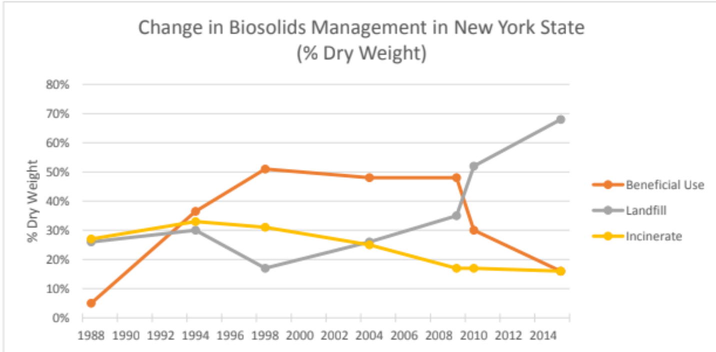


FIGURE 3: *NYS beneficial use of biosolids*

FIGURE 4: *NYS beneficial use of biosolids over time*

Livestock

Over the past several decades, the number of livestock operations in NYS have tended to decrease and become more concentrated. A consequence of these high animal density areas is the mass accumulation of manure. While this organic substance has traditionally been composted or combined with crop residues and applied to the land, the overabundance can become so great that farmers are incapable of distributing it to local crops and pastures. Alternatively, it is stockpiled, but this poses a pathogen risk to nearby watersheds and a nutrient concentration that exceeds the carrying capacity of the land (DOE Billion-Ton, 2016). To solve this problem, many farmers seek to decompose and stabilize this material through AD.

According to the USDA's National Agricultural Statistics Service, in 2012, NYS had approximately 625,000 dairy cows making it one of the nation's leading producer states. These animals generate an estimated 12 million tons of manure each year (NYS DEC Beyond Waste, 2010). Every day, a dairy cow can be expected to produce an average of 82 lbs of manure for every 1000 pounds lightweight (Midwest Plan Service, 1993). This equates to approximately 0.25 tons per week and 15 tons per year per animal. (Specific quantity estimates per animal weight are displayed in FIGURE 5 along with nutrient contents.) The Energy Information Administration (EIA) (a branch of the USDA) currently lists 26 ADs installed for these operations across NYS. FIGURE 6 displays the location of these facilities by county with the most being located in Cayuga and Wyoming. The oldest system was built in Tioga County in 1998 and the newest system was built in 2012 in Washington County. There are several digester types installed that include covered lagoons, horizontal plug flow, and mixed plug flow. All together, this services the manure from over 33,400 dairy animals with some systems incorporating co-digestion of other organic waste streams from various food processing industries.

Cow	Total manure production			Nutrient content, lb/day		
Size lb.	lb/day	ft3 day	gal/day	N	P2O5	K2O
150	12	0.19	1.5	0.06	0.02	0.05
250	20	0.32	2.4	0.10	0.04	0.08
500	41	0.66	5.0	0.20	0.08	0.17
1,000	82	1.32	9.9	0.41	0.17	0.32
1,400	115	1.85	13.9	0.57	0.23	0.46

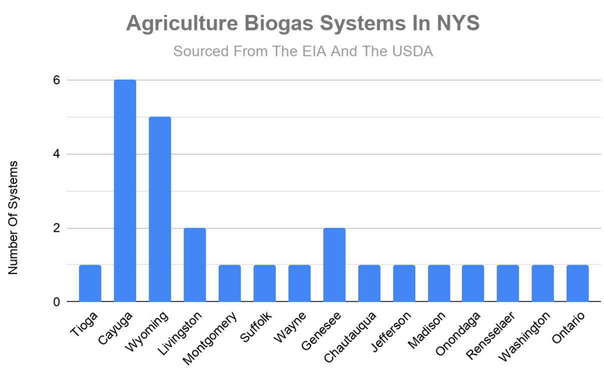


FIGURE 5: *Manure averages (Manure 1984)*

FIGURE 6: *NYS agriculture biogas systems*

According to the EIA, these operations produce approximately 2.45 million cubic feet of biogas every day. If only the animal population is considered for determining end use proportions of this renewable methane, this would equate to approximately 50% that is used for cogeneration and 35% used for electricity. FIGURES 7 and 8 depict the animal populations that are responsible for producing this biogas and the proportional end use allocation. About 14% of this total is not valorized and flared full time. This may be due to inadequate financing opportunities to invest the resources to upgrade these facilities (AD Funding, 2018). In many instances, the labor and maintenance resources are not available to justify on site energy capture. This is not uncommon to farmers throughout the country as the US DOE estimates nearly 1.5 billion cubic feet of digester gas from livestock farms are flared each year that could be recovered for energy. However, new financing initiatives and legislative mandates for renewable fuels are changing this perception and creating new opportunities for sustainable business models that include carbon credits and distribution to virtual utility grids.

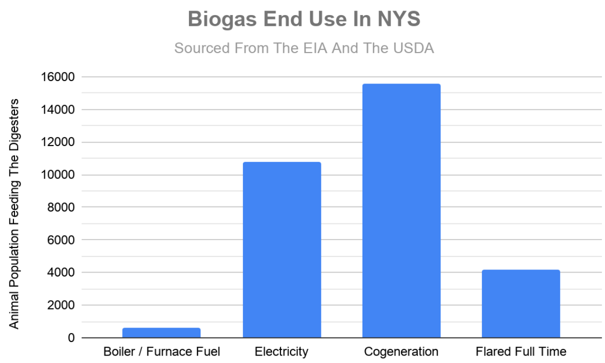


FIGURE 7: *Biogas end us in NYS by population*

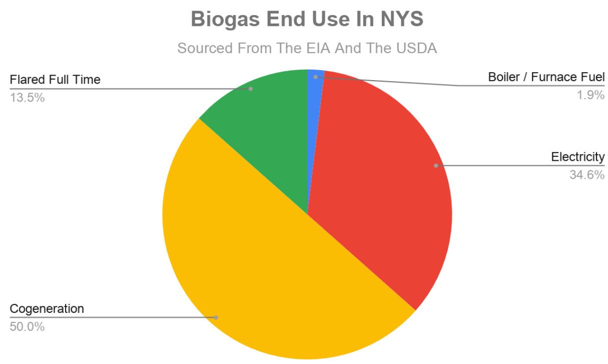


FIGURE 8: *Biogas end use in NYS by proportion*

Biocrops

In a 2016 report, the US Department of Energy (US DOE) estimated that the USA has the potential to produce at least 1 billion dry tons of biomass resources annually by the year 2040. This is more than 2.5 times the 365 million dry tons that are currently being produced. Untapped resources are suspected to emerge in the form of agricultural residues, waste, and forests that will complement energy crops, algae, and other feedstocks in this sector. This proposal is garnered by the premise that the bioeconomy can be designed in a way to be productive, profitable, and environmentally beneficial so that it can meet the growing demands for food, feed, fiber, and fuel (DOE Billion-Ton, 2016). Local production of these crops would also reduce reliance on fossil fuels and benefit the local economy through a new revenue stream (Untapped Potential, 2014).

IMAGE 1: *AD (Bioeconomy, 2020)*

Germany is one country with a well-developed bioeconomy that is allocating a significant portion of their biomass to the production of biogas. These developments were, in part, fostered by legislation through their Renewable Energy Act (EEG). In 2016, they had approximately 8,075 biogas plants in operation with a total installed capacity of 4.1 GW. At that time, 182 of these facilities were injecting their refined biomethane into the natural gas grid. The country continues to modernize more of their network to include this infrastructure. Maize is the primary biocrop used in their system due to a variety of advantageous qualities; high methane yield, digestibility, optimized growth, harvest logistics, and silage (Sustainable Biocrops, 2016), but there are potentially better alternatives.

Perennial grasses

The northeastern US has a climate with abundant rainfall and mild seasons. Precipitation tends to vary between 30 and 60 inches (760 and 1,520 mm) and temperatures typically range from 35 to 60°F (1.7 to 15.6°C). These qualities are comparable to the corn- and wheat-producing regions of the Midwestern US and conducive to growing bioenergy crops (Untapped Potential, 2014). While NYS is capable of expanding its corn production to provide biomass for biogas production, developing a strong reliance on this crop could lead to environmental problems and a low acceptance in public opinion. Annual cultivation is associated with high risk of erosion along with many negative impacts to biodiversity. In addition, high nitrogen fertilizer input can lead to groundwater pollution and deterioration of soil organic matter (Sustainable Biocrops, 2016). However, perennial grases offer some significant opportunities for this sector .

IMAGE 2: *Switchgrass (Penn State)*

There are two species of perennial grasses which have characteristics that are desirable for the Hudson Valley and contrast the disadvantages of corn and maize varieties. The US DOE has identified switchgrass (Panicum virgatum) as one of the most promising species suitable for the USA, and it is very capable of thriving in NYS. This plant contains a low ash content and has the best production on well-drained and sandy loam soils (Penn State Switchgrass).

Miscanthus is another perennial grass that shows promising biofuel feedstock properties for NYS. It is a tall reed that is a close relative of sugarcane. It is capable of withstanding cold conditions and poor soils. Some varieties can reach heights of up to 12 ft and have been shown to produce an annual average of up to 8 to 12 tons per acre. While this plant is a non-native species from Asia, there is a hybridized strain available that is sterile (Penn State Miscanthus). Miscanthus *x giganteus* is a variety observed for over two decades in Europe that did not produce any fertile seeds or escapes (Sustainable Biocrops, 2016).

IMAGE 3: *Miscanthus (Penn State)*

Both species have relatively low establishment and maintenance costs compared to other energy crops. There are also USDA programs available to support farmers with these perennial options. In contrast to corn, these species reduce soil and water erosion and provide an improved wildlife habitat for what otherwise may be idle farmland or marginal lands. One study conducted with miscanthus demonstrated a higher abundance of insects, spiders and earthworms than in arable land. It also offers niche environments for birds and other fauna. Similar effects can also be expected for Switchgrass, which suggests that these crops would increase the biodiversity of agricultural landscapes (Sustainable Biocrops, 2016). In addition, their deep root structures can extend down to 8 feet into the soil. This improves drainage and facilitates carbon restoration. Carbon sequestration in this form may be eligible for carbon credits in the future (Penn State Switchgrass Budget) which would further promote investing in this source of biomass. In the event that the crop is not harvested for bioenergy, farmers can have the security of a livestock grazing area that will outlast and outperform other grasses during hot, dry summers (Sustainable Biocrops, 2016).

Available lands

Sustainable production of biomass makes use of multi-functional landscapes that, in some cases, may be unusable for the production of food. Over two million hectares of marginal land in the northeastern US are no longer used for agriculture. Second generation cellulosic biocrops could take advantage of these idle lands and avoid competition with other crops. A significant amount of this area in NYS is due to degraded soil quality that resulted from poor farming practices in the 1800s. During that time, topsoil was lost to erosion and fertilizers were no longer effective. Abandonment ensued and was accelerated with the availability of more fertile lands to the west (Untapped Potential, 2014). The introduction of biocops to these areas would generate a valuable feedstock while simultaneously repairing soil health, improving water retention, and restoring carbon content (BR&D Bioeconomy, 2016). It would also offer an end-point destination where digestate can be deposited to the land and nutrient byproducts can be recycled. Any potential contaminants would be subject to a closed production loop and segregated from other farming activities.

Landfills

The EPA estimated that, in 2018, 24% of landfilled material was due to organic food waste; more than any other material in everyday refuse. Methane gas results as this matter undergoes AD within the landfill. The process occurs on a much longer timeline than industrially controlled AD because of absent mechanical mixing and decreased moisture composition. First, aerobic bacteria consume the oxygen and begin the breakdown of the organics. This can last for days or months depending on parameters such as oxygen content and temperature. Once the oxygen is depleted, AD ensues and creates a more acidic environment. As methane-producing bacteria begin to establish themselves, the pH becomes more neutral. Ultimately, a fourth phase will be reached in which decomposition becomes more constant and the gas byproduct reaches a more static composition. This final, methanogenesis stage, begins after approximately two years and will produce 45 to 60% methane, 40 to 60% carbon dioxide, and 2-9% other gases such as sulfides. FIGURE 9 provides a graphical representation of the gas composition and its variation over the four aforementioned phases. This production will typically continue for about 20 years, however, it is different for every landfill. In some cases, the gas will continue to be emitted for over 50 years (NYS DEC Beyond Waste, 2010).

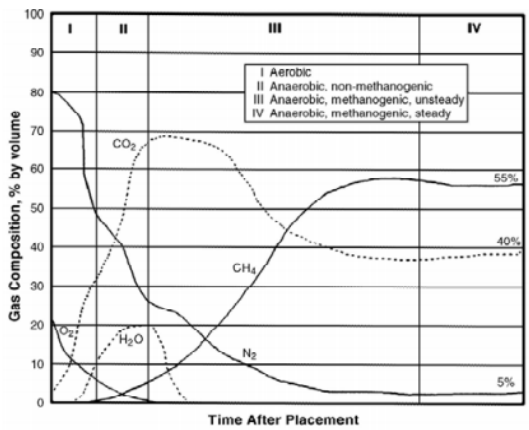


FIGURE 9: *Landfill off-gas concentrations*

The EPA estimates that 20% of U.S. methane emissions emanate from landfills (EPA Wasted Food Report, 2018). Diverting organic matter prior to landfilling is the preferable action according to the food pyramid hierarchy, however, valorizing these materials after they have been landfilled offers an opportunity to take advantage of this naturally occurring AD and collect the biogas for industrial application. NYS DEC regulations require this gas to be combusted to convert the methane into carbon dioxide (which has a lower short-term GHG impact). In many cases, this requirement is met through flaring, however, it's more advantageous to combust the methane to generate electricity or power an engine. Application further mitigates GHG emission by reducing the need for this power generated by alternative sources.

Invasive species

NYS has been exposed to a large variety of invasive plant species which have negatively impacted land and water ecosystems in addition to recreation and tourism. Each year, public taxes help fund management and removal efforts throughout the state. Unfortunately, these actions have not been able to mitigate the prevalence of these plants. Current management of select species includes manual and mechanical harvesting as well as chemical methods, or herbicides. There are several aquatic infestations which are highlighted for their severe impacts (DEC Invasive, 2018). Utilizing these select species as a feedstock for AD in the Hudson Valley is an alternative management option that would serve as an economic driver for ecosystem restoration efforts throughout the Hudson River watershed.

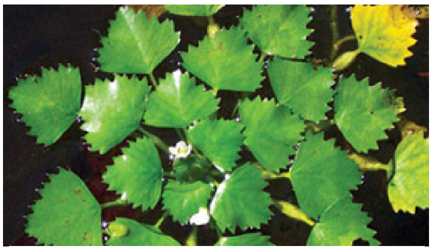


IMAGE 4: *Water chestnut (NYS DEC)*

Water chestnut, or *Trapa natans*, is native to Eurasia and Africa and was introduced into the US in the mid-1800s as an ornamental plant. Today, the NYS DEC has recorded its presence in 42 out of 62 counties throughout the state. The plant thrives in freshwater lakes, ponds and slow-moving streams and rivers. It establishes a long root network that anchors to the bottom of the waterbody (DEC, Water Chestnut). NYS DEC is currently funding research on biocontrol which is examining the effectiveness of predator insects (DEC Invasive, 2018). AD offers a treatment methodology that wouldn't risk the introduction of a foreign insect into our local environment and mitigate the use of herbicide applications.


IMAGE 5: *Hydrilla (NYS DEC)*

Hydrilla *verticillata*, or more commonly known as "water thyme," is another invasive aquatic plant species from Asia. This plant grows up to an inch a day establishing itself along lake and river beds and extends a series of intertwined stems and leaf structures up to the surface. Waterfowl feeding areas and fish spawning are adversely affected as a result. In addition to disrupting the water flow, hydrilla also decreases the amount of dissolved oxygen in the water. It is identified by the USDA as a federally noxious weed and the NYS DEC has reported that it is one of the most difficult aquatic invasive species to control and eradicate in the US. It was once a popular aquarium plant, but it was recently prohibited from sale or possession in NYS (DEC Hydrilla, 2020) due to its escape to the local environment. Harvesting for use with biogas production could serve as an eco-friendly removal process.


IMAGE 6: *Phragmites (Cornell)*

There are at least three strains of common reed in the US. Phragmites australis subsp. *americanus* is one which is native to North America and is found throughout NYS. Another strain is non-native and was accidentally introduced from Europe in the late 18th or early 19th century in ship ballast. This invasive plant is now the most common phragmites found in NYS as well as the Northeast, and it has been identified in marsh lands throughout the lower Hudson Valley. It is a perennial that can reach over 15 feet in height and is often found in dense clonal stands made up of living and dead stems (Cornell Phragmites). This invasive has qualities similar to switchgrass and could be destroyed through AD. At this time, there is no field evidence of hybridization with the native phragmites.

Composting

There are many institutions that currently separate their excess food waste from their MSW. If it is not suitable for food banks, the waste is provided to local farms for animal feed. If this is not a viable option, it is composted. Herein lies an opportunity to introduce AD as an intermediary process. Composting is the aerobic biological degradation of solid organic wastes maintained with controlled conditions such as temperature and moisture content (Ulster SWMP, 2020). Diverting this organic waste stream for the industrial process of biogas production offers an opportunity for additional resource valorization and it abides by the food waste hierarchy. The resulting digestate would undergo subsequent aerobic stabilisation at the composting facility and rejoin established distribution markets. There is precedent for combining these processes and related infrastructures throughout the world (ISWA Global Assessment, 2020). AD can shorten the time necessary for complete decomposition of the organics and provide an additional revenue stream.

Methods

The following analysis of available biogas feedstocks reflects a compilation of data from a variety of national, state, regional, and institutional sources. There are a total of 7 categories investigated; food waste, biosolids, livestock, biocrops (with respect to land availability), landfills, invasive species, and compost. Each section provides a detailed investigation of these resources in the 10 identified counties located within the lower Hudson Valley of NYS; Columbia, Delaware, Dutchess, Greene, Orange, Putnam, Rockland, Sullivan, Ulster, and Westchester. Quantitative analysis has been conducted with respect to studies that have available numeric measurements or estimates of the feedstock category. If this data is not available, a qualitative approach is presented. Each category represents a potential component of an integrated AD system that can be designed to maximize resource valorization and facilitate the energy goals of the CLCPA.

Excess food waste

The quantity of food waste has been estimated from two perspectives; the generation source at the entity and the end point at the waste management facility. Conducting an analysis with respect to each of these measurement methods provides an opportunity to compare output and input flows and develop an improved estimation that is more likely to reflect the real amounts. The source analysis only includes food data from commercial entities while the end point analysis represents a collection of complete MSW waste streams that includes both residential and commercial sources. Therefore, food waste estimations at the end source are expected to be much higher than the estimations which represent the generation source due to the residential component. A data extrapolation is done at the end of each analysis to attempt a complete comparison.

Source analysis

New York State Pollution Prevention Institute (NYS2PI) is an organization funded by Empire State Development (ESD) that offers services related to food waste management, technology commercialization, supply chain analysis, and life cycle assessment (LCA). They are sponsored by the NYS DEC and led by the Golisano Institute of Sustainability (GIS) at Rochester Institute of Technology (RIT). Their website has an organic locator tool for NYS with estimations of generated excess food waste for thousands of commercial entities throughout the state. Data from 2018 was downloaded and filtered to aggregate food waste estimates for each of the 10 selected counties. Each entry is assigned to 1 of 5 sectors; food processors, hospitality, institutions, restaurants, and retail. For this study, each of these categories were aggregated, compared in two different ways, and presented in graphical form; first, with respect to each other and second, with respect to each county. This strategy is used to determine the sectors which are the highest generators of waste. The results are presented either with respect to total mass or in terms of proportional amounts. In this way, sectors responsible for significant amounts of excess food waste in the less populated counties are normalized with respect to overall proportions of excess food waste in sectors within counties that have higher generation rates. NYS2PI has also labeled each entity with a respective industry sub-category within each sector. For example, there are 4 different industries in the institutions sector; colleges & universities, commercial facilities, hospitals, and nursing homes. In comparison, there are 13 industries within the food processors sector. Following the initial sector analysis, this study proceeds with a similar investigation of excess food waste by industry to further refine the identification of primary generators of excess food waste.

The US EPA also has a published data set of estimated excess food waste generated per entity for 2018. These metrics are also considered in this analysis in order to provide a comparative source of information to weigh against the estimates inferred from NYS2PI. The categorization wording of the US EPA's data is slightly different than that of NYS2PI's, so an effort has been made to reconfigure the identifier names and categories of the US EPA data to align with those of NYS2PI. Specifically, the US EPA assigns each entity to 1 of 7 sectors; correctional institutions, educational institutions, healthcare & facilities, food manufacturers & processors, food wholesale & retail, hospitality, and restaurant & food services. The data has been combined to reduce the number of categories to 5. This was done by summing the data from correctional institutions, educational institutions, and healthcare & facilities into a single 'institutions' sector. This strategy is appropriate because each of these institution types are also classified as industries within this sector of the NYS2PI data. The specific names of these US EPA sectors have also been modified in this report to visually align with the NYS2PI sector names.

The US EPA's metrics present two estimates of how much excess food waste each entity generates; one low estimate and one high estimate. When the data is aggregated for all entities within each sector, the differences in these two values can be substantial and have significant variations relative to each category. For example, on a per county basis, the smallest difference between high and low estimates was with correctional institutions where the high estimate amount is approximately 1.8 times the low estimate amount. Meanwhile, the remaining sectors have high estimates that are approximately 3 to 5 times greater than the low estimates. An extreme exception far outside these bounds is exhibited with the food wholesale & retail sector. In this category, the high estimate is approximately 50 times greater than the low estimate. In lieu of these variances, a conservative approach has been taken by only analyzing the low estimates. In this way, there can be greater certainty that the conclusions formed by this study represent quantities of food waste that can be guaranteed to be generated with a high degree of confidence. Therefore a system of ADs can be designed with this capacity and ultimately expanded to accommodate additional higher volumes and additional flows. One more note is that the US EPA's data is provided as annual estimates, so it has been divided by 52 to allude to total weekly tonnages that can be compared to the weekly tonnage estimates provided by NYS2PI.

One entity, Pepsico Inc, has been removed from the EPA data analysis because it is an obvious outlier. This company is categorized in the soft drink industry of the food processing sector in Westchester County and skews the entire data set. It is estimated to produce 350 tons of excess food waste each week, on its own, which is almost equal to all of the other excess food waste produced by all of the other food processors throughout the county. Further investigation into this company should therefore be conducted to determine the accuracy of this figure and assess the viability of capturing this waste stream for the purpose of biogas production. No other anomalies were removed or discarded from the data representation.

End point analysis

Of the 10 counties examined, only 7 have published and available solid waste management plans (SWMPs); Delaware, Dutchess, Orange, Putnam, Rockland, and Ulster. Some of the publications are as old as 2010. Columbia, Greene, and Sullivan do not have any published materials with MSW estimates and therefore are not included in the results. For Westchester, a food waste study published in 2020 for the county has some end point analysis data that was used for this study. It has estimates for the total amount of processed MSW.

In 2010, the NYS DEC, in their Beyond Waste report, estimated that food scraps make up a concentration of 17.65% of the state's MSW waste stream. There have since been many awareness campaigns and public efforts throughout various NYS counties to divert food waste and attempt to mitigate this percentage. However, this proportion will be used for this analysis to compare with estimations calculated by means of the other aforementioned methods. The total quantity of MSW generated on an annual basis has tended to increase over the past 10 years as is apparent from the data available in recently published SWMPs. Therefore, this NYS DEC's estimate, when applied to these outdated estimates, likely represents a smaller fraction of mass than the same metric applied to today's actual values. NYS DEC also estimates that 54% of the MSW generated statewide is residential and 46% is commercial/institutional. Since the data from NYS2PI and the US EPA only represent excess food waste generated from commercial entities, these proportions are applied to the end point estimates to aggregate and compare the different quantification approaches.

Biosolids

The NYS DEC surveys all publicly-owned treatment works (POTWs), or WWTPs, in NYS concerning their biosolids management practices about every 5 years. The latest survey completed by these facilities reflects data from the 2015 calendar year. A total of 580 POTWs completed the survey (95% of those surveyed) throughout NYS. This represents 99.7% of the total design flow rates and approximately 2,400 MGD (million gallons per day). The flow rate for the entire state is approximately 2,400 MGD with most facilities averaging less than 1 MGD (DEC Biosolids, 2018).

The survey requested information concerning the wastewater treatment process, the quantity of flows, treatment methods employed, management of the generated biosolids, and other general topics. Facilities were also able to list questions and concerns surrounding biosolids management, as well as inform the NYS DEC of any upcoming changes to their treatment processes. Due to the state's interest in reducing the amount of food scraps sent to landfills and incinerated, the survey also asked if they were considering adding this waste stream to their treatment systems in the future. A copy of the survey is included in APPENDIX 2.

One entry error was realized in the Delaware County data because it is recorded as an extreme outlier. Specifically, the Delhi POTW is noted as having generated 25,300 dry tons of biosolids in 2015. This was calculated as the 11% portion of the 230,000 wet tons value provided in the survey response. However, the Walton POTW manages about 50% more flows than Delhi and generated only 388 dry tons that same year which is an amount more fitting with the rest of the data. Therefore, it seems reasonable to assume that a decimal point error was made and the actual amounts are 2,300 wet tons and 253 dry tons. Corresponding landfilled and composted values are therefore 10% and 90% of this dry ton amount, respectively.

Animal manure

When selecting which farms to build an AD, primary candidates are generally considered to be dairies with at least 500 cows. However, this is a rough estimate that accounts for general manure production rates, and smaller operations have also been successfully developed into beneficial use applications. Swine facilities with at least 2,000 sows or feeder pigs should also be considered as primary candidates for AD (EPA RNG, 2020). The US EPA does not identify any thresholds for concentrated horse and poultry feeding operations, so they will also be mentioned in this study and identified as operations that require their own AD viability assessments. Data from NYS2PI on concentrated feeding operations and number of animals is used to identify which counties have these resources potentially available for energy capture.

Biocrop land availability

Farms are the first category of land type considered for this study. The USDA contains a data set of the number of acres of farmland in each state by county. This information is updated about every 10 years, however, the most recent available data is from 2007. Farming should be prioritized for food production, but land that is not in use could be considered for growing secondary biocrops in a biogas production market. Only a small fraction of the total may be available for crops such as miscanthus and switchgrass, therefore, this amount provides a metric of comparison and total market size for future investigations.

Land Trusts & Conservancies also present viable land opportunities to establish biocrops. Whether their land has been purchased or remains under private ownership, these designated spaces will remain undeveloped for the purpose of environmental preservation. Metrics for the total amount of land that is overseen by these organizations was gathered from their individual websites. Sometimes there are several different land parcels listed. These were combined to produce an aggregate figure for each organization. Much of this land is forested and thus not available for biocrops, however a significant portion is dedicated farmland or idle. These organizations were individually contacted to gain insight on the proportions of land types in their respective portfolios. However, this level of detail is not available at this time and would be valuable to investigate in the future.

Idle & marginal lands have also been investigated. The USDA has estimates in regards to the quantity of idle land throughout the state and how it has changed over several decades. However, they do not make any distinctions as to how much of this land may be of marginal quality. Therefore, a qualitative approach has been taken for this category. Information about the potential for these areas, which are prevalent throughout the state and available for bioenergy crops, has been extracted from a variety of publications and mentioned.

Environmental remediation sites and brownfields may also qualify as available land to introduce to biocrop production. The NYS DEC maintains a database of these site classifications and locations. This study limits the investigation of these areas to the quantity of sites in each county as well as the specific assignment of contamination type. Additional research will be required to determine the feasibility of these opportunities and the specific classifications that would be acceptable for secondary biocrops and relevant studies.

Landfills

Information about landfills within the Hudson Valley has been gathered through county SWMPs. However, there are likely many which are no longer mentioned because operation ceased many years before the documents were published. The US EPA has published information about local landfills in the Hudson Valley that was also used for this analysis. The data includes details regarding locations and how their methane emissions are being managed. Additional investigation is necessary to confirm the complete number of sites and their locations, many of which may be privately owned and managed. There are likely many landfills not listed with data that may be available for energy recovery.

Invasive Species

The NYS DEC provides information about invasive species which have infested NYS. They have a published a series of reports and management plans which have served as a foundation for assembling relevant information on this topic; NYS Prohibited and Regulated Invasive Plants (September 2014), Aquatic Invasive Species Management Plan (July 2015), and NYS Invasive Species Comprehensive Management plan (November 2018). Their website also provides general information about where these species have been reported and efforts that are currently being implemented to mitigate their spread.

Hudsonia is a not-for-profit organization that shares facilities at the Bard College field station; laboratory, library, boats, field equipment, etc. They have conducted environmental research, education, training, and technical assistance to protect the natural heritage of the Hudson Valley and neighboring regions since 1981. Their projects are funded by a variety of public and private sources. Members of their organization have authored many science journal publications on invasive species. This report specifically references several of their publications on water chestnut and phragmites. One paper also examines the potential of utilizing phragmites for the production of biogas (Phragmites Bioenergy, 2014). Satellite imagery has been used to provide a pictorial representation of the size of marshlands where infestations have been observed according to these research papers. Additional investigation and study will be necessary to determine the amount of available biomass.

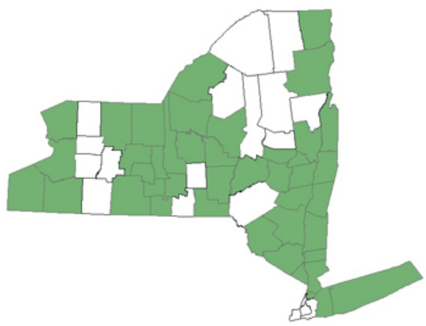


FIGURE 10: *Water chestnut infestations*

The Beacon Institute for Rivers and Estuaries, which is the Hudson Valley campus of Clarkson University, is currently conducting a viability-based control method of invasive water chestnut by means of AD. This study involves mapping various infestation locations throughout NYS and estimating the total amount of biomass infiltrating waterways. They are using aerial and underwater photography to establish metrics for growth rates, nutrient uptake dynamics, and life cycle. Communication with the project's leader has aided the content and idea formulation for this study in regards to the inclusion of this species as potential biogas feedstock for the Hudson Valley. They plan to publish a paper on their findings which can be referred to once it is released. In the meantime, satellite imagery has been used for this report to specify large infestation patches on the Hudson River. They are easily identifiable due to their color and coastal locations. FIGURE 10 shows the counties throughout NYS where the presence of water chestnut has been recorded.

Composting

Cornell Waste Management Institute (CWMI) is a public service program hosted by the College of Agriculture and Life Sciences at Cornell University. More specifically, they are in the Soil and Crop Sciences Section of the School of Integrative Plant Science. Their NYS Compost Facilities Map is hosted on their website and is displayed in FIGURE 11. This tool provides a variety of information about compost facilities throughout the state including their ownership, primary feedstocks, permitting, and many more specifics. The corresponding survey, however, did not investigate the quantity of material flows that are imported and exported from each facility. Therefore, no information has been included in this study with respect to potential feedstock quantities. The source data for this map was used to determine the locations and types of compost facilities that are operating throughout the 10 counties. This information can provide the foundation for future biomass transportation and logistics research that would accompany the design of an integrated system of biogas production.

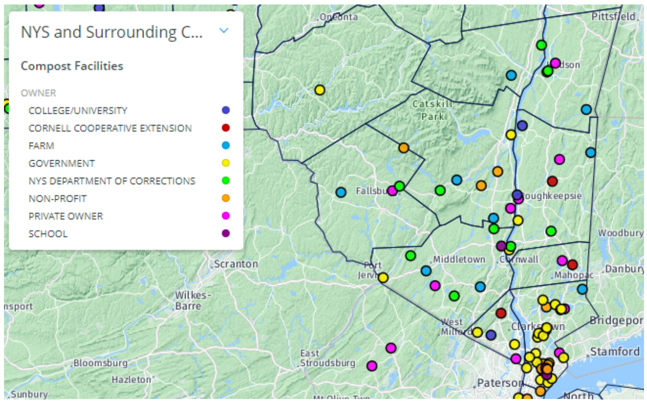


FIGURE 11: *CWMI's NYS compost facilities map*

Results

The following results represent a compilation of quantitative and qualitative analyses derived for the following biogas feedstocks in the lower Hudson Valley. An assessment is presented from gathered data with respect to excess food waste, biosolids, livestock, biocrop land availability, landfills, and compost facilities. Complete tables conveying the concluded data are available in APPENDIX 3.

Excess food waste

First, the source analysis is presented with the data from NYS2PI followed by the data from the EPA. Then, the end point analysis is conducted for the counties which have published data . Finally, these perspectives are aggregated and compared to each other to reveal differences in the estimation methods.

Source analysis

Westchester is the most populated of the 10 examined counties, and FIGURE 12 reflects that it generates the greatest amount of excess food waste. Orange is also a densely populated area and produces about half as much excess food waste as Westchester. Columbia and Delaware are very rural environments, by contrast, and produce a much smaller fraction of the total excess food waste. Important insights can be gained by investigating the specific industries which generate food waste within each county. Columbia, Dutchess, Greene, Orange, Rockland, Sullivan, and Westchester (7 out of 10 counties) each generate 25 to 70% of their food waste from the food processors sector as can be seen by FIGURE 13. This source of organics equates to approximately 1000 tons per week or about 38% of the total estimated available. Delaware, Dutchess, Greene Orange, Putnam, Ulster, and Westchester produce 25 to 60% of their excess food waste from the retail sector or 24% of the total estimated available. The combination of these two NYS2PI sectors culminates to 1,640 tons, or 62% of the total generated excess food waste estimate.

FIGURE 12: *County food waste (NYS2PI)*

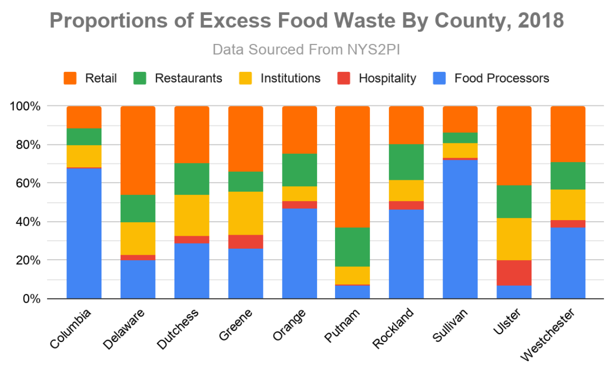


FIGURE 13: *County food waste % (NYS2PI)*

According to the US EPA's low estimates, all 10 counties produce about 1,400 tons of food waste per week (FIGURE 14). This is 53% of the NYS2PI estimate. Columbia, Delaware, Dutchess, Putnam, Rockland, Sullivan, and Westchester (7 of 10 counties) each generate 40 to 65% of their food waste from the restaurant & food services sector which equates to approximately 450 tons per week or about 32% of the total. Orange, Rockland, Ulster, and Westchester (4 of the 10 counties) each generate 25 to 50% of their food waste from the food manufacturers & processors sector which equates to approximately 425 tons per week or about 30% of the total (FIGURE 15). These aggregate to 875 tons per week or 62% of the total excess food waste.

FIGURE 14: *County food waste (US EPA)*

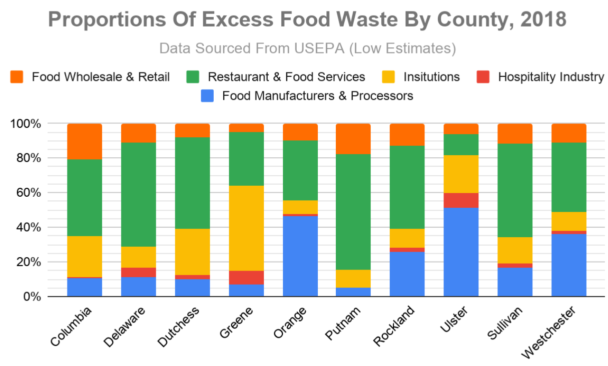


FIGURE 15: *County food waste % (US EPA)*

Each data set identifies the food processing sector as a primary generator of excess food waste, but they differ with their estimations of the restaurants and retail industries. The remaining investigations of excess food waste will only include data from NYS2PI, however, the restaurant sector will also be explored as a result of this finding with the US EPA (FIGURES 16 and 17). The institution sector, from NYS2PI, is also investigated because it generates an amount of food waste relative to the restaurant sector.

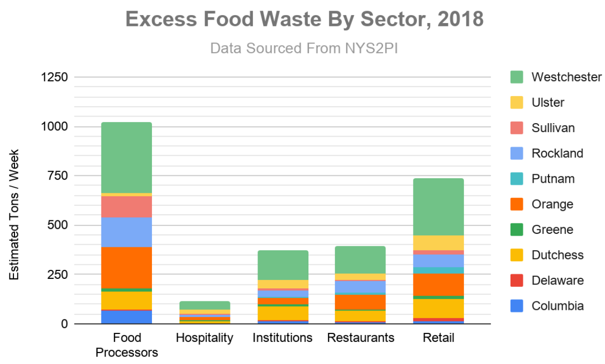


FIGURE 16: *Sector food waste (NYS2PI)*

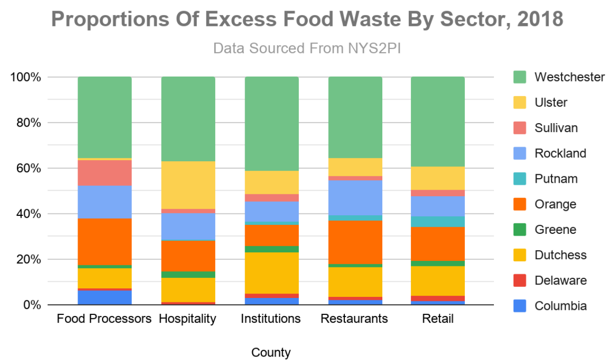


FIGURE 17: *Sector food waste % (NYS2PI)*

Food Processing (FIGURES 18 and 19)**:** According to NYS2PI, bakeries and the aggregated miscellaneous category make up the largest portion of this sector each representing about 25% of the total excess food waste. However, for a practical implementation of a food waste diversion plan, it may be difficult to identify and coordinate a miscellaneous grouping of businesses. Therefore, this category will not be considered to be a high priority market. Of the bakeries in each county, Dutchess, Orange, Rockland and Westchester, represent the largest producers at 250 tons per week which is 24% of the total 1,024 tons produced. Sullivan County has the greatest amount of waste produced from meat processing and represents 90 tons or 9% of the total. Wineries in Orange, Ulster, and Westchester counties represent about 70 tons or 7% of the total. Breweries in Dutchess, Greene, Orange, and Westchester represent about 50 tons or 5% of the total. Soft drink businesses in Columbia, Orange, and Westchester Counties represent about 110 tons or 11% of the total. Also, canning and specialty facilities in Westchester generate about 50 tons or 5% of the total. Combined, these sub-sectors represent approximately 620 tons or 62% of the total available excess food waste estimate.

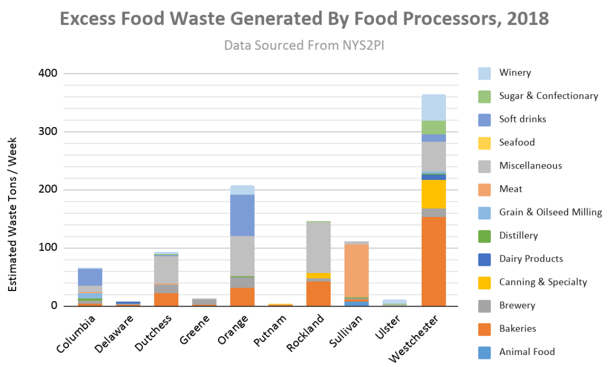


FIGURE 18: *County food processor waste*

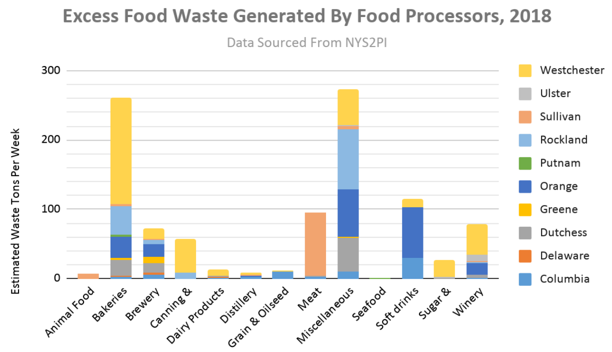


FIGURE 19: *Food processor waste by industry*

Institutions (FIGURES 20 and 21)**:** Together, Dutchess and Westchester Counties produce about 375 tons which is approximately 60% of this sector or 10% of the total. Each of the 4 sectors make up a significant proportion of the overall amount estimates, so the data has been investigated with respect to each county. Colleges and universities in Delaware, Dutchess, Rockland, Ulster, and Westchester generate over 85 tons per week which represents about 23% of the total institutions sector. Correctional facilities in Dutchess, Greene, Ulster, and Westchester are responsible for about 20% of the waste generated by all correctional facilities which is over 15% of the institutions sector. Hospitals in Dutchess, Orange, Rockland, and Westchester generate almost 100 tons of excess waste which is about 25% of the total produced in the institutions sector. In all counties except for Greene, Nursing Homes are responsible for more than 20% of the respective food waste. However, Delaware, Putnam, and Sullivan Counties each produce under 3 tons per week representing a small fraction of the total waste. The remaining amount is 92% of nursing homes and represents almost 25% of the total institutions sector.

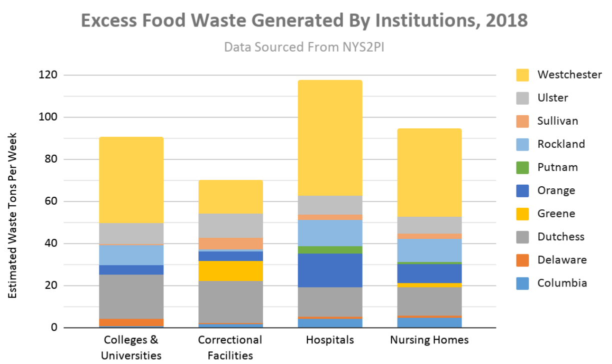


FIGURE 20: *Institution food waste*

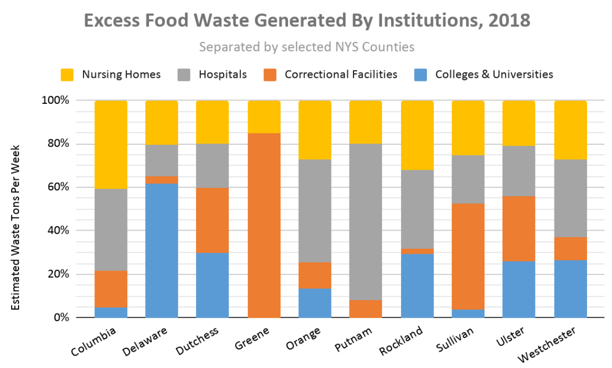


FIGURE 21: *Institution food waste %*

Restaurants: The restaurant sector, according to NYS2PI, shows that each county produces 5 to 20% of its excess food waste from these businesses. All together, this sector generates about 400 tons per week which is about 15% of the total amount estimated. However, there are vast differences in the total quantities produced between counties with low density populations like Greene and counties with high density populations like Rockland, which generate approximately 5 and 60 tons of food waste per week, respectively. Therefore an intra-county sector analysis reveals that Dutchess, Orange, Rockland, and Westchester are responsible for over 80% of the restaurant food waste or 15% of the total.

Retail (FIGURES 22 and 23)**:** Over 93% of the retail sector consists of supermarkets while the remaining percentage represents convenience stores. According to NYS2PI, the majority of this excess food waste comes from supermarkets in Westchester County which produce about 285 tons of excess per week. Meanwhile, a collection of all the supermarkets in the 7 counties highlighted earlier (Delaware, Dutchess, Greene Orange, Putnam, Ulster, and Westchester) produce a total estimated amount of 600 tons per week. Proportionally, this represents approximately 23% of the total available food waste across all sectors and counties. This sector should undergo additional investigation in future studies because these numbers are a very low estimate relative to the US EPA's high estimate which in some instances is 50 times greater than the estimates generated by NYS2PI. Therefore, this sector, and specifically supermarkets, could serve a critical role in providing high quantities of feedstock necessary for a large integrated network of biogas production.

FIGURE 22: *County retail food waste*

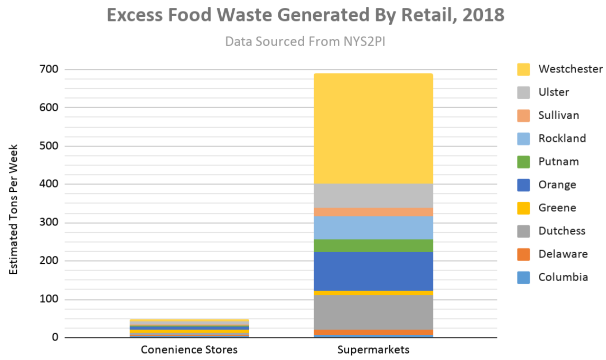


FIGURE 23: *Industry retail food waste*

End point analysis

Delaware: In 2016, Delaware County generated 52,424 tons of waste according to their 2017 SWMP. 38,824 tons or 74% was classified as MSW. They claim to divert 100% of the organic waste contained within this amount via their material recovery facility. In 2016, this resulted in an MSW composition that contained an estimated 18.0% organics with 13.3% or 5,163 tons of food scraps and 4.7% or 1,843 tons as yard waste (leaves and grass / pruning and trimmings). Wood represented 5.3% or about 2,000 tons of the municipal waste, but only 90% was diverted. The measured food scraps, which includes residential, was over 3.5 times greater than NYS2PI's commercial source estimate at a total of 1,940 tons of estimated excess food waste from the county's commercial operations (Delaware SWMP, 2017).

Dutchess: The 2013 Dutchess County Local SWMP indicated that in 2010, there were 255,678 tons of waste generated by the county. Of this, 196,963 tons or 77.04% consisted of MSW. No food waste streams were identified in the study, therefore the NYS DEC's 17.65% food scraps estimate yields an estimate of 34,764 tons of food scrap in the MSW that is inclusive of the residential sector. This amount is more than 2 times greater than NYS2PI's estimated 16,754 tons of excess food waste from the county's commercial operations (Dutchess SWMP, 2013).

Orange: In 2009, a total of 494,800 tons of waste was generated in Orange County according to their 2010 SWMP. 296,880 tons or 60% came from residential sources while the remaining 197,920 tons or 40% came from commercial sources. MSW represented 268,760 tons or 54% of the total amount and all of it was transported out of the county for disposal. County law requires all waste generators to separate certain waste for recycling. All waste transporters operating in the county are required to collect this source separated material from their accounts and keep recyclable materials separate from other solid waste. This includes pickup of plastic, glass, metal containers, paper and cardboard, however, food waste is not one of the required source separations. Applying NYS DEC's 17.65% food scraps estimate yields 47,436 tons of food scrap potentially in the MSW. This amount is also more than 2 times greater than NYS2PI's estimated 22,942 tons of excess food waste from the county's commercial operations (Orange SWMP, 2010).

Putnam: In 2010, Putnam County collected a total of 161,355 tons of waste. This included 89,713 tons of MSW or 55.6% of the total. Of this amount, 16,261 tons were organics or 18.12% of the total MSW. More specifically, 9,933 tons or 11.07% of the MSW consisted of food scraps and 6,329 tons or 7.05% consisted of yard trimmings. Out of 66 haulers, 7 handled yard waste, but none handled food waste. The next solid waste management report should be produced for 2020 which should provide updated information with respect to current tonnage and percentages. The NYS DEC's 17.65% food scraps estimate yields 15,834 tons of food scrap in the MSW. This amount is 1.5 times greater than the measured amount. However, the measured amount is more than 3.5 times greater than NYS2PI's estimated 2,792 tons of excess food waste from the county's commercial operations (Putnam SWMP, 2010).

Rockland: The 2020 Rockland County SWMP reported that in 2019 the county accounted for 115,407 inbound tons of MSW to the Hillburn transfer station, 191,748 to Clarkstown, and 46,249 to Bowline which yielded an annual total of 353,404 tons. This solid waste is currently being long-hauled to landfills in upstate NY; the Ontario County Landfill in Stanley, NY and the Hyland Landfill in Angelica, NY and on occasion to the Chemung Landfill in Elmira, NY. Each of these landfills takes more than five hours to drive to, one-way, from each of the Authority's transfer stations. Applying the NYS DEC's 17.65% food scraps estimate yields 62,376 tons of food scrap in the MSW. This amount is more than 3.75 times greater than NYS2PI's estimated 16,442 tons of excess food waste from the county's commercial operations (Rockland SWMP, 2020).

Ulster: Ulster County Resource Recovery Agency (UCRRA) is responsible for processing all of Ulster County's MSW. In addition, they offer waste separation into a variety of waste streams including food and yard waste for suppliers or individuals who drop off waste that is pre-sorted. In 2018, they processed 152,553 tons of waste and this total included 3,537 tons, or 2.32%, which was already diverted food waste. 66.45% or 101,379 tons was classified as MSW and therefore the NYDEC's 17.65% food scraps estimate yields 17,893 tons. This amount is 1.92 times greater than NYS2PI's estimated 9,339 tons of excess food waste from the county's commercial operations (Ulster SWMP, 2020).

Westchester: According to the 2020 Westchester County Food Waste Study, there is a total amount of 188,500 tons of excess food waste in the county's MSW which represents 21% of the total MSW generated in 2018. This equates the total MSW for that year to be 897,619 tons. Using the NYDEC's 17.65% food scraps estimate yields 158,430 tons of food scrap which is about 30,000 tons less than the study suggests. Meanwhile, NYS2PI estimates that there is 51,579 tons of excess food waste from the county's commercial operations which is 73% less than the county's study estimate, and 67% less than the NYDEC's estimate.

Aggregated estimates

FIGURES 24 and 25 display the results of total excess food waste estimates calculated through the 3 different methodologies. In FIGURE 24, the total MSW generated per week was multiplied by 17.65% to estimate the total food waste and then multiplied by 46% to estimate the portion generated by the commercial sector. In FIGURE 25, the NYS2PPI and US EPA commercial sector estimates were divided by 46% to extrapolate and estimate the total food waste estimates inclusive of residential sources. Dutchess, Orange, and Ulster have the most consistent results with respect to MSW and NYS2PI. (Data tables are available in APPENDIX 3.)

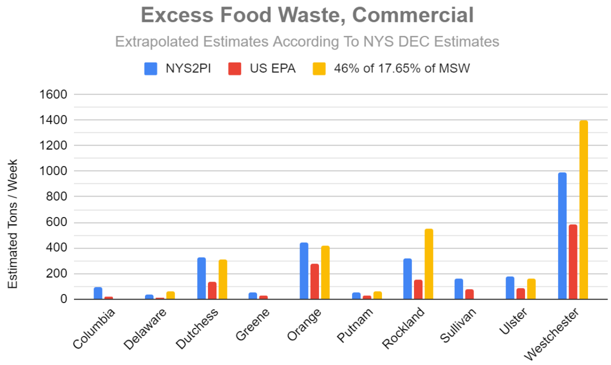


FIGURE 24: *Commercial food waste Estimates*

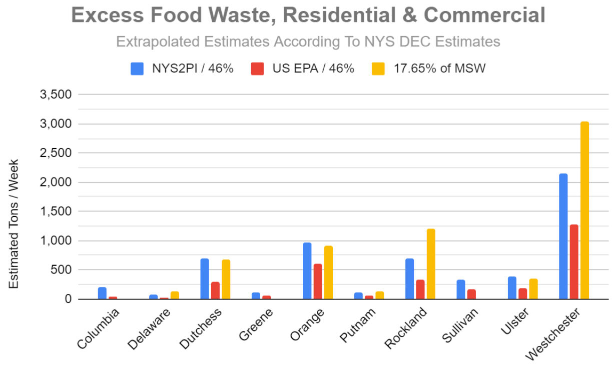


FIGURE 25: *Total food waste estimates*

Biosolids

FIGURE 26 shows a total of 165 WWTPs located in the 10 counties. 133 of these facilities are located within Region 3 of the NYS DEC and the remaining 32 are located in Region 4. Orange and Dutchess Counties have the greatest number of WWTPs with 33 and 26, respectively. Flows in 2015 summed to over 220 million gallons per day (MGD) for all of these facilities (FIGRUE 27). Westchester is responsible for the majority of this flow with 120 MGD or 55% of the total. Rockland and Orange Counties have the next largest flows at 30 and 27 MGD, respectively. Dutchess processes about 16 MGD, and the other facilities are under 10 MGD.

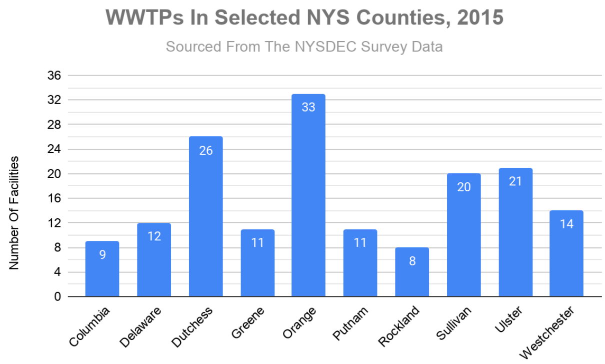


FIGURE 26: *WWTPs per county*

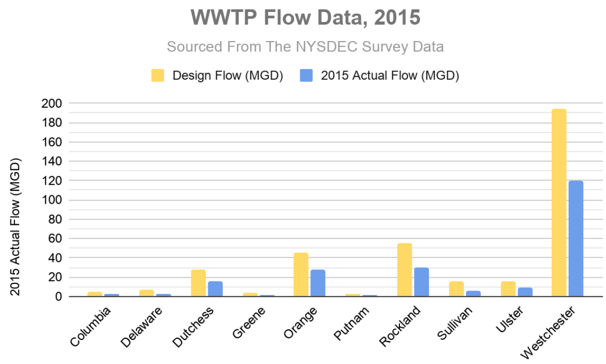


FIGURE 27: *WWTP flows per county*

There are a variety of technologies implemented within and among these treatment plants for managing their inflow volumes. The most prevalent method is aerobic digestion which is conducted at 77 WWTPs or almost 50% of the total (FIGURE 28). Meanwhile, anaerobic digestion is only conducted at 18 of them, or 11% of the total. However, these numbers can be misleading because a flow analysis reveals that 110 MGD or about 50% are currently being treated via AD. Therefore, 110 MGD are treated by other processes that may be able to be upgraded to AD and become an available biogas feedstock (FIGURE 29).

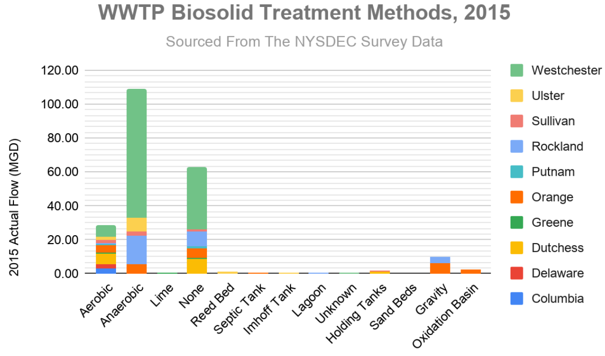


FIGURE 28: *WWTP treatment methods*

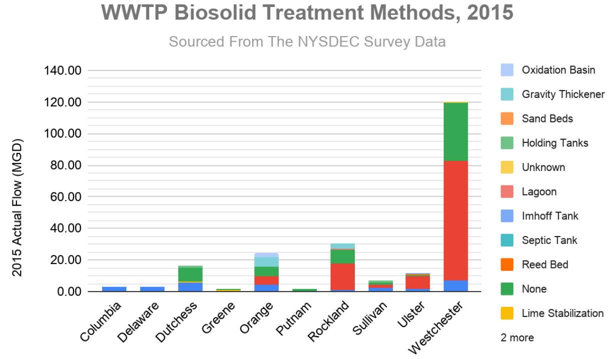


FIGURE 29: *County WWTP treatment methods*

Westchester thas the greatest flow volume that is not treated by AD (FIGURE 30). This 44 MGD represents 37% of the county's biosolids waste stream and 20% of the total biosolids waste stream. Rockland has the second highest flow at 30 MGD with 17 MGD or 44% of the county's biosolids which are not treated by AD. Orange has the third highest flow rate with 22 MGD not treated by AD. The flow in Dutchess is 16 MGD and essentially none of this waste stream is treated with AD. Ulster has the greatest percentage of flows treated with AD equating to only 2 MGD which are not treated with this method (FIGURE 31).

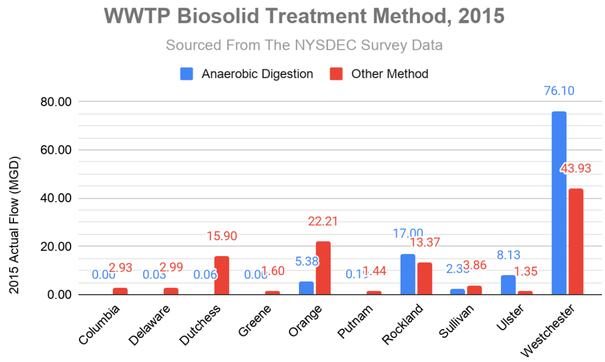


FIGURE 30: *WWTP anaerobic digestion flows*

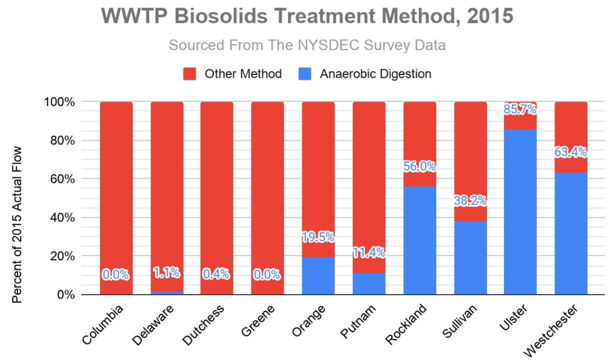


FIGURE 31: *WWTP anaerobic treatment % flows*

Even though these identified quantities in each county are not treated with anaerobic digestion, there are, in most cases, other treatment methods implemented with the exception of 62 MGD or 29% of the daily flow that is identified as not receiving any treatment. Ultimately, further investigation of each facility would have to be conducted in order to determine the viable amount of biosolids which could be used to create biogas via the anaerobic digestion process.

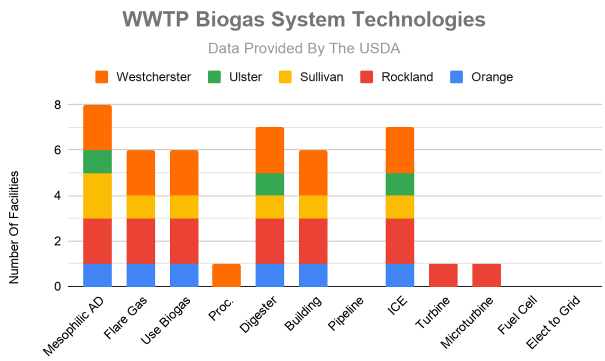


FIGURE 32: *WWTP biogas technologies*

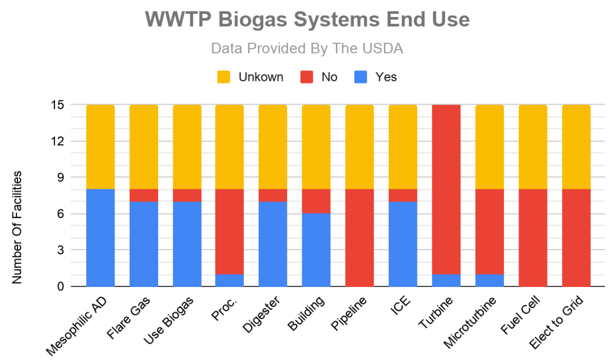


FIGURE 33: *WWTP biogas end use*

The USDA provides some additional information about 15 of the WWTPs using anaerobic digestion technologies (FIGURE 32). The data reveals that at least 6 facilities flare the resulting biogas that is generated. Specifically, 1 in Orange, 2 in Rockland, 1 in Sullivan, and 2 in Westchester (FIGURE 33). These facilities should undergo an additional study to discover if this biogas is viable for resource valorization. These statistics may be included in the NYDEC's next WWTP survey that will be conducted for the year 2020.

Animal manure

A cow will produce an average of 100 pounds of manure per day (NYS DEC Beyond Waste, 2010). This estimate can be extrapolated to approximately 0.25 tons per week and 15 tons per year. The USDA data reveals that there are over 22,000 milk cows in the lower Hudson Valley. Multiplying this figure by the weekly and annual manure production estimates yields 5,500 tons per week and 330,000 tons on an annual basis. However, many of these animals spend a significant portion of their life out to pastures and thus it is likely unfeasible and inefficient to collect this material as a feedstock. However, concentrated feeding operations offer a centralized location where large quantities of manure are aggregated and must be managed. These locations therefore offer a significant opportunity to implement a system of ADs to generate biogas.

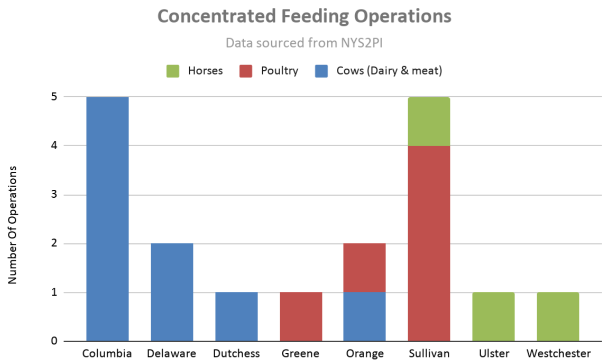


FIGURE 34: *Feeding operations by county*

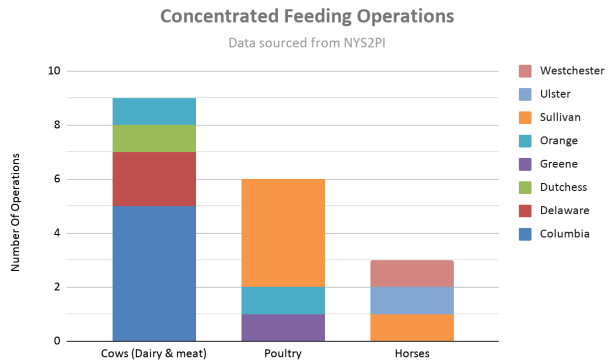


FIGURE 35: *Concentrated feeding operations*

NYSP2I has data on 18 concentrated feeding areas that reside in the lower Hudson Valley; 9 for cows, 6 for poultry, and 3 for horses. Columbia County has 5 operations that feed a collective 8,000+ cattle. 4 out of the 5 of these facilities have over 500 cows and therefore should be classified as primary candidates for AD infrastructure according to the EPA. The remaining feeding sites located in Delaware, Dutchess, and Orange Counties have between 300 and 500 cows, but even though they are smaller operations, their viability for AD warrants an investigation. In addition to these concentrated feeding centers for cows, there are also facilities for poultry and horses. Sullivan County has 5 operations responsible for feeding a collective 550,000+ poultry.

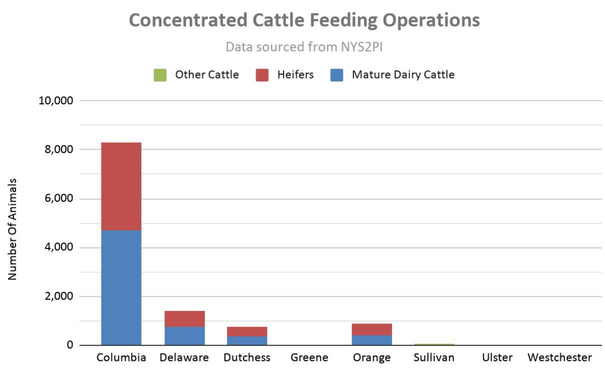


FIGURE 36: *Number of feed center cattle by county*

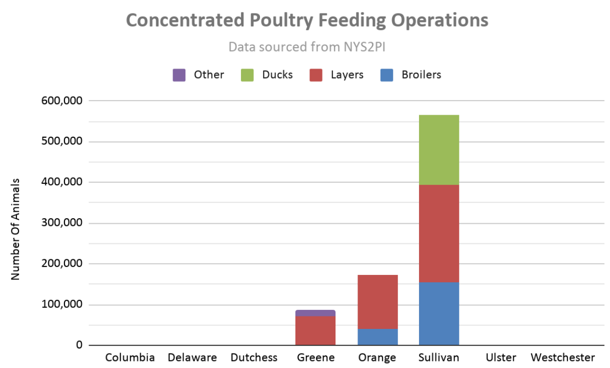


FIGURE 37: *Number of feed center poultry by county*

Biocrop land availability

A qualitative assessment of available lands has been conducted to identify opportunities where biocrops can be grown. Any potential land should not compete with agriculture production for food and should have a planned crop establishment for approximately 10 years.

Farms: The most recent farm data available through the USDA is from 2007. At that time, there were a total of 3,908 farms in the lower Hudson Valley region. The majority of these were in Columbia, Delaware, Dutchess, Orange, and Ulster counties, with each having over 500 farms (FIGURE 38). All of these farms represent 308,326 acres (FIGURE 39) with the aforementioned counties containing over 80% of this area. The number of farms has changed over the past decade and in some cases has increased. For instance, in 2019, there were approximately 421 registered farms in Ulster County covering an area of 58,932 acres. This represents an increase in acreage of 86% relative to the USDA's reported number in 2007.

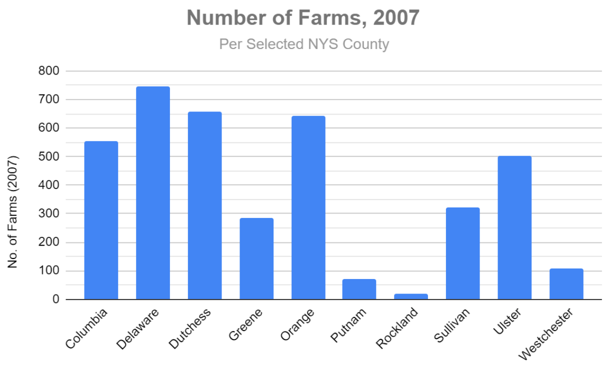


FIGURE 38: *Number of farms by county*

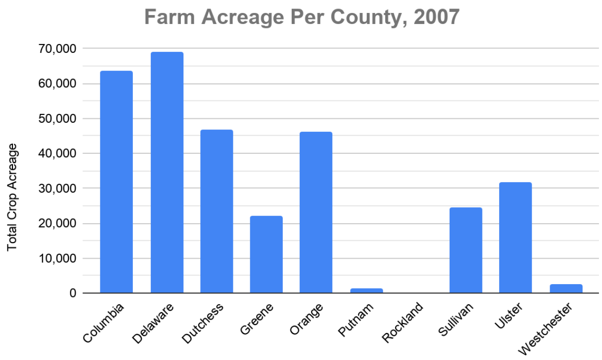


FIGURE 39: *Farm acreage by county*

These aggregates do not represent the amount of land available for secondary biocrops. They merely provide a metric as a point of reference for establishing the percentage of farmland that can justifiably be assigned to agriculture for biogas production. More research is necessary to asses farm and land viability.

Land Trusts & Conservancies: The Hudson Valley is home to several land trusts and conservancy groups including Columbia Land Conservancy (4,500 acres), Dutchess Land Conservancy (43,500 acres), Esopus Creek Conservancy (353 acres), Hudson Highlands Land Trust (2,866 acres), Stony Kill Foundation (1,000 acres), Wallkill Valley Land Trust (255 acres), and Westchester Land Trust (9,000 acres). While each organization's mission is slightly different and focused to a specific region, they offer a collective vision of conserving natural landscapes and protecting the rural character of the environment. Several of these entities have dedicated farmland as well as idle lands within their portfolios. These areas should be investigated for their potential to support the production of biocrops and/or or provide another stream of biomass feedstock. This type of implementation would aid the protection of natural habitats, promote biodiversity, and share natural resources with the community all of which could be facilitated through public outreach, education and advocacy. Several of these organizations also offer educational programs for both adults and children. Facilitating the production of biogas feedstock on these lands would therefore establish a positive public awareness and outreach to a wide-scale and integrated production system.

Idle & marginal lands: The USDA reported that NYS had over 318,000 acres of completely idle land in 2012 which represents lands seeded to soil improvement crops but not harvested or pastured. Herein lies the potential to utilize a portion of this area for biocrop production as well as an endpoint for anaerobic digestate. This information is only presented at the state level and does not provide information in regard to each county. Therefore, investigation at the county level along with an assessment of marginal lands is necessary to determine the potential for use with biocrops in a network of ADs throughout the Hudson Valley.

Environmental remediation sites and brownfields: The NYS DEC currently has 884 environmental clean-up & brownfield sites registered within the 10-county scope of this study (FIGURE 40). Many of these are no longer classified as contaminated and have been remediated, some sites are undergoing active cleanup, while other sites have been identified as future sites for remediation projects. These land areas have the potential to serve as agricultural land for the purpose of growing biocrops. Introducing this type of growth may offer additional benefits for the soil that are characteristic of the aforementioned biocrops; a deep root structure that restores carbon content in the ground. Digestate created from these crops would be returned to this specific land to recycle nutrients and maintain any contaminants in closed system loop. This type of system design could also serve as a research opportunity to assess any additional remediation characteristics that may take place as a result of this floral introduction.

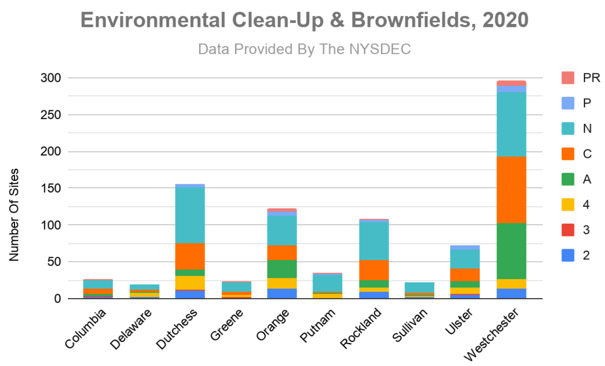


FIGURE 40: *Environmental clean-up sites*

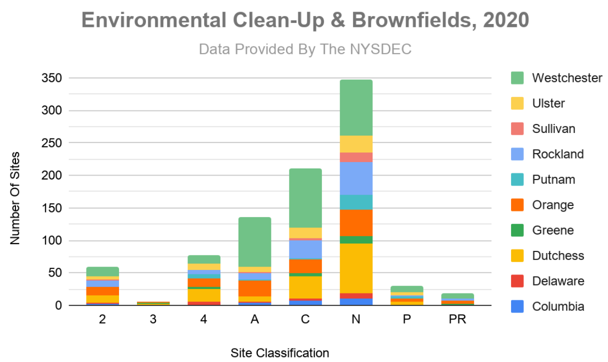


FIGURE 41: *Environmental clean-up site classifications*

348 or 40% sites have been assigned an 'N' classification (FIGURE 41). This could mean several that there was a determination that contamination at the site does not warrant placing the site on the registry, the site is being addressed under a brownfield program, it was the location where a drum(s) or other discrete waste was at one time present and subsequently removed by the NYS DEC or others, or an application to the BCP, ERP or VCP was submitted, and was then withdrawn or terminated before any actions were taken to investigate or remediate the site. 210 or 24% of the sites have been assigned a 'C' classification. In this case, the NYS DEC determined that remediation has been satisfactorily completed under a remedial program (i. e., State Superfund, Brownfield Cleanup Program, Environmental Restoration Program, Voluntary Cleanup Program, and RCRA Corrective Action Program). 136 or 15% of the sites have been assigned an 'A' classification. This means that it is a non-registry site in any remedial program where work is underway and not yet complete (i.e., Brownfield Cleanup Program, Environmental Restoration Program, Voluntary Cleanup Program and RCRA Corrective action Program sites) and it may be used for manufactured gas plant sites or those being remediated under an EPA cooperative agreement (NYS DEC Website).

Landfills

While there are many closed landfills throughout the Hudson Valley, their potential for biogas production may have declined just as the aforementioned landfill in Delaware County. However, these sites could become ideal locations for ADs. They are, after all, centralized and were designed to accommodate heavy-weight vehicles and high hauler volumes. Implementing biogas production at these locations, which are already classified as commercial properties, may therefore be a viable and efficient option.

Orange County has a total of 24 publicly and privately owned landfills and a number of smaller 'town dumps.' All of them are inactive or closed with the exception of the coal ash landfill operated by Dynegy in the Town of Newburgh which only serves the needs of the Danskammer Point Electric Generating Facility (Orange County 2010 SWMP). The Ameresco, Inc Al Turi landfill located in Goshen, which operated from 1968 to 1995, has in place two LFGE systems that valorize the methane off-gas. The first was installed in 2007 and the second in 2011. They are two reciprocating engines with capacities of 0.8 and 1.6 MW, respectively. This is the only landfill in the lower Hudson Valley, according to the EPA, that is utilizing the methane that is produced.

Delaware County once worked with the Delaware County Electric Cooperative, Inc. (DCEC) in the operation of a landfill gas to electricity (LFGE) project located at the county's solid waste management center. A distribution line connects to the transmission system of the local utility (NYSEG) serviced by the Delhi substation. This project operated successfully from 2008 to 2012 when the system was decommissioned due to eventual insufficient quantities of methane. Since then, the DCEC assets have been liquidated and the remaining infrastructure was turned over to the county which retains ownership of the landfill gas recovery network and stationary utility flare that is still active (Delaware SWMP).

Invasive species

This study has selected three site locations of water chestnut infestations. They are on the Hudson River along the coast of Dutchess County. Satellite imagery displays the plant's green hue where it has established itself in shallow water. Its pervasiveness in local ecosystems is quite clear. IMAGES 7 and 8 depict a lateral distance across their entire width of approximately 3 miles (~5 km). IMAGE 7 is centered over Denning Point which is south of the Newburgh-Beacon bridge. There are large patches of water chestnut to the north of this peninsula and to the south extending up the mouth of the Fishkill Creek. IMAGE 8 is centered over Bowdoin Park where there is a large patch of this plant along the eastern coast. A severe infestation can be seen extending up Wappinger Creek and into Wappinger Lake. IMAGE 9 is centered over Esopus Island and spans a lateral width of approximately 1.75 mi (~3 km). (Larger aerial photos are available in APPENDIX 3.)

IMAGE 7: *Denning Point*

IMAGE 8: *Wappinger Creek*

IMAGE 9: *Norrie Point*

Water Chestnut has a high density growth rate and is capable of covering nearly 100% of the water surface in an infested area. This results in the interception of 95% of incident sunlight and effectively destroys opportunities for other aquatic plant life below the water chestnut canopy. Submerged vascular plants and their symbiotic microscopic flora and fauna become shaded and hypoxiated. The plant may remove a significant amount of nitrogen from runoff waters that is seasonally released downstream as the plants decay in the fall. Thus, removal could have an additional benefit of reducing eutrophication impact throughout the watershed. Successful eradication depends on removal of rosettes before mature fruits, colloquially known as "buffalo heads," detach and migrate downstream. There is precedent for harvesting the plant by hand-pulling smaller colonies or via machines that have underwater cutters. Specifically, physical control methods have been employed in the Potomac River, Lake Champlain, Chesapeake Bay, the Sudbury River, the Concord River, and the Hudson River (Water Chestnut, 2004). APPENDIX 3 also includes satellite imagery of two ponds in Orange County's Algonquin Park that are infested. There are also some pictures of manual removal efforts at that location. Publications are anticipated from Clarkson University which will provide estimates of the amount of biomass present in each of these images as well as many other locations. Their research will also include the effectiveness of AD efforts in terms of biogas production quantities and seed destruction. These efforts are essential for determining resource recovery potential for the local economy.

Hydrilla was first discovered in 2008 in a small pond in Orange County and has since been discovered in 2013 in the Croton River in Westchester County (IMAGE 10). For several years, a fluridone treatment was applied to the waterway to diminish the pervasiveness of this plant. Its presence decreased significantly between 2017 and 2018 as a result. Only moderately dense sites were observed the following year which exhibited signs of herbicide injury. Regular field testing is done to monitor the spread of this plant, however, there are no estimates of total biomass at this time (Hydrilla Control, 2019).

IMAGE 10: *Hydrilla sampling (Hydrilla Control, 2019)*

Phragmites populate many marshes throughout the Hudson River Valley. Laboratory evaluations have revealed that the composition of phragmites is very similar to that of switchgrass. There are two exceptions; crop biomass is higher in reeds and they sometimes contain more chloride. The invasive variety, while difficult to identify, has been spotted in several locations, and is often sharing the same area as native varieties. The following satellite images convey the size of some of these local habitats. The plants have a mixed brown and green color in imagery taken in the summer months. The color changes to a light brown once the leaves die with the seasonal change to winter. IMAGE 11 spans a width of almost 2 mi (~3 km) and is centered around Iona Island in Rockland County. The marsh is visible to the southwest of this landmass. IMAGE 12 is centered around Constitution Island in Putnam County and spans a width of about 1.5 miles (~2km). The Constitution Marsh constitutes the brown area on the right side. IMAGE 13 is of the Tivoli North Bay in Dutchess County. This image spans a width of about 2.5 mi (~4km) and is centered around the marsh.

IMAGE 11: *Iona Island*

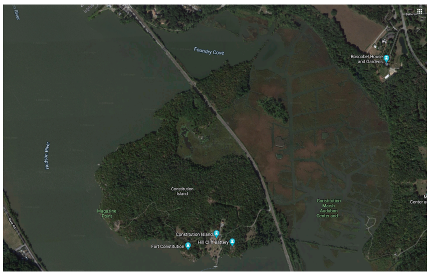


IMAGE 12: *Constitution Island*

IMAGE 13: *Tivoli North Bay*

While it is tough to assess the impacts of this plant, the Hudsonia publications portray that there are probably more adverse effects than positive ones. One option is to prioritize harvesting of invasive phragmites stands that are clearly a threat to delicate ecosystems and monitor them over time to assess longer-term impacts (Phragmites, 2010). The plant can be harvested by hand cutting or with a variety of light or heavy machinery. Locally available farm equipment may also be an option for winter harvesting. While this could have some risk to the local biodiversity, harvesting can be less threatening than the chemical applications that are typically used (Phragmites Bioenergy, 2014). Further investigation is necessary to determine quantities of biomass and to create catalogue of locations which have high densities of the invasive variety.

Compost

The Cornell Waste Management Institute has surveyed and reported on 56 compost facilities located within the 10 New York counties of focus. FIGURES 42 and 43 depict the number of compost centers in each county and what type of ownership they are operated under. Westchester has the greatest number with 15 facilities and Dutchess and Ulster each have 9. All together, 15 facilities are government, 11 are private, 9 are NYS Department of Corrections, 7 are farm, 5 are non-profit, and 3 are Cornell Cooperative Extension.

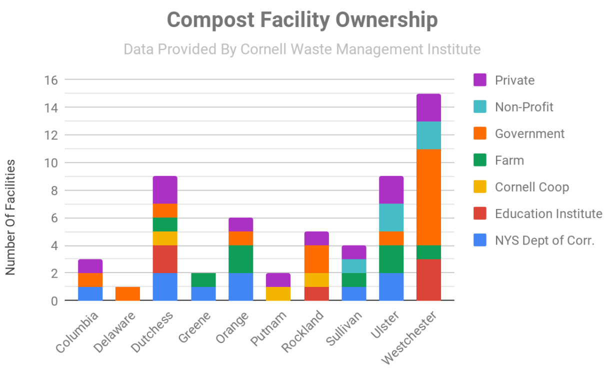


FIGURE 42: *County compost facility ownership*

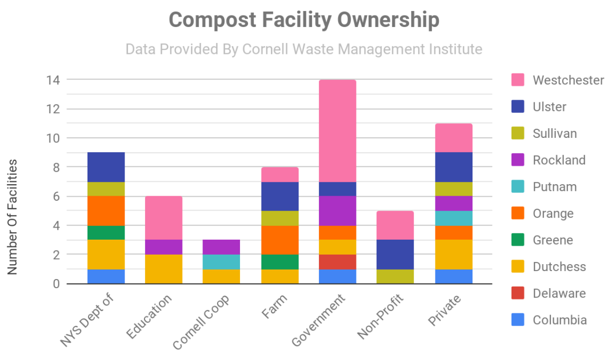


FIGURE 43: *Compost facility ownership*

Compost centers can accept different waste streams according to specific NYS DEC permitting regulations. Overall, there are 19 facilities that accept food waste; this includes all counties except for Delaware and Rockland. Rockland is the only county with a facility that accepts biosolids. Animal manure is accepted by 11 facilities located throughout Dutchess, Greene, Orange, Sullivan, Ulster and Westchester. Additional information regarding these primary feedstocks, the number of facilities, and their respective counties are displayed by FIGURES 44 and 45. All of these waste streams warrant further investigation to determine if they can be diverted to local ADs and adhere to the food recovery hierarchy. Large facilities should be prioritized as biogas production centers to limit energy expended for transportation and to take advantage of existing supply lines. The byproduct can be applied to composting and distributed as is ordinarily practiced.

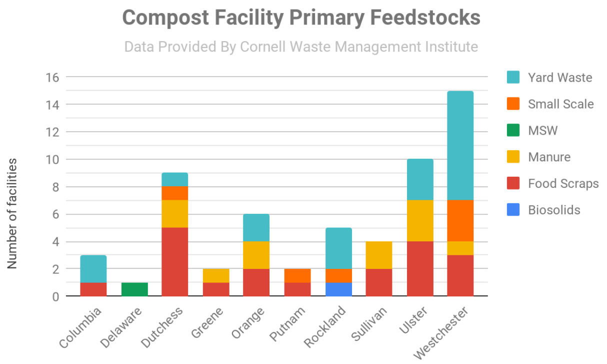


FIGURE 44: *Compost feedstocks by county*

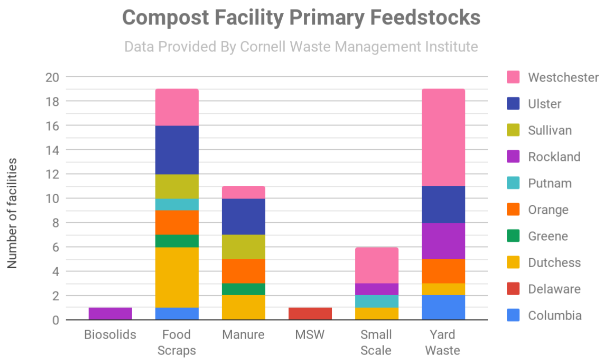


FIGURE 45: *Primary compost feedstocks*

Miscellaneous

There are some additional accumulations of biomass which are worth mentioning as other opportunities for biogas feedstocks. AD can be conducted with many types of organic matter, therefore, further investigation into local resources is warranted to maximize resource valorization and production capacities. Each year, more than 25,000 animals are killed on NYS roads which consists primarily of deer. There are also an estimated 14,000 cow carcasses generated by dairy farms across NYS which are not part of or diverted from the meat processing industry. In addition, there are 46 poultry and swine farms throughout the state which also generate a substantial amount of animal carcases (NYS DEC Beyond Waste, 2010). Landfill operators typically don't accept large animals, and the practice of dragging carcasses into wooded areas is no longer an option in many communities. A number of NYS Department of Transportation (NYS DOT) sites have established compost piles specifically designed to handle road-killed animals with procedures developed by Cornell University. UCRRA is another facility permitted to conduct this type of mortality composting. In 2019, they managed approximately 11 tons of deceased deer carcasses (Cornerstone, UCRRA). Since these remains are organics, they have the potential to serve as an additional feedstock for biogas production. AD may offer a quicker and more efficient decomposition process than the current method of managing this biomass that would also help to eliminate odors and pathogens.

Discussion

Bioenergy will continue to play an increasing role in transitioning the US and NYS away from its reliance on fossil fuels and to renewable resources. AD is a mature technology that offers an effective approach for resource valorization and mitigation of anthropogenic impacts to the environment. In linear production systems, waste is largely unavoidable. Therefore emphasis should be placed on conversion to value-added products through the food-energy-waste-water nexus so that the products of one process are always available for another process. The feedstocks reviewed in this report would each play an important role in an integrated network of biogas production. There are many examples in which the addition of these co-benefits far outweigh their segregated values. In order to take full advantage of these embedded opportunities there are several gaps in this research that require additional review and investigation. These discussion points are related to existing food waste diversions, added potential of co-digestion, congruent legislation, biogas application, and investment strategies. These details must be reviewed and refined to implement a viable system that echoes the guidelines of the CLCPA and the state's energy initiatives. They also play an essential role in validating efficient economic models that maximize productivity.

Diversions

Neither the NYS2PI nor US EPA data sets include information about percentages of food waste estimates that are already diverted. There are many institutions throughout the region which demonstrate some adherence to the food hierarchy through activities such as donations to shelters, animal feed, and composting. This realization is also echoed by conclusions provided by the Westchester County Food Waste Study. Additional studies are necessary to determine a more accurate mass flow analysis of these waste streams and determine their ultimate end points. Related questions can also be applied downstream to known diversions that are already implemented. For instance, there are some pilot programs in Westchester County for residential (and some commercial) collection of food waste that is ultimately transported to UCRRA where it is added to their composting operations (Westchester Food Waste Study, 2020). Other counties in this study, such as Dutchess, also transport a portion of their organics to UCRRA for processing (Dutchess Organics, 2017). Meanwhile, biosolid flows have a higher accountability which is partially due to the regulatory nature that surrounds them. A significant amount of data is available in regards to their end of life including locations. This is useful for performing a mass flow analysis. However, NYS DEC could request some additional information for their 2020 survey that would be necessary for an LCA. Information such as the total mass and regularity of individual hauling activities would offer opportunities to accurately assess the related environmental impacts and compare these to the energy offsets that can be achieved with an AD facility.

Co-digestion

As AD operations in NYS have become more popular, some WWTPs and farms have expanded to include multiple feedstocks. Along with valorizing additional sources of energy, more consistent input flows are achieved with an increased production capacity. The simultaneous management of food, water, energy, and waste streams leads to more sustainable production, consumption, and distribution processes. Developments in life cycle optimization, modeling of multiple stakeholders, and integrated supply chains can enhance this nexus and take advantage of the co-benefits available through co-digestion (FWEN, 2017).

WWTPs and food waste

A variety of co-digestion studies for WWTPs throughout the country have been investigated. New and refined technologies are increasing the feasibility of transforming WWTPs into energy-positive recovery facilities. The introduction of organic waste to digestion with biosolids demonstrates several beneficial results including higher methane yields, more efficient digester volume utilization, and reduced biosolids production (DEC Beyond Waste, 2010). For instance, the biosolids fact sheet produced by the NYS DEC writes that fats, oils and grease can increase biogas production. Advanced combined heat and power (CHP) design with internal combustion engines (ICE), microturbines, gas combustion turbines, and fuel cells can further maximize energy recovery from these facilities (DOE Billion-Ton, 2016). The high water requirements are accommodated by the high flow volumes through WWTPs. ADs utilize this resource that would otherwise have to be retrieved from elsewhere for a stand-alone operation. These advantages directly improve the economics of these facilities and simultaneously mitigate environmental impacts.

For small WWTPs, the additional power that can be generated from co-digestion can significantly improve project economics, and, in many cases, it be the tipping point for moving ahead with combined heat and power generator projects. There are many examples of successful operations throughout the country. A WWTP in Sheboygan, Wisconsin increased biogas production at its 10 MGD facility by introducing co-digestion with food waste to their AD process. The added substrate included whey and cheese processing waste and thin stillage from ethanol manufacture. Another example is a 5 MGD WWTP in Massachusetts that uses excess food waste from beverage companies, breweries, and dairy processing. A similar example is in the Village of Essex Junction, Vermont which has used brewery waste and oily waste by-products for AD since 2007. For all of the facilities, the rate of biogas production was improved (EPA Co-Digestion, 2019).


IMAGE 14: *WWTP in the GLSD, MA*

Large-scale, centralized installations can also be explored. A WWTP in the Greater Lawrence Sanitary District (GLSD) of Massachusetts plans to ultimately process more than 90,000 MGD of source separated organic waste, avoiding landfill and waste-to-energy disposal of food waste, while considerably boosting biogas production. Formerly, it treated a municipal sewage flow rate of 23.5 MGD, but in 2018, additional AD capacity and a combined heat and power (CHP) system was installed to expand energy recovery operations (EPA Co-Digestion, 2019). Over $10 million in incentive grants were received for this project, and it will satisfy more than 40% of the state's food scrap diversion goal (GLSD, 2020). Another facility in St. Petersburg, Florida is upgrading to co-digestion infrastructure that is expected to generate over $500,000 per year for the city (NYSERDA Biogas Barriers, 2012). Digestate will be class AA biosolids which meet the US EPA's guidelines for fertilizer. The biogas will be used to heat and power the plant and excesses will be sold on the market to produce significant cost savings for the city (Haskell, 2020).


IMAGE 15: *WWTP in St. Petersburg, FL*

Mixed feedstocks

One study which examined the co-digestibility performance of food waste and switchgrass determined that an optimum mix ratio for maximum methane yields occurs when the mass is combined in equal parts. Food waste has a low carbon to nitrogen ratio, and switchgrass has higher cellulosic content. Volatile fatty acids can affect variation in pH levels and thus inhibit system performance. The switchgrass helps neutralize this effect and acts in a buffering capacity (Food & Switchgrass, 2018). These conclusions promote the introduction of biocrops into the food-energy-water-waste nexus and the design mixed feedstock AD system.

Agricultural and organic waste streams on a farm can be difficult to manage due to both volume and susceptibility to creating environmental impacts. However, they are characterized by a rich mix of organic compounds that can provide a rich recipe for conversion into energy or value-added products (FWEN, 2017). A study published in 2014 conducted AD with substrate inputs composed of 52% energy crops (of which 73% was maize) and 43% manure, based on mass. This was also shown to increase biogas yield rates. The proportion of methane produced from biocrops is considerably higher than their proportion by mass of their substrate content (Sustainable Biocrops, 2016) and thus has a positive effect when added to AD with manure. According to the USDA, there are currently 15 digestion facilities in NYS that process manure and crop residues and take advantage of this benefit. (Some of these operations also incorporate local food scraps.)

In another study, wood chips were mixed with food waste in AD. The result was a staggering 6.4 times more methane than the control reaction under the same reaction conditions without wood chips. It was concluded that the wood chips expedite the AD by serving as a conducive habitat for the active microorganisms. Increases in hydrogen were also observed, and the amount of sludge generated was reduced (Food & Wood, 2018). Many of the compost facilities presented in this study also accept wood waste that may be viable as AD feedstock to increase production capacity. Another alternative may be to use shrub willow, a fast-growing, short-rotation woody crop. Studies have been conducted on this poplar tree with respect to bioenergy and CHP plants for decades by SUNY-ESF along with many other institutions (Shrub Willow, 2014). Future innovations in AD may present an opportunity for it to be incorporated into biogas production cycles.

Legislation

There are a series of policy and legislative pathways precedent throughout the world and the US that could be implemented to promote the production of RNG. Some countries have had these biogas production strategies for decades and they could serve as a model for implementing similar practices throughout the NYS and Hudson Valley. Specifically, waste diversion programs and fuel standards can promote a system that represents that of a circular economy, promotes conservation, and mitigates environmental impacts.

Food waste diversion

The US does not have any federal or nationwide organic waste diversion programs, processing laws, or policies. However, in September 2015 the USDA announced the nation's first-ever food waste reduction goal of 50% by 2030. Meanwhile, yard and food waste disposal bans along with landfill diversion targets have been introduced in many states including California, Connecticut, Delaware, Florida, Massachusetts, Michigan and NY (ISWA Global Assessment, 2020). In some cases, these policies have been extended to counties and municipalities to encourage localized organic waste diversion and processing.

In April 2019, NYS legislators passed the NYS Food Donation and Food Scraps Recycling Law which requires large generators of food scraps (more than 2 tons per week on average) to redirect excess food to those in need and organic recycling as long as they are within 25 miles of an organics recycler. This legislation specifically includes “organics recycling on-site via in vessel composting, aerobic. or anaerobic digestion” as acceptable methods of managing this waste (NYS Food Law, 2019). Therefore, this law presents an opportunity to apply localized biogas production throughout the state.

One important aspect to note is that hospitals, nursing homes, adult care facilities, and k-12 schools have been excluded from this law. However, according to NYS2PI, hospitals and nursing homes in the selected 10 counties generate approximately 8% percent of the total excess food waste at over 200 tons per week. This should be compared to colleges and universities, which would be required to follow this law even though they only produce about half of this quantity. Therefore, one could conclude that this exclusion should be critiqued, reviewed, and reconsidered to include some of these exempt institutions. For instance, collectively, hospitals in Dutchess, Orange, Rockland and Westchester account for 55 tons of excess food waste per week which represents about 4.5% of the total. Refining this regulation to incorporate these areas with the highest generation rate would therefore improve the desired recovery rate. One must also consider that it may be more logistically favorable and feasible to collect food waste on a regular basis from these larger institutions than other small business owners such as restaurants. Having these larger entities as primary food waste generators for AD would be integral to a large-scale implementation of biogas production. Hospitals, nursing homes, adult care facilities, and k-12 schools would have the added benefit of offering a relatively secure and predictable feedstock supply. The NYS DEC is currently developing regulations for implementing the law, and they will be released for public comment throughout 2021 allowing the public and policy makers to explore these details further. The law is set to take effect on January 1, 2022 (NYS Timeline, 2020).

More stringent legislation has already taken place in Ulster County independent of this state law. In 2019, the local legislature passed the “Food Waste Prevention and Recovery Act” which maintains the same threshold of two or more tons per week of excess food waste that must be diverted to alternative use. This includes animal feed, on-site compositing, or arrangement with licensed services to deliver it to a processing facility for composting or anaerobic digestion, as per the written language. This law is set to begin January 2021, but goes further than the state by mandating that these thresholds are reduced to generators of 1 or more tons per week by July 2021. This will further be reduced to generators of 0.75 tons per week in July of 2022, and 0.5 tons in July of 2023 (Ulster Food Law, 2019). The UCRRA is in the process of expanding their organic recovery facility to help accommodate an anticipated influx of material (Ulster SWMP, 2020). Unlike NYS, this local law offers no exemptions for hospitals and schools nor transport distances. However, the large generator classification will remain at 2 or more tons per week for health care facilities. FIGURE 46 is from the Ulster County Government website and displays the differences between the state and local legislation in regards to their thresholds and respective enactment months and years.

Organics Diversion Legislation, Regulation Timeline, and Regulating Entity (TPW = tons per weeks of food waste generated)							
Effective Date	2021		2022		2023		Notes
	January	July	January	July	January	July	
Ulster County Food Waste Prevention and Recovery Act	>2.0 TPW		>2.0 TPW health care only				UC Legislation includes hospital and schools; No exemption for distance from compost facility
		> 1.0 TPW					
				> 0.75 TPW			
						> 0.5 TPW	
NYS Food Donation and Food Scraps Recycling Law			> 2.0 TPW				NYS regulates generators within 25 miles of a compost facilities. Does NOT include health care or schools

FIGURE 46: *Organics diversions legislation & timeline (NYS Timeline, 2020)*

Fuel standards

The EPA reported that, in 2014, the equivalent of nearly 53 million gallons of biogas and RNG gas were produced; more than 20 million gallons of biogas, 15 million gallons of renewable CNG, and 17 million gallons of LNG. Both fuel types are suitable for use in light-, medium-, or heavy-duty vehicle applications. At present, only about 0.1% of natural gas in the US is utilized with transportation. However, renewable biogas is positioned to increase this market share and expand fueling infrastructure throughout the country (DOE Billion-Ton, 2016). Around the world, there are several examples of government subsidy programs designed to promote the use of renewable biogas. In particular, Italy has implemented subsidies in the transport sector that will continue through 2022 (IEA, 2018). Also, in Sweden and Norway, biomethane is exempt from fuel taxes. The US is following suit with similar programs and incentives at the national and state levels.

Federal RFS

The federal renewable fuel standard (RFS) is a US mandate which requires transportation fuels sold throughout the country to contain a minimum volume of renewable fuels. The program was created under the Energy Policy Act of 2005 which was an amendment to the Clean Air Act. Distributors have a renewable volume obligation based on the amount of petroleum-based fuels they produce or import annually. The RFS was designed as a system of tradable credits, called RINs, which are issued to the producers of the fuel. When an overabundance of these credits is obtained by a corporation, they can be marketed to producers that are incapable of meeting this requirement. Each fuel type has a D-Code, and there are two different classifications of RNG under this system. D3 cellulosic biofuel represents biogas captured from landfills, municipal WWTP digesters, agricultural digesters, separated MSW digesters and biogas from the cellulosic components of biomass processed in other waste digesters. D5 advanced fuel represents biogas created from waste digesters. The US EPA is responsible for administering the RFS along with renewable fuel volume requirements. Diagrams representing the pathway for generating and marketing these RINs have been included in APPENDIX 4. There are also screenshots of the ABC's online RIN calculator which can be used to estimate the value of earned credits.

State-specific LCFS

California's low carbon fuel standard (LCFS) was designed to compliment the RFS and encourage the use and production of cleaner low-carbon fuels throughout the state. Transportation providers in the state must meet a carbon intensity target each year, and this amount decreases over time thus requiring a higher percentage of low carbon fuels such as RNG, hydrogen, and electricity. These metrics equate a fuel's carbon intensity to the amount of GHG emissions created throughout the product's production and consumption. Similar to the RFS, LCFS credits can be obtained through a variety of pathways which include RNG made from the various feedstocks of AD. Oregon offers a similar incentive through their Clean Fuels Program with carbon intensity credits that also honor pathways for RNG made from AD biogas.

New Yorkers are permitted to participate in these markets and there are several biogas production facilities currently taking advantage of these opportunities throughout the state. The ABC reports that the greatest number of credits is typically obtained at contentraded livestock feeding facilities. The council reports that these programs can value RNG at 3 to 30 times more per MMBTU than natural gas produced from fossil fuels. This opportunity exists because of the reduction in carbon equivalents that is accomplished by collecting the methane that would otherwise be released to the atmosphere throughout natural decomposition.

A LCFS is being proposed in NYS as Senate Bill S4003A that is directly inspired by California's legislation. It is intended to complement the state's shift to renewable fuels as well as reduce carbon intensity from the on-road transportation sector by 20% by the year 2030. Similar to California LCFS, this system would also be measured through LCA methods and be accommodated through a market-based system of credits to be applied to future obligations. The bill was introduced in February of 2019 and is currently in front of the Environmental Conservation Committee. A copy of the legislation is attached in APPENDIX 4.

Organic certification

The effluent byproduct from AD can be refined into a solution that resembles commercially produced agricultural fertilizers. In order to be marketed as an organic, it must receive special fertilizer classification under the USDA's National Organics Program (NOP). At the time of the USDA's 2015 Biogas Roadmap publication, at least one petition had been submitted to this organization's standards board requesting for the product to be approved. Legislative efforts like this are key to facilitating successful implementation of a bioeconomy and establishing the food-energy-water-waste nexus. There are also methods of treating digestate that can significantly improve the availability of nitrogen to plants. Additional policy measures may be necessary to facilitate these approvals and complement regulatory measures (Biogas Roadmap, 2015). When biocrops are part of the biogas production system, the fertilizer can be applied to these crops and the digestage biomass returned to the land. This type of implementation represents the epitome of a circular economy in which the waste from the AD process is utilized by the agriculture sector.

Mitigating emissions

Relative to 1990 levels, total emissions from fossil fuels have decreased by almost 20%. The greatest decrease can be observed in the electric power sector with a reduction of almost 60%. Residential emissions have remained about the same while the commercial and industrial sectors have also experienced substantial decreases by about 15 and 20%, respectively. Meanwhile, the emissions generated from the transportation sector are higher than 1990 levels by almost 20%. Relative to the other sectors, in 1990 this sector represented about 30% of emissions while today it represents approximately 40% of the overall emissions. The CLCPA's objective of a 85% reduction in overall emissions by 2050 implies a targeted reduction goal of about 30 million metric tons of CO2 per year. Given that current emissions form the transportation sector are equivalent to approximately 40 million metric tons of CO2, if emissions from all of the other sectors are reduced to 0, emissions of the transportation sector would still have to be reduced by a minimum of 10 million metric tons of CO2, or 25% of their current levels to meet this goal.

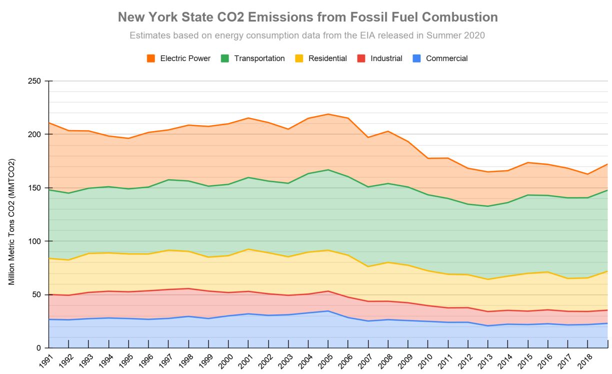


FIGURE 47 : *NYS fossil fuel emissions by sector*

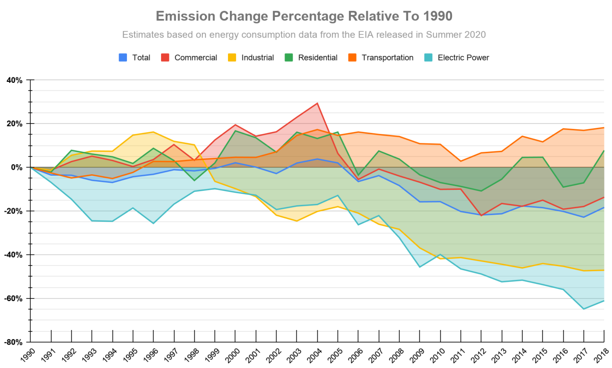


FIGURE 48: *NYS fossil fuel emissions sector % changes*

There is precedent for biogas application to the transportation sector around the world and within the United States. In Nordic countries, especially Sweden, this practice is very popular, and in some instances, producers are converting from electricity generation to fuel supply due to market advantages (IEA, 2018). Additional studies are necessary to determine which applications can result in the greatest reduction of emissions and which strategies are the most effective for meeting the CLCPA targets.

Energy investments

With legislative efforts to curb and redirect food waste, NYS should explore financial incentives to assist with relevant processing infrastructure and technologies. Biogas production systems have high start-up costs and high inherent financial risks when they are not managed properly. For private farm installations, farmers have typically had to rely on funding assistance programs to make these installations profitable and keep them maintained. There is precedent for the funding of these technologies at the national and state levels to accompany personal or private equity. Just as special financing programs and tax incentives, such as power purchase agreements (PPAs), were offered with the introduction of solar panel installations, analogous opportunities can be engineered for biogas production infrastructure and network designs to scale growth.

The USDA is one organization that has traditionally offered energy investments for biogas production. Throughout NYS, this federal department has invested $115 million across 967 projects that include solar, wind, energy efficiency, geothermal, AD, and renewable biomass. The lower Hudson Valley has received about 13%, or $15 million of this financial assistance across 117 projects, or 12% of the total. FIGURES 49 and 50 display the distribution of these projects and their respective funding by type and county. Over 93%, or $14 million of the funds allocated to the region have been directed to solar installations, with Orange and Sullivan Counties receiving $7.5 and $5 million, respectively for these project types. Meanwhile, across the state, $58 million has been allocated to renewable biomass and $6 million to AD. This is over 50% and 5% of the total assisted funds, respectively. The USDA clearly has an interest in investing in bioenergy across the state, and the lower Hudson Valley is well-positioned to take advantage of these opportunities. A complete system design, inclusive of renewable biomass, would establish a biogas production network coinciding with the food waste diversion programs that are about to take effect throughout NYS. There are even more opportunities within the USDA through the Advanced Biofuel Payment Program, and the Rural Energy for America Program. In addition, the US DOE offers funding through the US Department of Energy's Qualified Conservation Bonds. All funding channels should be explored to aid the local communities.

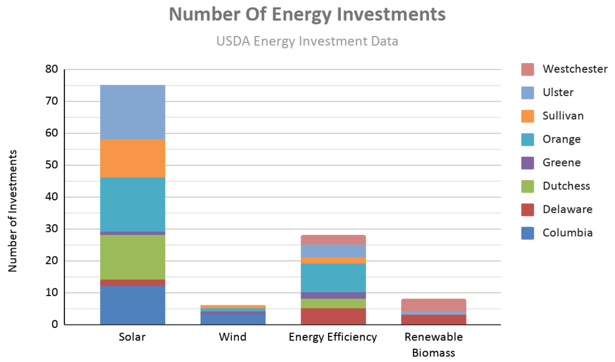


FIGURE 49: *Number of energy investments*

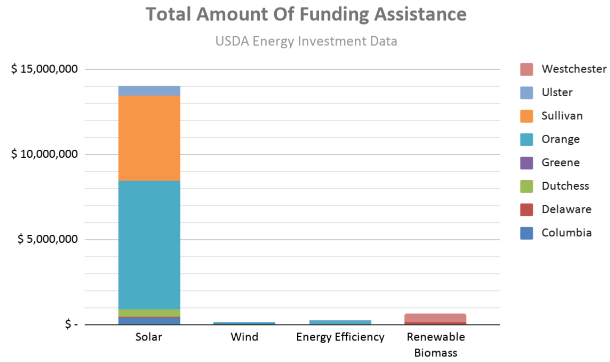


FIGURE 50: *Total amount of funding assistance*

In the past, NYSERDA has provided capacity and performance based incentives for ADs at the state level. Capacity types are provided during the startup phase, and performance types are offered annually based on the AD's production output. However, they have since shifted from financial incentives to funding assistance programs. An alternative third-party ownership consisting of a land and facility lease has developed into a common model that attracts outside investors. This results in a lower cost and mitigated risk for the site owner. Meanwhile, the third-party investor receives a return on capital through product sales and benefits from tax credits (NYSERDA AD Financing, 2014). In 2018, NYSERDA announced an offering of $16 million to accelerate the AD sector throughout the state (made available through the state's 10-year, $5.3 billion Clean Energy Fund). Nearly half of this amount was designated to fund new systems that could demonstrate a replicable business model or strategy that could be used to expand the AD marketplace. The remaining funds were used to cost-share the refurbishment of existing digesters and associated equipment to extend lifetime and expand capacity (AD Funding, 2018). However, this funding is no longer available today as more investments are allocated to solar, wind, electric vehicle infrastructure, and energy efficiency initiatives for the building sector. With new food waste laws planned to take effect in the coming years, policy makers need to consider reinstating these former programs to equip constituents with the accompanying processing facilities.

The NYS DEC has advocated for an increase in these funding opportunities at the state level. Specifically, their Beyond Waste publication advises the expansion of the "Empire State Development's (ESD) investment authority to allow for support of ADs and other technologies that can "cost effectively convert organic residuals to biogas and other energy products in addition to generating a valuable end product." ESD is the umbrella organization for the NYS Urban Development Corporation and the NY Job Development authority; two principal economic development public-benefit corporations. Biogas production can be advantageous for communities by creating new "green jobs." This renewable infrastructure is a scalable technology that can empower communities and embrace environmental justice initiatives.

This is one way in which lawmakers encourage and enhance resource valorization to accompany the effectiveness of their recent laws for large producers of food waste. A program can be designed to be inclusive of co-digestion opportunities that accommodates a complete biogas production network inclusive of many of the aforementioned available feedstocks. It would also help to secure profitability for the installation and a return on investment. When AD is partnered with an organic substrate provider, such as a food processor that generates a large amount of food waste, margin risk is greatly mitigated. These types of contracts are not often reliable though because they may only last for one or a few years which is far less than the typical 8 to 15 year lifespan (NYSERDA AD Financing, 2014). However, this constraint would be removed if coordinated on a collective basis with a centralized receiver of organics. Rather than partnering with individual institutions that may not be able to provide consistent and periodic volumes, composting centers would be able to control this flow and serve as a buffer capable of handling any potential overflow by means of traditional aerobic decomposition. The Food Waste Reduction & Diversion Reimbursement Program is a reimbursement grant program administered by NYSP2I for NYS businesses that may be available as a source of funding to help establish this type of program. It also provides opportunities to NYS businesses or not-for-profit companies that generate, haul or recycle large amounts of wasted food and food scraps and avoid disposal through landfilling and incineration. Tools like these are key for fostering a circular economy and building an effective GGDP for local markets.

Conclusion

Just as the Hudson Valley gave birth to the modern American environmental movement in the 1960s, this community is again positioned to prescribe a system of prosperity and sustainability to inspire the nation. With renewable energies as the primary focus for the future, herein lies an opportunity to consider new and innovative technologies that will propel and encourage the community for generations to come. A sophisticated biogas production network can be deployed throughout the region to facilitate the goals and initiatives set out by the CLCPA and model a circular economy in which resources are reused and recycled. By mapping the availability of these bioresources, corporations and policy makers can now use this data as a foundation for designing and implementing an integrated bioenergy system that creates new green jobs, and empowers environmental justice. Columbia, Dutchess, Delaware, Greene, Orange, Rockland, Putnam, Sullivan, Ulster, and Westchester are 10 NYS counties that have an expansive variety of potential biogas resources which can significantly shift the downstate region's dependency on fossil fuels to that of renewables. The Hudson Valley is positioned for a leadership role in these efforts, and can take advantage of relevant feedstocks to become a model for energy technology and system design throughout the state and the nation. The assessment results are as follows:

Review

The total amount of excess food waste generated by commercial entities is about 2,650 tons per week as estimated by NYS2PI. Strategic selection of food waste diversion among supermarkets, restaurants, and bakeries within counties that are proportionally responsible for the highest generation of this respective waste, can result in a capture of almost 45% of this market or 1,350 tons of food waste. Supermarkets in the retail sector are the highest contributor representing over 35% or 650 tons of this total. Restaurants represent the next largest contributor of excess food waste responsible for over 20% of the total, or 400 tons. Diverting this particular waste stream in Dutchess, Orange, Rockland, and Westchester Counties would capture over 12% or 325 tons of this total. Bakeries in the food processors sector represent almost 15% or over 260 tons of the total amount. Specifically diverting this particular waste stream in Dutchess, Orange, Rockland, and Westchester Counties would capture almost 10% or 250 tons of this total. Deploying a collection strategy based on the conclusions of this report can effectively capture 82% of this commercial segment. Each county should consider conducting their own independent organics and food waste studies to improve the accuracy of these findings. Additionally, these counties should all request designs and construction estimates for ADs to be implemented within their own respective counties. This would offer a more detailed and complete picture of organic waste streams that can be diverted from MSW to avoid landfilling and incineration.

Of the 165 wastewater treatment plants (WWTPs) in the region, only 18, or 11% utilize AD as a sewage sludge treatment method. This equates to about 50% of flows, or 109 million gallons per day (MGD), that may be able to be upgraded with anaerobic treatment technologies. The next NYS DEC survey of WWTPs throughout the state should request more information about biogas end-use (if AD is implemented at the facility). These specific inquiries can be modeled after the US EPA's categorizations (FIGURE 33). Additional details about hauling activity and facility power use should be requested to conduct an LCA and cost-benefit analysis conducive to operation upgrades.

There are at least 18 concentrated livestock feeding facilities where animal manure is collected in high quantities and could be applied to biogas production. These feedstocks locations should be examined to determine if their operations could benefit from AD installations, and if they could facilitate a co-digestion with multiple locally sourced feedstocks.

The lower Hudson Valley has over 300 thousand acres of farmland. A proper quantitative assessment of the amount of marginal and idle lands needs to be conducted to determine how much of this land could be desirable for biorops. A large portion of land has the potential to be revitalized through the production of biocrops while generating a value feedstock for AD. In addition, the 60 thousand acres of land trust & conservancy groups should be examined and assessed with this same perspective. This also applies to the 884 environmental clean-up sites identified by the NYS DEC. These organizations may be able to serve as leaders for carbon sequestration and soil restoration initiatives.

The water chestnut is an aquatic invasive which can be mechanically harvested and destroyed as a biogas feedstock. There are many infestations around the state and ongoing research relevant to biogas production seems promising. Meanwhile, the invasive variety of phragmites presents a more complicated scenario because of its close similarity to the native variety. Harvesting this plant could cause non target impacts of unknown dimensions (Phragmites, 2010).

While there are many closed landfills throughout the Hudson Valley, their potential for biogas production may have already declined. However, these sites could become ideal locations for ADs. They are, after all, centralized and were designed to accommodate heavy-weight vehicles and high hauler volumes. Implementing biogas production at these locations, which are already classified as commercial properties, may therefore be a viable and efficient option.

Finally, there are 19 composting facilities with food waste as a primary source where AD may be implemented as an intermediary process to effectively honor the food recovery hierarchy. Large facilities should be prioritized as biogas production centers to limit energy expended for transportation and to take advantage of existing supply lines. The byproduct can be applied to composting and distributed as is ordinarily practiced.

Looking to the future

This study prescribes a foundation of research elements to promote future investigative work for resource potential of biogas feedstocks in the Hudson Valley. Inputs for AD can have many variations and responses to different conversion pathways and technologies and optimizing these processes and flows is essential to successful implementations. Supply chains need to be assessed and designed in a way that can scale production (BR&D Bioeconomy, 2016) and bolster economic opportunities. Outflows need to be directed to beneficial uses so that losses are avoided and anthropogenic impacts are minimized. End of life ramifications must always be considered and, if possible, avoided. These are methods which best exemplify the food-energy-waste-water nexus and honor the UN’s sustainable development goals (SDGs).

Enhanced AD processes are continually being developed and portray an excitement for the future of the industry. One project with the US DOE at Argonne National Laboratory succeeded in developing a method in which more than 90% methane was produced from WWTP sludge (Biogas Roadmap, 2015). This type of innovation is inspiring the development of biogas production and can accelerate humanity's transition away from fossil fuels. Post-processing technologies such as hydrothermal carbonization (HTC), hydrothermal liquefaction (HTL), and pyrolysis may offer additional opportunities to capture more energy from the digestate and provide a gateway for extracting heavy metals and other harmful contaminants. The opportunities are limitless when analyzed as components of a continuous cycle.

The US DOT, USDA, US DOE, and US EPA are leading agencies available for biogas production assistance relative to transport, distribution, end-user research & development, and deployment. APPENDIX 5 lists some additional roles that these organizations serve and how they can help in the Hudson Valley. Counties and communities can take advantage of various national funding opportunities available for AD installations that aid startup costs and establish an operational system. This would reduce the bottleneck pressures of renewable energy that are prevented from reaching these downstate communities and diversify investments from solar installations to other beneficial renewable technologies. Finally, NYS legislators need to incorporate bioenergy into the CLCPA. This form of renewable energy is responsible for a large portion of NYS's power, and it serves a primary role in all global climate mitigation strategies and scenarios including that of the IPCC's 1.5°C mitigation pathway. Biogas production represents innovation for the future of these 10 counties. The time for implementation is now so that it coincides with new food waste diversion initiatives and upcoming low carbon fuel standards. The Hudson Valley is positioned for a leadership role in these efforts, and can take advantage of native feedstocks to become a model for this renewable technology and system design throughout the state and the nation.

Recommendations

- The NYS DEC survey of WWTPs throughout the state should request information about biogas end-use if AD is implemented at the facility. These specific inquiries can be modeled after the US EPA's categorizations (FIGURE 33). Additional details about hauling activity and facility power use should be requested so that there is sufficient information to conduct an LCA, MFA, and cost-benefit analysis conducive for analyzing operation upgrades and incorporation of additional feedstocks.

- Many county solid waste management plans (SWMPs) are outdated or not available online. They must be renewed and updated to reflect the latest federal and state sustainability goals. Historical records of these plans should also be accessible online with the NYS DEC.

- Each county should consider conducting their own independent organics and food waste studies to improve the accuracy of the findings presented in this report. These should include design and construction estimates for AD and WWTP co-digestion upgrades. This would offer a more detailed and complete representation of organic waste streams which can be diverted from MSW to avoid landfilling and incineration. Food waste collection strategies need to accompany these studies.

- Land Trusts & Conservancy groups should reexamine and assess their portfolios to establish proportions of land types and land uses that their organization presides over. These areas may serve as prime locations for research and field studies related to biocrop production that can contribute to the local bio-economy and offer educational outreach programs related to renewable biogas.

- Composting facilities should be investigated for more specific information on their input and output flows. Quantifying these values is necessary to assess AD opportunities at these locations and foster a better understanding of these waste stream flows throughout the region.

- Exemptions for state and local laws related to excess food waste need to be reexamined. The findings of this report suggest that the current policy excludes a large market share of excess food waste. Collection strategies should accompany this legislation.

- NYSERDA and other state organizations need to reinstate former funding programs that assist communities and individuals with opportunities for AD installations. These programs are necessary to accompany the prospective low carbon fuel standards that legislators are aiming to implement.

- Counties and communities should explore the various national funding opportunities for AD's to diversify and implement local sources of renewable energy. There are several programs with the USDA and the USDOT that can provide adequate resources for establishing a successful system.

- NYS legislators should seek to incorporate bioenergy into the CLCPA. This type of renewable energy capture is responsible for a large portion of NYS's power, and is part of all global climate mitigation strategies and scenarios including the IPCC's 1.5°C mitigation pathway.

- NYS counties can begin working with utility companies to establish effective pathways for RNG pipeline injection. Centralized facilities for gas cleaning and upgrading can be negotiated and installed to accommodate collective interests and regional initiatives.

- Avoided environmental impacts through the use of these feedstocks should be assessed and quantified. This can help to determine the best applications of RNG whether it be to the electricity or transportation sector. Mitigation of emissions need to be examined to recognize the system potential.

- Environmental clean-up centers and brownfields should be accessed for their potential to serve as areas for biocrops. Additional investigation must consider what site classifications would be acceptable for this type of land use and if there is potential for biocrops to restore these land parcels.

Appendices

APPENDIX 1: Background

Barriers & mitigation strategies

Table 6-3. **Small Plant Barriers and Mitigation Strategies**	
Barrier	**Mitigation Strategy**
Plant Too Small	• Use alternative feedstocks to increase biogas production. • Consolidate solids handling with other small plants or at a larger, centralized facility.
Lack of Available Capital	• Investigate alternative sources of funding.
Inadequate Payback/Economics	• Investigate alternative sources of funding. • Re-frame economics to something beyond simple payback. • Use alternative feedstocks to increase biogas production and provide a source of revenue associated with tipping fees.
Complications with Outside Agents	• Leverage current discussions/relationships with third parties.
Maintain Status Quo	• Highlight risk of status quo to decision makers. • Involve potential blockers in decision-making process.
Technical Merits and Concerns	• Simplify O&M. • Visit successful sites to improve familiarity/acceptance.
Complications with Liquid Stream	• Use chemical precipitation of phosphorus or deammonification process • At small plant scale, liquid biosolids program can avoid recycled nutrient issues.

Barriers to biogas use for renewable energy: WRF & NYSERDA (NYSERDA Biogas Barriers, 2012)

NYS biogas systems with food scraps

Facility Name	City	County	Type of Facility	Status
Morrisville State College	Morrisville	Madison	Stand-alone: Multi-source digester	Operational
Cayuga County Soil and Water Conservation District's Community Digester	Auburn	Cayuga	Stand-alone: Multi-source digester	Operational
Niagara BioEnergy	Wheatfield	Niagara	Stand-alone: Multi-source digester	Operational
Buffalo BioEnergy	West Seneca	Erie	Stand-alone: Multi-source digester	Under Construction
Patterson Farms	Auburn	Cayuga	Stand-alone: Industry dedicated digester	Operational
Anheuser-Busch Brewery	Baldwinsville	Onondaga	Stand-alone: Industry dedicated digester	Operational
Ridgeline Farm	Clymer	Chautauqua	Farms with AD that accept food waste or FOG	Operational
Lawnhurst Energy	Stanley	Ontario	Farms with AD that accept food waste or FOG	Operational
Hi-Vu	Oakfield	Genesee	Farms with AD that accept food waste or FOG	In permitting process
Synergy Dairy	Covington	Wyoming	Farms with AD that accept food waste or FOG	Operational
Gloversville-Johnstown Joint WWTP	Johnstown	Fulton	WWTP accepting food waste or FOG	Operational

Source: *Energy Information Administration (EIA)*

APPENDIX 2: Methods

NYS DEC biosolid management survey, 2015

NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

2015 BIOSOLIDS (SEWAGE SLUDGE) MANAGEMENT SURVEY

Facility Name: ____ SPDES No: NY-________________

This survey has been developed as a data collection tool for the update of the *Biosolids Management in New York State* report, last published in 2011. If you have any questions, please contact Molly Baker at (518) 402-8706, or by email: molly.baker@dec.ny.gov. This form may be scanned and emailed, or mailed in to the address at the right. Thank you!

Molly Baker
NYS Dept. of Environmental Conservation
625 Broadway, 9th Floor
Albany, NY 12233-7253

DESIGN FLOW: ____________ mgd 2015 AVERAGE ACTUAL FLOW: ____________ mgd

DO YOU SEND BIOSOLIDS (LIQUID SLUDGE) TREATED AT THE FACILITY TO ANOTHER WASTEWATER TREATMENT PLANT FOR MANAGEMENT OR PROCESSING?

☐ No, biosolids are managed by this facility ☐ Yes, biosolids are sent to: (facility name) ______________________________

BIOSOLIDS TREATMENT: (Check all that apply)

☐ Aerobic Digestion ☐ Septic Tank
☐ Anaerobic Digestion* ☐ Imhoff Tank
☐ Lime Stabilization ☐ Lagoon
☐ None ☐ Unknown
☐ Reed Bed ☐ Other (specify): ______________________________

*Do you accept food waste/food processing waste directly into the AD?
☐No ☐Yes: Type: ________________ Amount: ________________

*Are you interested in accepting food waste/food processing waste, etc. into your AD?
☐No ☐Yes; Please explain: ____

BIOSOLIDS DEWATERING:

☐ Belt Filter Press ☐ Drying Beds ☐ Plate & Frame Press
☐ Centrifuge ☐ Vacuum Filter ☐ None
☐ Other (specify): ____

DOES YOUR FACILITY ACCEPT SEPTAGE?

☐ No ☐ Yes; Quantity: ______________ gallons/year

DOES YOUR FACILITY ACCEPT BIOSOLIDS (OR LIQUID SLUDGE) FROM OTHER WASTEWATER TREATMENT PLANTS?

☐ No
☐ Yes List treatment plants: ____
____

TOTAL BIOSOLIDS QUANTITY FOR 2015: (Fill in at least one)

a) ____________________ dry tons/year

b) ____________________ cubic yards/year at ____________________ percent solids

c) ____________________ wet tons/year at ______________________ percent solids

d) ____________________ gallons/year at ________________________ percent solids

Does the above figure include biosolids received from other wastewater treatment plants?

☐ No

☐ Yes

CURRENT BIOSOLIDS END USE/DESTINATION:

a) METHOD(s):	b) QUANTITY:	c) NAME & LOCATION:
☐ Landfilling	_______________	____________________________
☐ Land application	_______________	____________________________
☐ Composting	_______________	____________________________
☐ Chemical stabilization (N-Viro)	_______________	____________________________
☐ Heat Drying or Pelletization	_______________	____________________________
☐ Incineration	_______________	____________________________
☐ Long-term lagooning	_______________	____________________________
☐ Storing in tanks on-site	_______________	____________________________
☐ Stockpiling on-site	_______________	____________________________
☐ Hauling to another facility	_______________	____________________________
☐ Other (specify): _______________	_______________	____________________________

PLANS TO CHANGE BIOSOLIDS MANAGEMENT AT YOUR FACILITY IN THE NEAR FUTURE?

☐ No

☐ Yes; please explain below:

____

____

____

ANY COMMENTS/CONCERNS ABOUT BIOSOLIDS MANAGEMENT?

____

____

Survey Responder:

Name: ________________________________

Phone: ________________________________

E-mail: ________________________________

Date: ________________________________

Chief Operator:

Name: ________________________________

Phone: ________________________________

E-mail: ________________________________

The following list represents the number of facilities that did not respond to this survey and therefore represent a gap in the flow and treatment data; Columbia (2), Delaware (0), Greene (1), Orange (4), Putnam (0), Rockland (0), Sullivan (1), Ulster (2), Westchester (2).

APPENDIX 3: Feedstocks & study results

Excess food waste

	NYS2PI	US EPA	SWMPs	NYS DEC	Facility
	Estimated	Estimated (Low)	Measured	Estimated 17.65% of MSW	Diverted and Measured
County	Food Waste Tons/Week	Food Waste Tons/Week	MSW Tons/Week	Food Scrap Tons/Week	Food Scrap Tons/Week
Columbia	96	21			
Delaware	37	9	747	132	99
Dutchess	322	135	3,788	669	
Greene	51	27			
Orange	441	275	5,168	912	
Putnam	54	29	747	132	
Rockland	316	148	6,796	1,200	
Sullivan	156	76			
Ulster	180	89	1,950	344	68
Westchester	992	584	17,262	3,047	
Total	**2,644**	**1,394**	**36,457**	**6,435**	**167**

County	Food Waste Tons/Year	Food Waste Tons/Year	MSW Tons/Year	Food Scrap Tons/Year	Food Scrap Tons/Year
Columbia	4,992	1,092			
Delaware	1,940	473	38,824	6,852	5,163
Dutchess	16,754	7,025	196,963	34,764	
Greene	2,626	1,394	0	0	
Orange	22,942	14,321	268,760	47,436	
Putnam	2,792	1,503	38,824	6,852	
Rockland	16,442	7,712	353,404	62,376	
Sullivan	8,091	3,957			
Ulster	9,339	4,628	101,379	17,893	3,537
Westchester	51,579	30,368	897,619	158,430	
Total	**137,498**	**72,472**	**1,895,773**	**334,604**	**8,700**

Food Waste: Commercial food waste estimates

	Estimated	Estimated (Low)	NYSDEC Estimate
County	**NYS2PI**	**US EPA**	**46% of 17.65% of MSW**
Columbia	96	21	0
Delaware	37	9	61
Dutchess	322	135	308
Greene	51	27	0
Orange	441	275	420
Putnam	54	29	61
Rockland	316	148	552
Sullivan	156	76	0
Ulster	180	89	158
Westchester	992	584	1401
Total	**2,644**	**1,394**	**2,960**

Food Waste: Total food waste estimates

	Extrapolated	Extrapolated	NYSDEC Estimate
County	**NYS2PI / 46%**	**US EPA / 46%**	**17.65% of MSW**
Columbia	209	46	
Delaware	81	20	132
Dutchess	700	294	669
Greene	110	58	
Orange	959	599	912
Putnam	117	63	132
Rockland	687	322	1,200
Sullivan	338	165	
Ulster	390	193	344
Westchester	2,156	1,270	3,047
Total	**5,748**	**3,030**	**6,435**

Food Waste: Sector Sources (NYS2PI)

County	Food Processors	Hospitality	Institutions	Restaurants	Retail	Weekly Total	Annual Total
Columbia	65.1	0.2	11.1	8.5	11.1	**96**	**4,992**
Delaware	7.4	1.1	6.3	5.3	17.2	**37.3**	**1,940**
Dutchess	93.1	12.3	68.5	51.9	96.4	**322.2**	**16,754**
Greene	13.2	3.6	11.2	5.2	17.3	**50.5**	**2,626**
Orange	207.3	15.4	34	74.2	110.3	**441.2**	**22,942**
Putnam	3.7	0.4	5	10.6	34	**53.7**	**2,792**
Rockland	146.6	13.9	33.5	59.1	63.1	**316.2**	**16,442**
Sullivan	111.9	2.1	11.2	8.7	21.7	**155.6**	**8,091**
Ulster	11.9	23.8	39	30.5	74.4	**179.6**	**9,339**
Westchester	363.8	43.2	153.6	140.9	290.4	**991.9**	**51,579**
Total	**1024.0**	**116.0**	**373.4**	**394.9**	**735.9**	**2644.2**	**137498.4**

Food Waste: Primary Sector Sources (NYS2PI - Filter 1)

County	Food Processors	Institutions	Restaurants	Retail	Weekly Sub-Total	Total Available
Columbia	65.1				**65.1**	**96.0**
Delaware				17.2	**17.2**	**37.3**
Dutchess	93.1	68.5	51.9	96.4	**309.9**	**322.2**
Greene	13.2			17.3	**30.5**	**50.5**
Orange	207.3		74.2	110.3	**391.8**	**441.2**
Putnam				34.0	**34.0**	**53.7**
Rockland	146.6		59.1		**205.7**	**316.2**
Sullivan	111.9				**111.9**	**155.6**
Ulster				74.4	**74.4**	**179.6**
Westchester	363.80	153.60	140.90	290.40	**948.7**	**991.9**
Total	**1,001.00**	**222.10**	**326.10**	**640.00**	**2,189.20**	**2,644.20**
% Weekly Sub-Total	**45.72%**	**10.15%**	**14.90%**	**29.23%**	**100.00%**	
% of Total Available	**37.86%**	**8.40%**	**12.33%**	**24.20%**		**82.79%**

Food Waste: Primary Industry Sources (NYS2PI)

County	Bakeries	Brewery	Canning & Specialty	Meat	Soft drinks	Winery
Columbia	3.2	5.8	0.2	2.1	29.2	1.2
Delaware	1.3	2.9				
Dutchess	22.8	13.6		1.6	1.2	4.5
Greene	1.9	9.4				0.6
Orange	31.7	17.4			72.1	15.4
Putnam	2.1			0.2		0.6
Rockland	41.7	6	9		0.8	1.2
Sullivan	2.9	2.9		91.1		1.4
Ulster						8.9
Westchester	153.5	14.7	48.7	1	11.7	45.1
Sub-Total	**261.1**	**72.7**	**57.9**	**96**	**115**	**78.9**

County	Colleges & Universities	Correctional Facilities	Hospitals	Nursing Homes	Restaurants	Supermarkets
Columbia	0.5	1.9	4.2	4.5	8.5	6
Delaware	3.9	0.2	0.9	1.3	5.3	15.4
Dutchess	20.6	20.2	14.1	13.6	51.9	89.9
Greene		9.5		1.7	5.2	11.4
Orange	4.5	4.2	16.1	9.2	74.2	99.8
Putnam		0.4	3.6	1	10.6	33.5
Rockland	9.8	0.8	12.2	10.7	59.1	61.1
Sullivan	0.4	5.5	2.5	2.8	8.7	20.4
Ulster	10.2	11.7	9	8.1	30.5	65.2
Westchester	40.9	15.8	55.2	41.7	140.9	286.4
Sub-Total	**90.8**	**70.2**	**117.8**	**94.6**	**394.9**	**689.1**

Food Waste: Primary Industry Sources (NYS2PI - Filter 2)

	Food Processors					
County	**Bakeries**	**Brewery**	**Canning & Specialty**	**Meat**	**Soft drinks**	**Winery**
Columbia					29.2	
Delaware						
Dutchess	22.8	13.6				
Greene		9.4				
Orange	31.7	17.4			72.1	15.4
Putnam						
Rockland	41.7					
Sullivan				91.1		
Ulster						8.9
Westchester	153.5	14.7	48.7		11.7	45.1
Sub-Total	**249.7**	**55.1**	**48.7**	**91.1**	**113**	**69.4**
Sub-Total %	**13.26%**	**2.93%**	**2.59%**	**4.84%**	**6.00%**	**3.69%**
Sub-Total Available	**261.1**	**72.7**	**57.9**	**96.0**	**115.0**	**78.9**
Sub-Total % Available	**95.63%**	**75.79%**	**84.11%**	**94.90%**	**98.26%**	**87.96%**
Total % Available	**9.44%**	**2.08%**	**1.84%**	**3.45%**	**4.27%**	**2.62%**

WWTPs

County	DEC Region	Anaerobic Digestion	Number of Facilities	2015 Actual Flow (MGD)	2015 Actual Flow (MG/Week)
Columbia	4	0	9	2.93	20.52
Delaware	4	1	12	3.02	21.15
Dutchess	3	2	26	15.96	111.75
Greene	4	0	11	1.60	11.19
Orange	3	2	33	27.59	193.10
Putnam	3	1	11	1.63	11.38
Rockland	3	2	8	30.37	212.60
Sullivan	3	3	20	6.24	43.71
Ulster	3	5	21	9.49	66.41
Westchester	3	2	14	120.03	840.22
Total		**18**	**165**	**218.86**	**1532.04**

Biosolids

County	Landfilling (dry tons)	Land applied (dry tons)	Compost	Incineration (dry tons)	Hauling to another facility (dry tons)
Columbia	266.7	0	61.39	108.66	34.109
Delaware	3289.28	0	22857.8	0	14.86
Dutchess	1661.7	0	200	2504.467	6557.9
Greene	180.6	0	0	94.5	29.8
Orange	1723.82	582.02	50	2520.68	830.48
Putnam	0	0	0	259.66	435.07
Rockland	1063.5	0	3302.98	0	0
Sullivan	339.48	0	0	174	234.61
Ulster	1139.19	0	76.64	0	179.5
Westchester	187.5	9033	0	6917	4197.09
Total	**6295.79**	**9615.02**	**3629.62**	**12470.307**	**12464.45**

Livestock feeding centers (number of animals)

County	Mature Dairy Cattle	Heifers	Other Cattle	Horses
Columbia	4,705	3,595	0	0
Delaware	765	655	0	0
Dutchess	385	360	0	0
Greene	0	0	0	0
Orange	400	475	0	0
Sullivan	0	0	44	400
Ulster	0	0	0	1,300
Westchester	0	0	0	146
Total	**6,255**	**5,085**	**44**	**1,846**

County	Broilers	Layers	Ducks	Other
Columbia	0	0	0	0
Delaware	0	0	0	0
Dutchess	0	0	0	0
Greene	0	72,000	0	16,000
Orange	39,000	135,000	0	0
Sullivan	155,000	240,000	170,000	0
Ulster	0	0	0	0
Westchester	0	0	0	0
Total	**194,000**	**447,000**	**170,000**	**16,000**

Biocrop Land Availability

Farm Land

County	Total Crop Acreage (2007)	No. of Farms (2007)	Avg. Farm Size Acres (2007)
Columbia	63,704	554	192
Delaware	68,959	747	222
Dutchess	46,938	656	156
Greene	22,234	286	155
Orange	46,268	642	126
Putnam	1,286	72	78
Rockland	128	21	0
Sullivan	24,614	323	156
Ulster	31,683	501	150
Westchester	2,512	106	80
Total	**308,326**	**3908**	

Land Trusts & Conservancy Groups

Organization	Acres
Columbia Land Conservancy	4,500
Dutchess Land Conservancy	43,500
Esopus Creek Conservancy	353
Hudson Highlands Land Trust	2,866
Stony Kill Foundation	1,000
Wallkill Valley Land Trust	255
Westchester Land Trust	9,000
Total	**61,474**

Environmental Clean-Up & Brownfields Site Classification

County	2	3	4	A	C	N	P	PR	TOTAL
Columbia	2	1		4	7	11		1	**26**
Delaware	2		6	1	3	7	1		**20**
Dutchess	11	1	19	9	35	77	4		**156**
Greene		2	3		5	12		2	**24**
Orange	13	1	14	24	20	41	6	4	**123**
Putnam	1		6	1	2	22	2	1	**35**
Rockland	9		6	10	28	51	3	2	**109**
Sullivan	2		1	2	3	14			**22**
Ulster	5	1	9	9	17	26	5	1	**73**
Westchester	14		13	76	90	87	9	7	**296**
Total	**59**	**6**	**77**	**136**	**210**	**348**	**30**	**18**	**884**

Landfills

County	Owner Type	Activity Desc	Authorization Issue Date	Expiration Date
Delaware	Private	Landfill - C&DD - permit	04/30/2018	04/30/2023
Delaware	Private	Landfill - land clearing debris	09/24/2004	
Delaware	County	Landfill - MSW - permit	06/01/2014	06/04/2019
Delaware	County	Landfill - C&DD - permit	06/01/2014	06/01/2019
Greene	Private	Landfill - land clearing debris	03/17/2017	

Invasive species satellite images

IMAGE 7: *Denning Point (water chestnut)*

IMAGE 8: *Wappinger Creek (water chestnut)*

IMAGE 9: *Norrie Point (water chestnut)*

IMAGE 11: *Iona Island (phragmites marsh)*

IMAGE 12: *Constitution Island (phragmites marsh)*

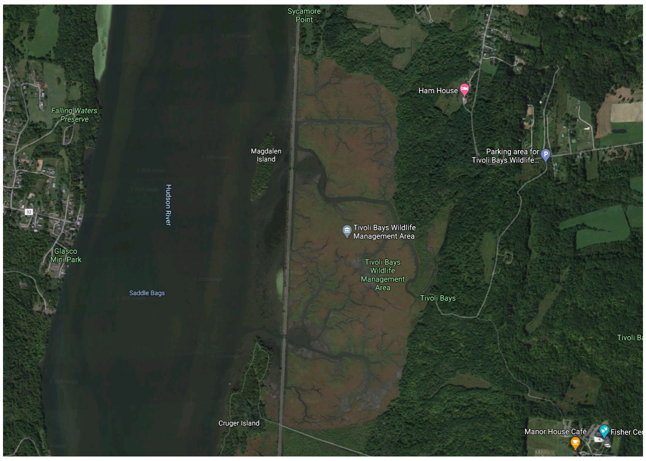


IMAGE 13: *Tivoli North Bay (phragmites marsh)*

Water chestnut infestation sample

Aquatic Water Chestnut infestation *(outlined in red)* - Algonquin Park, Newburgh, NY - Orange County

Volunteer water chestnut removal efforts, Algonquin Park, Summer 2016 - *Images provided by Nick Catania*

Composting Facilities

County	NYS Dept of Corr.	Education Institute	Cornell Coop	Farm	Govern ment	Non-Profit	Private	Total
Columbia	1				1		1	**3**
Delaware					1			**1**
Dutchess	2	2	1	1	1		2	**9**
Greene	1			1				**2**
Orange	2			2	1		1	**6**
Putnam			1				1	**2**
Rockland		1	1		2		1	**5**
Sullivan	1			1		1	1	**4**
Ulster	2			2	1	2	2	**9**
Westchester		3		1	7	2	2	**15**
Total	**9**	**6**	**3**	**8**	**14**	**5**	**11**	**56**

County	Biosolids	Food Scraps	Manure	MSW	Small Scale	Yard Waste
Columbia		1				2
Delaware				1		
Dutchess		5	2		1	1
Greene		1	1			
Orange		2	2			2
Putnam		1			1	
Rockland	1				1	3
Sullivan		2	2			
Ulster		4	3			3
Westchester		3	1		3	8
Total	**1**	**19**	**11**	**1**	**6**	**19**

APPENDIX 4: Discussion

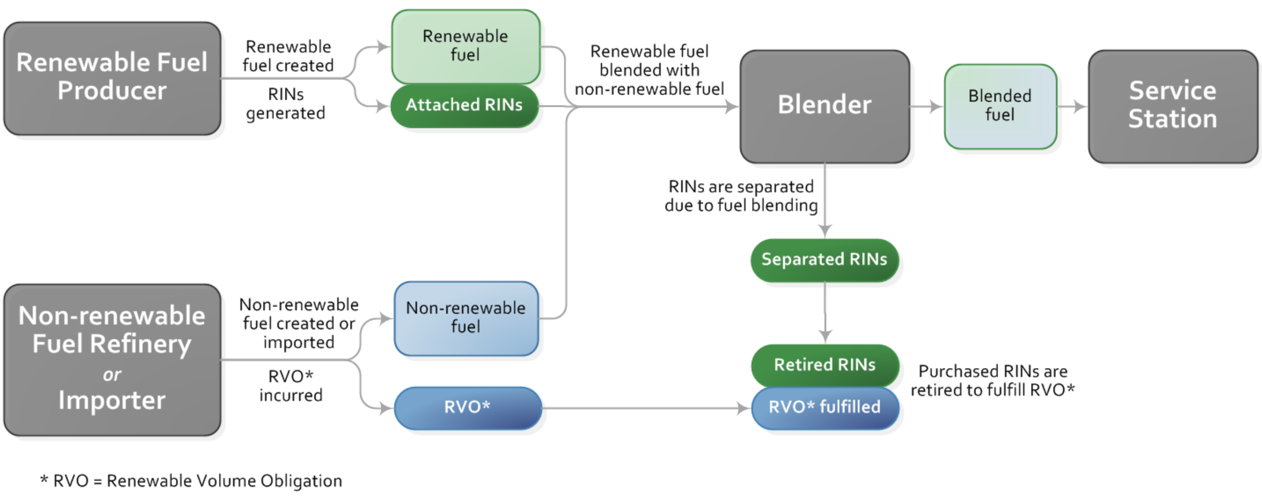
RFS: D Codes for fuel pathways

	Fuel Type	Feedstock	Production Process Requirements	D-Code
Q	Renewable Compressed Natural Gas, Renewable Liquefied Natural Gas, Renewable Electricity.	Biogas from landfills, municipal wastewater treatment facility digesters, agricultural digesters, and separated MSW digesters; and biogas from the cellulosic components of biomass processed in other waste digesters.	Any	3 cellulosic biofuel
T	Renewable Compressed Natural Gas, Renewable Liquefied Natural Gas, and Renewable Electricity.	Biogas from waste digesters	Any	5 advanced

Approved Pathways for Renewable Fuel | Renewable Fuel Standard Program | US EPA

https://www.epa.gov/renewable-fuel-standard-program/approved-pathways-renewable-fuel

RFS: Example lifecycle of a RIN

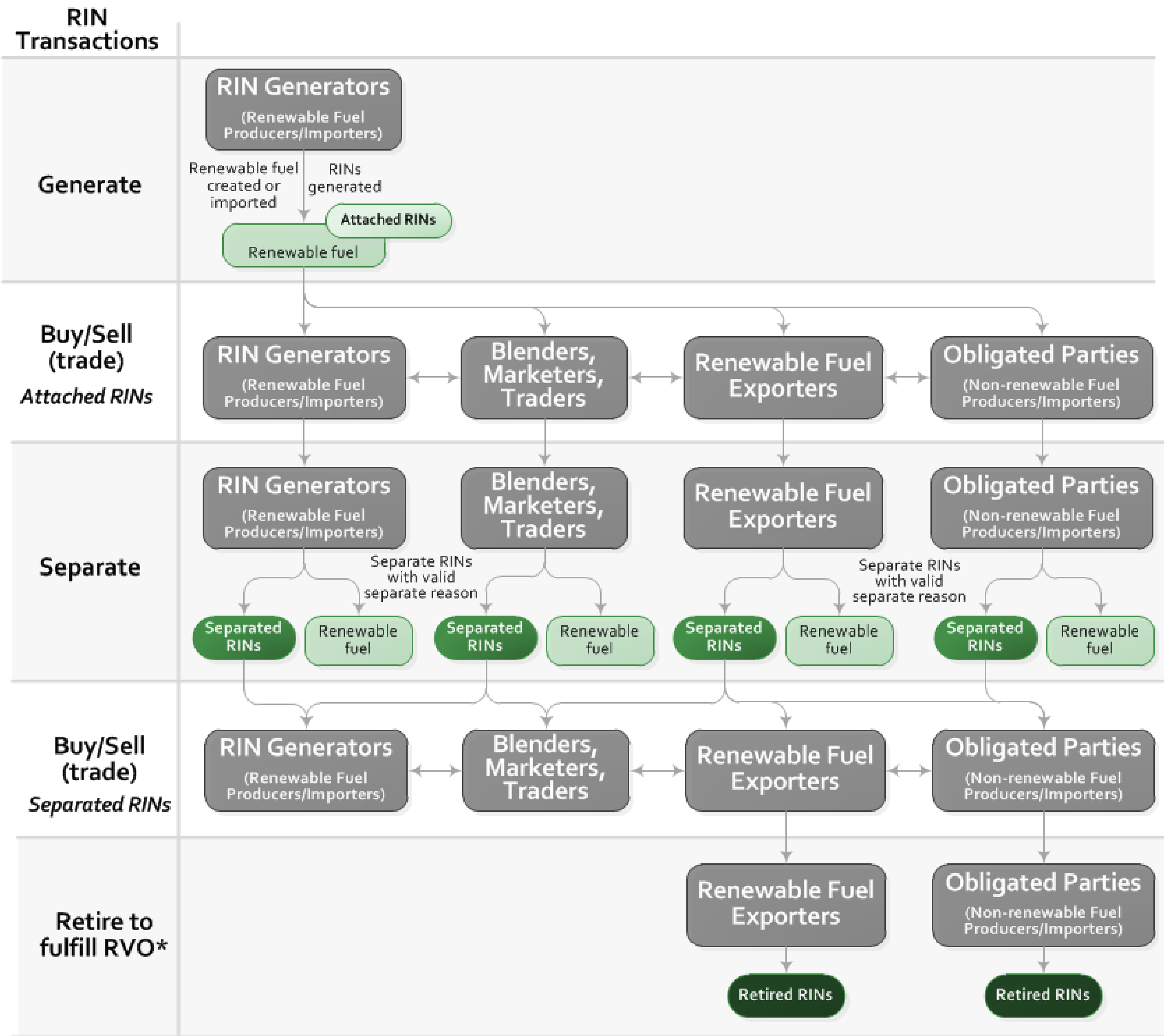


Renewable Identification Numbers (RINs) under the Renewable Fuel Standard Program

Renewable Fuel Standard Program | US EPA

https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard#Transactions

RFS: RIN transactions in the EMTS



*RVO = Renewable Volume Obligation

Renewable Identification Numbers (RINs) under the Renewable Fuel Standard Program

Renewable Fuel Standard Program | US EPA

https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard#Transactions

ABC RIN Calculator

AMERICAN BIOGAS COUNCIL

RIN Calculator

A tool created by the ABC's RNG Committee

1 Inputs 2 Results 3 Share

Standard cubic feet per minute (scfm) of biogas

Methane content of your raw biogas (% CH4)

Note: Input values as percentages (not decimals).

Upgrading system efficiency [CH4 recovery] x [availability] (%)

Note: This is project- and upgrading vendor-specific. If you are calculating the value of upgraded biogas/RNG, instead of raw biogas, enter 100 here.

Lower heating value of a gallon of gasoline

Note: US Department of Energy uses 114,000

Lower heating value of a gallon of diesel

Note: ABC recommends 127,000

Market value of one RIN ($)

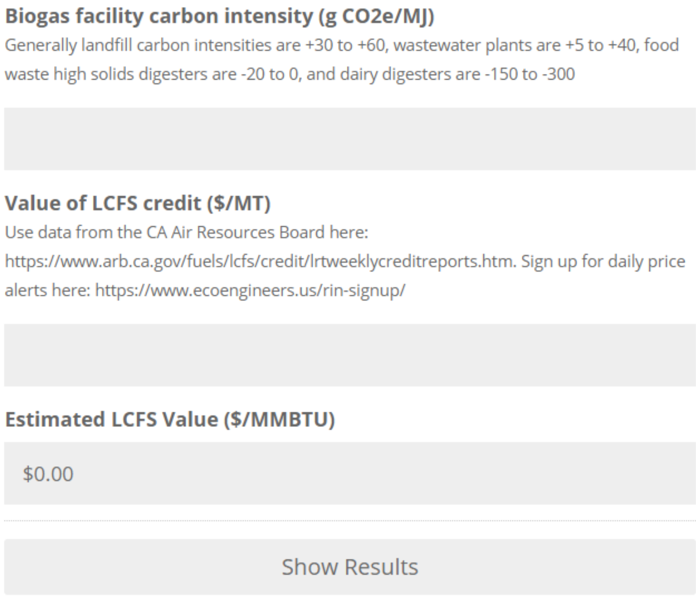
Note: Ensure correct RIN value used - D3 or D5. Sign up for daily price alerts here: https://www.ecoengineers.us/rin-signup/

LCFS Value

Note: Depends on the GREET net carbon intensity for your project. If you know your project's carbon intensity and the baseline carbon intensity for the fuel your biogas is replacing, you can estimate your value/MMBTU below.

Baseline carbon intensity (g CO2e/MJ)

CA gasoline is 95.86, CA conventional natural gas is 67.70 and CA diesel is 94.71. CA Air Resources Board lookup table here: https://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf



Biogas facility carbon intensity (g CO2e/MJ)

Generally landfill carbon intensities are +30 to +60, wastewater plants are +5 to +40, food waste high solids digesters are -20 to 0, and dairy digesters are -150 to -300

Value of LCFS credit ($/MT)

Use data from the CA Air Resources Board here: https://www.arb.ca.gov/fuels/lcfs/credit/lrtweeklycreditreports.htm. Sign up for daily price alerts here: https://www.ecoengineers.us/rin-signup/

Estimated LCFS Value ($/MMBTU)

$0.00

Show Results

RIN Calculator | American Biogas Council
https://americanbiogascouncil.org/resources/rin-calculator/

NYS Senate Bill S4003A

STATE OF NEW YORK

4003--A

2019-2020 Regular Sessions

IN SENATE

February 25, 2019

Introduced by Sens. PARKER, ADDABBO, BAILEY, BIAGGI, BRESLIN, BROOKS, CARLUCCI, COMRIE, GAUGHRAN, GIANARIS, GOUNARDES, HARCKHAM, HOYLMAN, KAMINSKY, KAPLAN, KENNEDY, KRUEGER, LIU, MARTINEZ, MAY, MAYER, METZGER, MONTGOMERY, PERSAUD, RIVERA, SALAZAR, SANDERS, SEPULVEDA, SERRANO, SKOUFIS, STAVISKY, THOMAS -- read twice and ordered printed, and when printed to be committed to the Committee on Environmental Conservation -- committee discharged, bill amended, ordered reprinted as amended and recommitted to said committee

AN ACT to amend the environmental conservation law, in relation to establishing the "low carbon fuel standard of 2019"

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

Section 1. Short title. This act may be known and may be cited as the "low carbon fuel standard of 2019".

§ 2. The environmental conservation law is amended by adding a new section 19-0329 to read as follows:

§ 19-0329. Low carbon fuel standard.

(1) A low carbon fuel standard is hereby established. The low carbon fuel standard is intended to reduce carbon intensity from the on-road transportation sector by twenty percent by two thousand thirty, with further reductions to be implemented based upon advances in technology as determined by the commissioner.

(2) The low carbon fuel standard shall apply to all providers of transportation fuels in New York, shall be measured on a full fuels lifecycle basis and may be met through market-based methods by which providers exceeding the performance required by a low carbon fuel standard shall receive credits that may be applied to future obligations or traded to providers not meeting the low carbon fuel standard. For purposes of this section the term "providers" shall include, but shall not be limited to, all refiners, blenders, producers or importers of transportation fuels, "carbon intensity" means the quantity of lifecycle

EXPLANATION--Matter in *italics* (underscored) is new; matter in brackets [-] is old law to be omitted.

LBD09329-04-9

greenhouse gas emissions per unit of fuel energy, and "full fuels lifecycle" means the aggregate of greenhouse gas emissions, including direct emissions and significant indirect emissions, such as significant emissions from land use changes as determined by the commissioner. The full fuels lifecycle includes all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel by the ultimate consumer. In calculating full fuels lifecycle greenhouse gas emissions, the mass values for all non-carbon-dioxide greenhouse gases must be adjusted to account for their relative global warming potentials. This conversion shall use the most appropriate conversion relative to global warming potentials as determined by the commissioner.

(3) Within twenty-four months following adoption of the low carbon fuel standard, the commissioner, in consultation with the New York state energy research and development authority, shall promulgate regulations establishing a low carbon fuel standard with performance objectives to implement subdivision one of this section. Such regulations may be phased into effect giving priority to the heavy-duty transportation sector consisting of vehicles with the classification of six or higher as classified by the Federal Highway Administration. The low carbon fuel standard shall take into consideration the low carbon fuel standard adopted in California and other states, may rely upon the carbon intensity of values established for transportation fuels in such states and shall include coordination with other Northeastern states to promote regional reductions in greenhouse gas emissions.

(4) The regulations adopted pursuant to this section shall include fees for the registration of providers to offset the costs associated with implementation of the low carbon fuel standard.

(5) Within twenty-four months following the adoption of regulations implementing a low carbon fuel standard, the commissioner shall report to the legislature regarding the implementation of the program, the reductions in greenhouse gas emissions that have been achieved through the low carbon fuel standard and targets for future reductions in greenhouse gas emissions from the transportation sector.

(6) Nothing in this section shall preclude the department from enacting or maintaining other programs to reduce greenhouse gas emissions from the transportation sector.

§ 3. This act shall take effect immediately.

APPENDIX 5: Summary

Helpful agencies

Agency	Feedstock Supply	Biomass Conversion	Bioenergy Distribution	Bioenergy End Use
DOE	Blue, Green, Yellow, Gray	Blue, Green, Yellow, Orange, Gray	Green, Yellow, Gray	Blue, Green, Yellow, Orange, Gray
USDA	Blue, Green, Yellow, Orange, Gray	Blue, Green, Yellow, Orange	Blue, Green, Yellow, Orange, Gray	Blue, Yellow, Orange, Gray
DOT	Green, Yellow, Orange, Gray	Blue, Yellow, Gray	Blue, Green, Yellow, Orange, Gray	Blue, Green, Yellow, Orange, Gray
EPA	Blue, Green, Yellow, Orange, Gray	Blue, Green, Yellow, Orange, Gray	Blue, Green, Yellow, Orange, Gray	Blue, Green, Yellow, Gray
DOI	Blue, Yellow	Yellow		
NSF	Blue, Green, Orange	Blue, Green, Yellow, Orange	Green	
DoD		Yellow, Gray	Blue, Yellow, Orange, Gray	Blue, Yellow, Orange, Gray

- Blue: Use an integrated systems approach
- Green: Provide the science and the technology
- Yellow: Public and private collaboration to overcome barriers and accelerate deployment
- Orange: Develop a workforce for the future bioeconomy
- Gray: Understand and inform policy

Federal Activities Report on the Bioeconomy (BR&D Bioeconomy, 2016)

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