Master's thesis

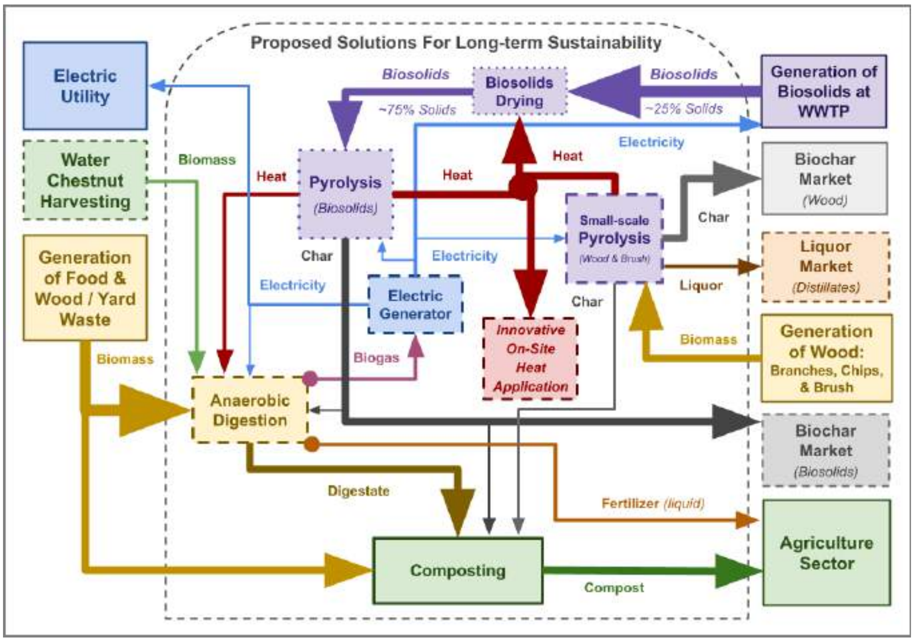
NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

Nicholas Paul Catania

Circular Biogas Systems For New York's Greater Hudson Valley

www.HudsonValleyBiogas.org

Master's thesis in Industrial Ecology
Supervisor: Francesco Cherubini
September 2021



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Abstract

New York State (NYS) has made great legislative strides in regards to climate change mitigation, excess food waste generation, and the renewable energy transition. Specifically, the NY Climate Act, the Food Donation & Food Scraps Recycling Law, and the introduction of the NY Low Carbon Fuel Standard have been key to introducing and adopting these initiatives. Biogas and other forms of renewable bioenergy will play an important role in New York State's transition to a circular economy, yet there are many uncertainties regarding the most efficient and sustainable constructs of an integrated system design. By combining a series of technologies related to anaerobic digestion (as well as pyrolysis) and cross-referencing these with locally available feedstocks and existing infrastructures, new and innovative system designs can be formulated to create localized circular production cycles while offering a series of solutions strategically aligned with a food-energy-waste-nexus. Success of these initiatives relative to sustainability, environmental justice, and workforce development, is highly dependent on capacity building efforts between stakeholders and the environment. The strength of these interdependencies is paramount to developing resilient and long-lasting business practices that maximize impact with credible, measurable claims and catalyze further investment.

This report offers 10 circular biogas production system designs for the greater Hudson Valley which covers an area extending from the northern limits of New York City and up through the capital district. In consideration of the excess food waste legislative stipulation that requires all NYS DEC identified generators to divert their organics to beneficial use if they are within 25-miles of a respective recycling facility, each proposal is located approximately 25- to 50-miles from each to offer networked regional coverage. (Some overlap is intended to facilitate collection and transportation logistics.) The resulting radial coverage spans the majority of the 11 NY counties selected for this study and suggests corresponding infrastructure investments in 8 of them including Albany, Delaware, Dutchess, Orange, Rockland, Sullivan, Ulster, and Westchester. Special attention has been given to the state's identified environmental justice regions in an effort to develop these systems with relevant humanitarian programs that can educate local residents on the opportunities and economical benefits available through conscious recycling efforts and systems thinking. The proposed installations will help to revitalize impoverished regions of NYS while creating green jobs and setting the necessary foundations for scaling innovative circular economy initiatives. These investments are necessary for long-term growth, increasing the workforce skills of citizens, and facilitating sustainable solutions for the greater Hudson Valley.

Presented herein is a regional plan of action and instructional outline designed to serve as a foundation for public engagement and implementation. The 10 proposed systems are as follows; 1) Monticello Transfer Station, 2) Taylor-Montgomery LLC, 3) Beacon Recycling & Transfer, 4) WeCare Denali | Rockland County, 5) Ulster County Resource Recovery Agency, 6) Delaware County Solid Waste Management Center, 7) Westchester County Wastewater Treatment Plant, 8) Wheelabrator Westchester, 9) Dutchess County Resource Recovery Agency, and 10) Town Of Colonie Landfill. Each integrated technological design offers innovative solutions that are iconic representations of circular production systems and treat available resources as high value materials for upcycle. Overall, this initiative will help NYS transition from its outdated linear business practices to more sustainable solutions that align with current legislative initiatives and meet the evolving and necessary demands of a low-carbon future. Each component plays an indicative and strategic role in the greater mission of achieving international sustainability, and these precedents can be scaled and replicated across the state, country, and world to truly empower the people, planet, and prosperity.

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 specs 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 in order 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. The completion of this work is not the end of my path, but the beginning, and I will remain connected to my homeland no matter where the world may take me.

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
ESG	|	Environmental, Social & Governance
FEWWN	|	Food-Energy-Water-Waste Nexus
GDP	|	Gross Domestic Product
GGDP	|	Green Gross Domestic Product
GHG	|	Greenhouse Gas Emissions
HPTA	|	Humic Products Trade Association
HVRC	|	Hudson Valley Regional Council
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
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
REDC	|	Regional Economic Development Council
RFS	|	Renewable Fuel Standard
RRA	|	Resource Recovery Agency
RNG	|	Renewable Natural Gas
SWM	|	Solid Waste Management
SWMP	|	Solid Waste Management Plan
UN SDGs	|	United Nations Sustainable Development Goals
USA (US)	|	United States of America (United States)
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
WWRF	|	Wastewater Recovery Facility
WWTP	|	Wastewater Treatment Plant

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Introduction: Motivations for action

The greater Hudson Valley is faced with a series of challenges that relate to transitioning towards a circular economy. This region needs a closed-loop production model that focuses on minimizing resource input, maximizing use of byproducts, and eliminating waste. Unsustainable consumption patterns of goods and services, driven by decades of extractive and polluting processes, must now be addressed by the current generation. Over recent years, a great number of residents have assembled into local and regional public action groups aimed to mitigate climate change and pursue developments that are designed to preserve and protect the environment. This form of paradigm shift can significantly alter current, linear business models and welcome the implementation of a regenerative economic cycle that values reuse, repair, refurbishment, remanufacturing, and recycling. 10 circular biogas production systems are herein proposed to meet these challenges for the region that extends from the northern limits of NYC and up through the capital district of Albany.

Previous assessment

In Fall of 2020, Hudson Valley Biogas published an assessment of resource potential for biogas production in New York's Hudson Valley. The outcomes explored the viability of this renewable technology across 10 counties and revealed ideas and concepts that can create an environmentally beneficial and economically prosperous industry. Through this research, a collection of quantitative and qualitative data on available biogas feedstocks inclusive of excess food waste, biosolids, animal manure, landfills, biocrops (crops grown specifically for anaerobic digestion), invasive species, and compost was aggregated. These results preface the following 10 circular system proposals and their respective conclusions. The data has been incorporated into this report's methodology and should be considered essential background information for continued implementation discussions.

Four drivers of change

This report provides a series of biogas solutions for New York's greater Hudson Valley while addressing four significant categories of need; A) managing excess food waste according to legislation mandates, B) restoring ecosystems overburdened with the invasive aquatic water chestnut, C) achieving NY's CLCPA renewable initiatives aimed to mitigate climate change, and D) catalyzing environmental justice efforts to revitalize our impoverished communities. Through these four perspectives, the proposed installations can help the region accomplish its economic development goals in an environmentally just manner while setting the necessary foundations for scaling related infrastructure. System solutions will invite additional innovation to the area and create a hub for education and information exchange. Investments in these technologies are paramount for long-term community growth, increasing workforce skills, and proliferating green jobs. With this strategy, the public can engage with many regional stakeholders, and welcome a unified pathway for sustainability. Further examination of these respective needs are as follows:

Excess food waste

In April 2019, New York State (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 this biomass for beneficial use. Diversion of this waste stream should follow the EPA's Food Recovery Hierarchy and, if suitable, first be donated to food banks, soup kitchens, and shelters. If the food is expired and pre-consumer, it should be added to animal feed (EPA Wasted Food Report, 2018). If it doesn't meet regulations for these two categories, it must be diverted to organic recycling as long as there is a facility within 25-miles of the point of origin. Anaerobic digestion falls within the EPA's next hierarchical category of 'industrial uses,' and the NY legislation specifically includes 'organics recycling on-site via in vessel anaerobic digestion' as an acceptable method of managing this waste (NYS Food Law, 2019). Therefore, this law presents an opportunity to apply localized biogas production throughout the Hudson Valley as a means to meet these stipulations. This solution eliminates a significant portion of otherwise necessary transport activity while conserving the food's inherent energy and nutrients within the local economy. In this way, these compounds can be recycled into the local ecosystem and shared throughout communities.

Watershed restoration

NYS has been exposed to many invasive plant species which have negatively impacted water ecosystems along with recreation and tourism. Water chestnut, or *Trapa natans* (FIGURE A), 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. This plant thrives in freshwater lakes, ponds, slow-moving streams, and rivers by establishing a long root network that anchors to the bottom of the waterbody (DEC, Water Chestnut). Each year, public taxes help fund management and removal efforts to temporarily reclaim some water access for recreational use and local biodiversity. Unfortunately, these actions have not been able to mitigate the plant's prevalence as it continues to overburden priority water bodies (DEC Invasive, 2018).

Anaerobic digestion offers an innovative solution to this problem by utilizing *Trapas natans* as a feedstock for biogas production. This alternative management concept for the Hudson Valley can serve as an economic driver for ecosystem restoration efforts while offering a renewable and energy efficient installation. According to the American Biogas Council (ABC), this species produces almost 50% more methane than cow manure. In addition, the process extracts excess phosphorus and nitrogen compounds which have eutrophied the Hudson River watershed and compounded this species' overgrowth. These nutrients can be returned to the agricultural sector and simultaneously create a pathway for biodiversity recovery by permitting the restoration of native plants and rehabilitating the river's dissolved oxygen levels.

FIGURE A: *Trapas natans*

Climate change mitigation

Energy discussions in NYS have become focused around climate change mitigation strategies as representatives and activists make substantial efforts to reduce dependencies on fossil fuels and implement new renewable sources. 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 (NYS CLCPA 2019). These Hudson Valley Circular Biogas System proposals seek to meet this ambitious challenge through avoiding current transportation and landfilled emissions, producing renewable energy, and sequestering carbon.

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). Therefore, these biogas solutions actively address climate action throughout the greater Hudson Valley where mitigation efforts matter most. In addition, bioenergy serves a primary role in the IPCC's 1.5°C emission reduction pathway. Thus, these circular systems also align with international strategies to reduce anthropogenic emissions and facilitate a green energy shift.

Environmental justice

The burdens of inequality, environmental hazards, and income disparity have affected many demographics across NYS. In response, the CLCPA has also established a Climate Justice Working Group to help identify disadvantaged areas and take action to repair and revitalize these respective communities. Under this legislation, environmental justice regions will be allocated at least 35% of the benefits associated with NY's clean energy and efficiency initiatives. An Environmental Justice Advisory Group is set to advise state agencies on how to embed this target goal into decision making while a corresponding Just Transition Group will prepare a comprehensive workforce development program. The Hudson Valley Circular System proposals are presented with consideration for this important factor and will help facilitate NY's commitment to this goal. The region of focus covers approximately 7,700 mi² (~20,000 km), and is home to over 2.6 million people, and spans 11 counties north of NYC; Albany, Columbia, Dutchess, Delaware, Greene, Orange, Rockland, Putnam, Sullivan, Ulster, and Westchester. Each proposal is nearby or within an identified environmental justice area, and these installations prescribe a series of roadmaps that inject investment capital into these communities. By aligning with key stakeholders, Hudson Valley Biogas is pursuing meaningingful treatment of all people, regardless of race, income, national origin or color and maximizing these efforts with respect to the development, implementation, and enforcement of environmental laws, regulations and policies.

10 proposals for action

Presented herein is a regional plan of action that spans 11 NY counties (FIGURE B) and serves as a foundation for public engagement and implementation. The 10 proposed systems are as follows; 1) Monticello Transfer Station, 2) Taylor-Montgomery LLC, 3) Beacon Recycling & Transfer, 4) WeCare Denali | Rockland County, 5) Ulster County Resource Recovery Agency, 6) Delaware County Solid Waste Management Center, 7) Westchester County Wastewater Treatment Plant, 8) Wheelabrator Westchester, 9) Dutchess County Resource Recovery Agency, and 10) Town Of Colonie Landfill. Each technological design offers innovative solutions that are iconic representations of circular production systems and treats the available resources as high value materials for upcycle.

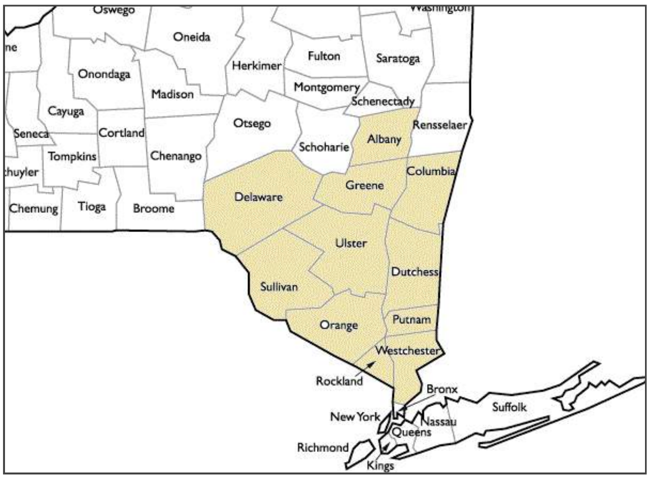


FIGURE B: ***NYS Reviewed Counties***

Circular economy

While anaerobic digestion is the highlighted component of each solution, there are multiple complementary technologies that offer a wide range of accompanying benefits. For instance, combined heat & power (CHP) generators are integrated to combust the biogas and produce renewable electricity. For some site locations, storage clamps, or silos, act as a feedstock buffer to permit continuous injection of perennial grasses for co-digestion. Another beneficial technology is pyrolysis which subjects biomass to a high heat and pressure in an oxygen-free environment. It initiates a self-sustaining process to produce heat and a densified char with sequestered carbon. More industrialized technologies such as carbon capture are also proposed to capitalize on the resale and offset market value of this gas byproduct. Respective background research has been conducted with a variety of manufacturers to offer accurate and relevant details for each system. Unique product specifications and attributes have been provided by company representatives to suggest footprint requirements and provide additional insights into proprietary technologies.

Previous studies such as the 2017 organics recycling report for Dutchess County (sponsored by NYSERDA) have only examined anaerobic digestion investments as individual solutions. They typically conclude that economic viability cannot be justified with these stand-alone technologies (Dutchess Organics, 2017). However, this economic outlook changes drastically with the approach of system designs that involve multiple integrated components. In this way, Hudson Valley Biogas is setting a new precedent for how to reimagine, rebuild, and renew the local economy. The technologies only prosper when they are designed into systems which are symbolic of the natural cycles exhibited by mother nature. This is the epitome of industrial ecology and the respective material flows and processes that are necessary to attain maximum impact.

Economic development strategy

According to the NYS Regional Economic Development Councils, local engagement and collaboration are critical components for success (REDC Guidebook 2021). Therefore, regional stakeholders have been identified and included with each proposal to create a communication roadmap for discussions regarding action and implementation. This aspect bridges existing gaps between towns and cities while empowering competitiveness, resilience, and prosperity. NYS and the greater Hudson Valley consider renewable projects as a priority when they appeal to a range of skill levels and further the economic growth of the region. In these regards, Hudson Valley Biogas has refined these 10 proposals to meet the goals of the Comprehensive Economic Development Strategy and incorporate the academic community to help ensure that employer workforce needs are actively pursued. Careful attention has also been given to the proposed installation placements and relative locations. This proximity awareness is crucial to maximizing the advantages associated with connecting NY's upstate and downstate economies. Several of these systems are positioned nearby and within the Hudson Valley Regional Council's twelve identified Opportunity Zones, and, therefore, each represents an ideal opportunity for community engagement (HVRC EDS 2019).

A precedent for success

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 energy sources 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 network of systems can be deployed throughout the region to meet the demands of a circular economy in which all resources are reused and recycled. Green gross domestic product (GGDP), or the sum of nominal GDP and the value of all relevant ecosystem services, is the form of accounting that a multilayered biogas production system can offer these many communities (FEWWN, 2019). 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. This form of operation is best for valorizing the Hudson Valley's local resources and positively influencing the energy and environmental goals envisioned by the state, the country, and the world. Each component plays an indicative and strategic role in the overall mission of achieving international sustainability, and the greater Hudson Valley can set invigorating precedents capable of being scaled and replicated across the state, country, and world to truly empower the people, planet, and prosperity.

FIGURE C: ***Storm King Mtn, Hudson Valley***

Background: System components

All of the presented system solutions consist of a collection of individual component technologies which are hereinafter referred to as 'processes.' Each process has a unique set of inputs and outputs that intake feedstocks and output byproducts. True to a circular economy, multiple processes can be combined to form an entire system where byproducts are continuously reclassified as useful and beneficial materials which are always required for subsequent processes. This concept is indicative of the phrase, 'closing-the-loop,' and it is intended to effectively eliminate any and all waste materials to create upcycled production value.

Technologies (processes)

The fundamental strategy outlined by this report is to use anaerobic digestion as a core technology for each respective system. This can be considered as the foundation for each proposal which can be expanded upon with complementary processes. Each of these additional technologies has been chosen for their ability to enhance the digestion process and improve the overall productivity of an integrated system. As such, they can be considered as part of a 'toolkit' for designing circular production cycles and drawn from accordingly to create an all inclusive solution. These respective processes are now presented with relevant background technological information in order to overview their stand-alone functions and benefits.

Anaerobic digestion

Biological decomposition of organic materials in the absence of oxygen is called anaerobic digestion. Microorganisms break down and convert incoming carbohydrates (glucose, fructose, and sucrose) to an aqueous digestate. The nitrogen-rich liquid effluent can be separated from this substance and distilled to create a concentrated fertilizer solution. Remaining digestate is then composted or pasteurized to eliminate potential vector pathogens. Additional advantages include reductions in odor and volume (DEC Beyond Waste, 2010). This process also produces biogas which is a combustible byproduct consisting of approximately 55% methane (CH4), 45% carbon dioxide (CO2), and trace amounts of other gases like hydrogen sulfide (H2S) (Ulster SWMP, 2020). For small operations, the biogas typically meets the power and heating demands of the host facility, and is generally the most economical because the biogas achieves full market value.

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). Anaerobic digestion is typically implemented at organic waste management facilities, municipal solid waste (MSW) facilities, WWTPs, livestock farms, and landfills. Factors such as water to solids ratio, carbon to nitrogen ratio, and pH can significantly affect productivity and must be monitored and balanced accordingly. Therefore, having flexibility with feedstocks as well as consistent biomass can help to maintain an optimized microbial environment.

Anaerobic digestion tanks have to be kept warm in order to promote microbial activity. Ideal temperature can range between 20°C (68°F) and 60°C (140°F). Mesophilic digestion occurs at this lower temperature and is the most common method employed as well as the most stable. Thermophilic digestion is conducted at the higher temperature and offers a more rapid reaction as well as increased biogas production. Numerous types of organic wastes including difficult-to-compost food products (such as dairy, meat, fats, oils, or greases), sewage sludge/biosolids, and other feedstocks that contain a high percentage of liquids (aqueous plants or perennial grasses) can be used as digestion feedstocks (Dutchess Organics, 2017). However, there are a variety of concerns which emerge when incorporating biosolids into digestion with these other feedstocks. The EPA has strict management practices imposed to ensure no detectable levels of pathogens (coliform and salmonella) along with several classifications based on the method of processing. For instance, Class A biosolids can be produced from thermophilic digestion according to time and temperature criteria described in US EPA Part 503, and they have no land application restrictions. Thus, they can be used with agriculture, reclamation sites, forestry, lawns and home gardens, etc. Class B biosolids do not meet the same processing standards and have stricter limits on beneficial use application.

Both of these classifications, unfortunately, do not address the potential presence of hazardous contaminants and compounds that can be present in sewage sludge that are not destroyed through any form of digestion. The EPA began tracking the occurrences of pollutants in 1993 with the adoption of 40 CFR Part 503, and their Biosolids Program assesses the potential public health and environmental risks. Depending upon the inputs to individual wastewater treatment facilities, pollutants found in biosolids can and will vary over time. While the presence of a contaminant does not mean that the biosolids pose harm, concerns of specific compounds such as pharmaceuticals, microplastics, heavy metals, and perfluoroalkyl / polyfluoroalkyl (PFAS) substances have been raised by the NY CLCPA's Waste Advisory Panel. In order to reflect these reasonable concerns, Hudson Valley Biogas has chosen to vehemently oppose co-digestion of sewage sludge with the other aforementioned feedstocks. To do so poses the risk of contaminating a valuable community resource that is otherwise not subject to the same cautionary regulations and measures. This is deemed to be the most responsible course of action to be certain that the health and safety of downstream community uses of the generated byproducts are not compromised.

There are many forms of this technology such as mixed-flow tanks with a high water requirement that are regularly used at sewage treatment plants and on dairy farms. Another style is a plug-flow design which has several benefits inclusive of definite retention time and isolated digestion that is not circulated with the entire batch. Some relatively new manufacturers have produced solutions in shipping containers which offer maximum flexibility for scaling while minimizing the investment barriers to entry. Hudson Valley Biogas highly recommends that communities first invest in these smaller, stackable products, to become familiar with the technology and quickly adapt to changes.

Pyrolysis

Biochar is a carbonaceous substance similar to coal, however, instead of taking millions of years to form, this product can be manufactured in less than an hour. It is primarily promoted as a way to sequester carbon, improve water retention in soil, correct the pH of soil, and increase crop yields (Mohammadi, 2019). This process of formation is called ‘Pyrolysis and is defined by the thermal cracking of organic matter in an inert atmosphere at elevated temperatures. It is an endothermic reaction which means that heat is released as matter breaks down in an oxygen-free environment. In addition to the ‘Biochar’ solid, there are also liquid and gaseous byproducts which emerge together in a vapor. The condensable liquid is called ‘Bio-oil,’ or ‘Black liquor,’ and is a product that can be utilized in many industries. It can be used as a fuel or upgraded and refined to extract a variety of specialty chemicals (Devon 2019). Meanwhile, the gas consists mainly of carbon monoxide (CO), carbon dioxide (CO2), methane (CH4), and hydrogen (H2), and it is usually combusted to provide heat to the continuing pyrolysis and keeping the process self-sustained.

The type and quality of biochar can vary significantly and is based on several parameters including feedstock, temperature, and retention time. While it is typically produced from cellulosic materials such as corn stover, switchgrass, or wood, other biomass such as biosolids can also be used as a feedstock. Biochar has many applications, but is most commonly used as a soil amendment or a carbon neutral fuel. With respect to Hudson Valley Biogas’ sustainability initiatives, this product is intended to be applied to the agricultural sector and relevant land restoration initiatives. According to the Humic Products Trade Association (HPTA), there is much variability in when it is used to promote seed germination, crop nutrient uptake, and crop yield. This range of outcomes is typically coincident with the concentration of toxins versus the proportion of favorable nutrients; calcium, magnesium, potassium, phosphorus, etc (HPTA 2015).

When biochar is manufactured at low temperatures such as 575 degrees F (300 degrees C), there is a high proportion of water-soluble nitrogen and phosphorous compounds. Meanwhile, higher temperature pyrolysis above 1,100 degrees F (600 degrees C) doesn’t contain as high of a concentration of plant-available nutrients. Since heavy metals are often present in biosolids and when this biomass is used as a feedstock for pyrolysis, the char will have different properties relevant to chemical speciation distribution, leaching toxicity, and bio-available contents based on the process temperature. Often, higher temperature will decrease the mobility of these elements resulting in a low risk of groundwater contamination and plant absorption (Lu et al 2016). As previously described with anaerobic digestion of biosolids, there are also concerns of hazardous compounds persisting in biochar that’s created from this feedstock. However, at least two different manufactures have performed tests with these contaminants and for both producers, all of the microplastics, pharmaceuticals, and PFAS compounds are completely destroyed at temperatures above 1,300 degrees F (700 degrees C) and retention times of at least 20 minutes.

With one manufacturer, the gaseous byproduct created throughout pyrolysis is entirely redirected back into process to keep it self-sustaining. Therefore, in addition to generating biochar, the second significant byproduct is heat. In order for an investment in this technology to be economically viable, there must be at least 1,000 tons of available feedstock on an annual basis. This company claims that their product for pyrolyzing biosolids reduces feedstock mass by up to 90%, sequesters over 250 tons of carbon per year, and can heat approximately 50 households. The carbonization process is compliant with EU environmental standards and the char is approved as an WU-wide marketable phosphorus fertilizer. They also produce a larger unit which can accommodate up to 3,000 tons per year. Hudson Valley Biogas has therefore designed each of the respective site-proposals according to these characteristics and specifications.

Another company produces pyrolysis technology that only becomes economically viable when there is about 10,000 or more tons of feedstock processed per year. This technology is significantly different though because it has been designed to capture the value of the gas byproduct. With this unit, the heat is effectively redirected to keep the process self-sustaining with little to none available for other applications. A composition analysis of the gas is provided in TABLE A and TABLE B which is different for each feedstock. For instance, biosolids produce mostly hydrogen and methane while wood produces significantly more hydrogen and relatively little methane. This company has a proprietary steam reformation technology to filter and upgrade this output according to the specifications of the host facility. One option is to refine the gas to renewable syngas which is a mix of hydrogen and carbon monoxide. Another option is to create green hydrogen which currently has a very high market value in the US due to government incentives. Therefore, a choice output will need to be made based on the most available and valuable local markets.

Biosolids	
Species	**Concentration**
H2	29.4%
CO	18.8%
CO2	8.5%
CH4	23.6%
Other HC (CnHy)	19.7%

TABLE A: ***Gas From Pyrolysis Of Biosolids***

Wood	
Species	**Concentration**
H2	49.5%
CO	28.9%
CO2	14.5%
CH4	3.3%
Other HC (CnHy)	3.7%

TABLE B: ***Gas From Pyrolysis Of Wood***

The 2015 Biosolids Survey distributed by the NYS DEC collected detailed information from each wastewater treatment plant throughout the state with details such as flow capacity, annually generated dry tons, and processed biosolids' end-destinations. A large proportion of the Hudson Valley's sewage sludge has been routed to landfill. These flows have been mapped for each county and are available in APPENDIX 1. Processing this valuable biomass within the local communities where it is generated can offer additional economic value for the region, create long-term jobs, and eliminate many tons of CO2 emissions currently emitted by hauling activities. These are some of the driving values for incorporating this technology into local production cycles.

Circular systems

Correspondence with many of these companies has revealed that their products represent economically viable investments. However, their benefits can be compounded when multiple technologies are combined into a collective system. Anaerobic digestion can serve as a precursor to composting while valorizing additional energy through the capture and energy conversion of biogas. This renewable fuel can be combusted in an electrical generator to produce electricity and power on-site operations. Yet, biogas faces several challenges as a stand-alone technology. For instance, during colder winter months, such as those experienced in the Hudson Valley, the decomposing organisms cease to function and stall the production process. As a result, a question emerges regarding a continuous heat energy supply. Clearly, this can be offered by an accompanying pyrolysis process. Therefore synergies with other technologies can be designed to significantly increase reliability and performance expectations of individual product components. This realization represents the origins of Hudson Valley Biogas' Circular Systems.

One study reviewed various literature on biochar created from different feedstocks and its respective benefits for incorporation with anaerobic digestion. For instance, biochar produced from corn stover can be applied to an anaerobic WWTP to increase methane yield and improve process stability. Therefore, this could represent a market opportunity for a production cycle that exports locally manufactured char to existing regional sewage sludge digesters. In another study, when biochar produced from sawdust was added to anaerobic digestion of food waste, benefits included a shortened lag time, an increased methane production rate, quicker micro-organism adaptation to high volatile fatty acid accumulation, and effective pH buffering (Song et al 2021). These benefits may also hold true for biochar created from sewage sludge. Since all traces of hazardous compounds (microplastics, pharmaceuticals, PFAS, etc) have been destroyed during pyrolysis, this biochar feedstock can be added to the anaerobic digestion process without concern.

Perennial grasses can be cultivated as part of land restoration projects and be applied for co-digestion to help maintain a healthy and consistent microbial environment. In addition, the digestate and effluent fertilizer byproducts can be returned to the local agricultural sector to promote local sustainable farming cycles that avoid the importation of excess compounds that can otherwise accelerate eutrophication. This cellulosic biomass can only be harvested two to three times per year which represents a constraint on supply. One solution is to construct a clamp for silaging the material as it is produced. This way it can be loaded into the digester as it is needed. A clamp consists of a sealed floor that is resistant to the acidity of silage and a cover that seals off the biomass from oxygen and sunlight. Sidewalls can be added, but they are not necessary. The cover is rolled back and removed as the feedstock is extracted for digestion. The economics for this infrastructure can be difficult to define, however, if viewed from the perspective of the value obtained by rejuvenating and repairing the soil for productive crops and nutritious food, the financial benefits begin to align. Therefore, Hudson Valley Biogas suggests this 'Clamp' process for some proposals.

Anaerobic digestion and pyrolysis represent the core technologies at the center of many of the Hudson Valley Biogas systems, but another technology of interest is CO_2 capture. Despite there seemingly being an overabundance of this greenhouse gas (GHG) available to the world, it still must be obtained in some way by industry demand. According to the American Biogas Association, in 2020, the United Kingdom experienced a shortage of this gas relevant to their food and & beverage sector and therefore had to have it imported. Since biogas is usually around 50% carbon dioxide, there is a continuous feedstock produced via anaerobic digestion. Though, in order for the corresponding infrastructure to be economically viable, there has to be a very significant quantity of biogas produced on a daily basis. There are several manufactures that have products for this, but they each offer different product capabilities. One company produces a system that aggregates biogas feeds from a collection of dairy farm digesters that are all within close proximity to each other. It then cleans the gas of contaminants, removes and packages the CO_2, and produces a renewable natural gas (RNG) product that can be injected into the natural gas line infrastructure.

CO_2 is also produced following biogas combustion with an electrical generator. The company that was previously referred to only has technology that cleans and upgrades biogas, and is not able to only process a CO_2 stream. However, a different company offers a technology to specifically capture, clean, and refine this exhaust to food grade standards. Here again, an installation would only be economically viable with a very large volume of CO_2. For each process, one of the key economic katalyst is the availability of heat energy. This is because the compression aspect of this process requires a significant amount of heat, and if this has to be produced from electricity, the profits do not balance out the losses. Yet, here is where a pyrolysis solution can contribute to the system and continue to expound upon symbiotic integration with each of the individual components. From these few examples, one can begin to recognize the foundation evidence and motivations for investigating new possibilities for the Hudson Valley. Ignoring these interrelated benefits would otherwise equate to the same doubtful conclusions of previous studies and result in stagnated growth while continuing business as usual. However, Hudson Valley Biogas presents these alternative solutions from this new perspective that warrants another investigation into development.

Methodology: Site selection & design process

A variety of criteria have been established to determine the most ideal sites to introduce circular biogas systems. These factors address the local availability of feedstocks, existing infrastructure, and general geographical location. Resource mapping was conducted using Hudson Valley Biogas' 2020 Assessment Of Resource Potential For Biogas Feedstocks In New York's Hudson Valley." This data set has been geolocated with Google's mapping tools and is presented in APPENDIX 2. Additional data points of existing infrastructure were also available through the USDA and have been added to this collection of resource maps. This includes, but is not limited to, power generation, existing biogas facilities, and CNG fueling stations. These resources represent opportunities to combine proposed system designs with existing operations and thus reduce the initial capital costs which can otherwise represent a financial barrier to adoption of this technology. Some consideration has also been given to county organics studies that have previously accounted for some of this data and alluded to specific locations for implementing anaerobic digestion.

With the goal of introducing a series of proposals that collectively form a network of continuous service from the northern edges of NYC to the capital region, consideration was also given to the spatial relativity of feedstock clusters between different counties. For instance, even though some regions exhibit multiple opportunities for proposals, the single location which appeared to meet the greatest criteria match, in accordance with this selection methodology, was prioritized for that particular area. Respective distances between the proposed locations was also influenced by the stipulation of the NYS Excess Food Waste Law that requires generators within 25-miles of an identified recycling facility to divert this respective waste stream. Therefore, adjacent proposals are typically separated by distances between 25- to 50-miles to facilitate maximum service coverage with potential for area overlap that can allow for logistic and transport optimization.

Finally, the number of proposals for each county is capped at 2 site installations. This threshold has been introduced by this study in order to maximize the number of counties that are provided with solutions while minimizing the overall quantity of installations necessary to satisfy the aforementioned regional coverage. This cap is also intended to assign an equitable distribution of project financing and investment capital throughout the Hudson Valley while implying a collective and coordinated effort among communities to successfully meet the climate mitigation goals of NY's CLCPA. Capacity building will play a crucial role in these endeavors with respect to getting the local populations to commit to responsible waste management practices and educating citizens on the nutritional and ecosystem restoration advantages that innovative system designs such as these circular biogas production installations can offer. Therefore, careful thought has been given to the site locations with respect to potential environmental justice regions that have been designated by NYS. These nearby communities are highlighted with each proposal to reveal and suggest this opportunity potential. Overall, this study presents these proposals as a positive course of action for each community as it relates to green jobs and the food-energy-waste-nexus.

Feedstock and infrastructure mapping

FIGURES D and E display select sample areas of the complete resource map that is available in APPENDIX 2. As previously described, this map is largely populated with data collected and researched by the previous 2020 Hudson Valley Biogas report “Assessment Of Resource Potential For Biogas Feedstocks in New York’s Hudson Valley” and has coverage now extending to 11 of New York’s counties. The bright yellow and orange icons represent potential sources of excess food waste presented by the NYSP2I excess food waste study. NYSP2I has since updated their data set to reflect a more complete listing of excess food waste generators and more accurate generation rate estimates, however, the locations presented in the original data set are still valid and represent a consistency from the previous assessment. The dark green icons are composting facilities listed with the Cornell Waste Management Institute survey. On the Hudson River, there are a series of bright green icons which represent significant infestations of the invasive aquatic water chestnut. This data was primarily provided by the Lower Hudson PRISM group, however some additional data points and references have been made through visual inspection of satellite imagery. There are also concentrated animal feeding centers which have a brown indicator, but they are few in number.

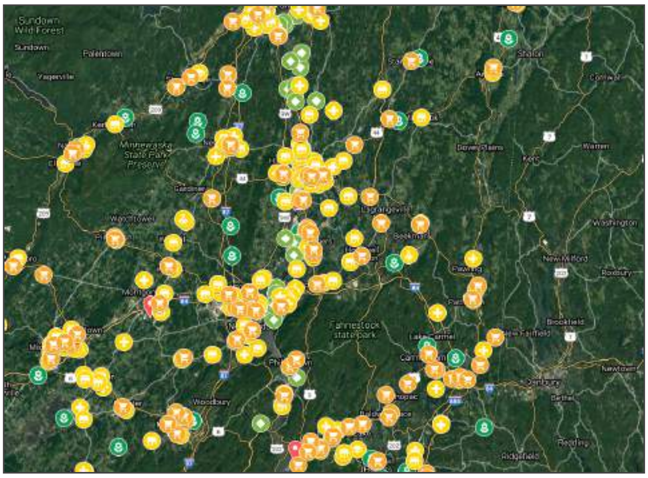


FIGURE D: ***Excess Food Waste Map (A)***

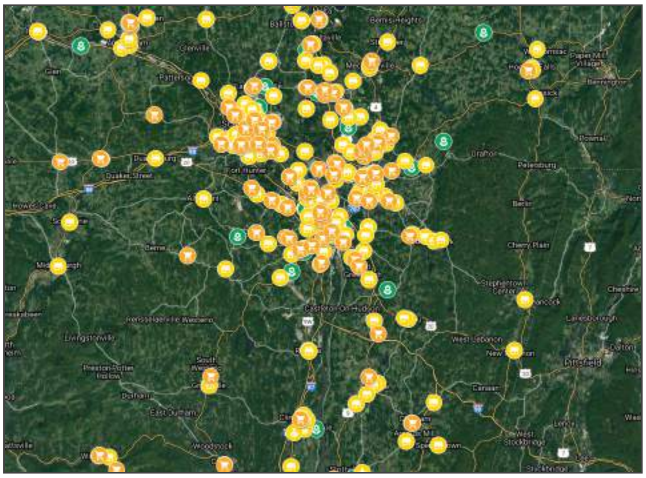


FIGURE E: ***Excess Food Waste Map (B)***

Two extracts from the feedstocks map offer some insight into the visual inspection that was required to identify the best candidate locations for site proposals and they represent regions with a high concentration of feedstocks. FIGURE D displays a sample of this map that extends from the northern part of Rockland County up through the southern part of Ulster County. Meanwhile FIGURE E reveals the concentration of these resources around the Capital District in Albany County and extends south to the northern parts of Greene and Columbia counties. Visual inspection reveals that there are many composting facilities, but, upon examining the survey details, it can be discovered that the majority of these facilities are specifically designated for wood and yard waste and do not accept food waste. This is an important distinction to observe because composting food organics requires different permits and approvals from the NYS DEC that these facilities may not be interested in attaining. However, these locations may offer opportunities to distribute the digestate byproduct from anaerobic digestion because it would fall within guidelines.

Resource & production potential matrices

Following this visual inspection, a systemized approach was employed to categorically examine potential site locations and attempt to remove any possible bias for certain regions or community districts. This strategy focuses on four main categories of questions to assess the current operations at the proposed sites as well as the potential for future infrastructure installations; 1) Is the location considered an industrial or commercial site with hauling activities?, 2) What is the variation of feedstock? 3) Is there potential to implement pyrolysis operations with high biochar production volumes? and 4) What space is available to host the proposed infrastructure? Each of these questions has a series of subset qualities and attributes which are presented and provided with further explanation.

Industrial / commercial site with hauling activities

TABLE C represents the first of four characterization charts for each site proposal and it is intended to convey whether the site is already zoned for industrial / commercial activities. In order to implement solutions that have the least barriers to entry, attention should be given to these specific attributes so that locations are proposed which offer the simplest path to infrastructure adoption.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE C: ***Industrial / Commercial Operations***

Three attributes are presented for classification of the site with respect to operations; recycling facilities, energy production, and landfill. Sub-categories are displayed below each of these items to offer some additional details about the designated characteristic. For the purposes of this report, 'Organics' refers to the transportation and/or repackaging of organic waste excluding wood and yard waste composting activities. Rather it is intended to refer to biomass processing or stockpiling inclusive of excess food waste, biosolids, manure. 'Energy production' could include any on-site capture of biogas, incineration activities, or combustion of natural gas, while 'Landfill' indicates that the facility is positioned at the site of, or nearby, an 'active' or 'closed' waste dump.

TABLE D displays a fictitious example chart to convey how this tool is utilized in the following results to indicate the characteristics and attributes of each proposal location. A box with the color 'green' indicates that the activity or process is currently existing and integrated with operations while the color 'yellow' alludes to the site's potential and proposed adoption of the operation.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE D: ***Industrial / Commercial Operations (example)***

In example TABLE D, the 'Industrial / commercial site with hauling activities' is in green which identifies the proposed site as a commercially zoned area. 'Recycling facilities' is also green and therefore signifies that the facility hosts a resource recovery operation. A waste management transfer station is one example of a commercial location which would not have this classification, and if this was the case, the box would remain the color white. This fictitious facility also manages and composts food waste so both of the 'Organics' and 'Composting' boxes are designated with the color green. In some cases, the facility may operate a biosolids waste stream, but export this biomass elsewhere for additional processing. Therefore, 'Organics' would be green but 'Composting' might appear yellow. Also, not all facilities that offer composting services are considered 'recycling facilities,' therefore, this study will only use this nomenclature if there is an on-site reutilization & repurposing of materials as publically classified by the host facility.

The next category in TABLE D, 'Energy production,' is yellow while the sub-category, 'Biogas' is green. This example might therefore represent a WWTP which is currently generating biogas via anaerobic treatment of biosolids, but it is not utilizing the biogas. While it could mean that the biogas is being captured and transported off-site, the most likely case is that the biogas is being flared and not applied to any beneficial use. The yellow color indicates that there is potential to upgrade the facility with energy production infrastructure that would build upon overall capacity.

In the third section, the green color indicates that the site is on or near a landfill. 'Active' is also green which identifies an ongoing MSW dumping operation while 'closed' is yellow which suggests that the landfill may be closed in the near future or its premature closure is being discussed.

Variation of feedstock

The most promising locations for circular biogas systems exhibit a series of locally available organic feedstocks. Therefore, TABLE E, 'Variation of feedstock,' offers a checklist of currently available and potentially available inputs to the biogas system. The five categorical types are referenced from Hudson Valley Biogas' 2020 feedstock assessment and includes excess food waste, wood / yard waste, invasive species, livestock manure, and perennial grasses. Biosolids have been excluded from this list regarding the aforementioned concerns of potential inherent hazardous compounds. With these systems, contamination of this nature should be strictly avoided so that the resulting fertilizer and digestate byproducts can be applied to the agriculture sector without any concern for potential harm. According to the 2020 assessment, co-digestion of multiple feedstocks can often improve methane yields and promote a more resilient microbial environment. The color green signifies that the feedstock is currently present at the site while yellow indicates that it may be locally available to incorporate. This chart therefore conveys the flexibility of input biomass feedstocks.

Variation of feedstock				
Excess food waste	**Wood / yard waste**	**Invasive species**	**Livestock manure**	**Perennial grasses**

TABLE E: ***Anaerobic Digestion Feedstocks***

Potential for pyrolysis

With many of the proposed designs, pyrolysis is offered as a solution to treat and destroy any potential substrate contamination as well as transform these organics into a series of beneficial byproducts. TABLE F depicts the 'Pyrolysis & biochar' table with subcategories listed as 'Biosolids,' 'Wood waste,' and 'Heat need.' None of the resulting proposals have the header marked in green because this technology is not currently present at any of the examined sites.

When 'Biosolids' or 'Wood waste' is depicted with the color green, this pyrolysis feedstock is currently passing through the proposed facility or processed on site with a corresponding quantity that is over 1,000 tons per year. If this box is the color yellow, it could signify that sufficient quantities of this feedstock are available on a regional basis. With no color, there is not a significant enough volume of biosolids generated on a daily basis to warrant further investigation of a pyrolysis solution. A site profile with this characteristic would have the 'pyrolysis & biochar' box with no color.

An important note is that in the case of wood waste generated by industries such as the construction sector, it may also be too contaminated with inorganic materials and compounds and thus not represent a quality material for producing biochar. For instance, if the wood contains screws and nails, these materials cannot be carbonized and would produce a contaminated char that should be avoided. For this study, consideration of wood feedstock was only considered with respect to branches and brush. However, several of the proposed facilities do manage general wood waste, so more investigation of this potential pyrolysis feedstock would have to be conducted in order to confidently recommend this beneficial technology.

Pyrolysis & biochar		
Biosolids	Wood waste	Heat need

TABLE F: ***Pyrolysis Potential***

Space to host the proposed system

The fourth chart, TABLE G, provides more insight into the amount of available and unused space at the proposed site. The three subcategories are, 'sufficient to support proposal,' 'space to scale-up the proposed system with increased feedstock,' and 'available area to introduce innovative circular economy initiatives.' As with the previous charts, each box is marked accordingly with the color green to indicate 'yes' for the respective condition, yellow to indicate that the area has 'potential' for the respective condition, and left blank to suggest that the condition does not seem to be viable. For many of the proposals, satellite imagery was used to make this assessment, but for some of the sites, communication with on-site managers provided relevant insight to these parameters.

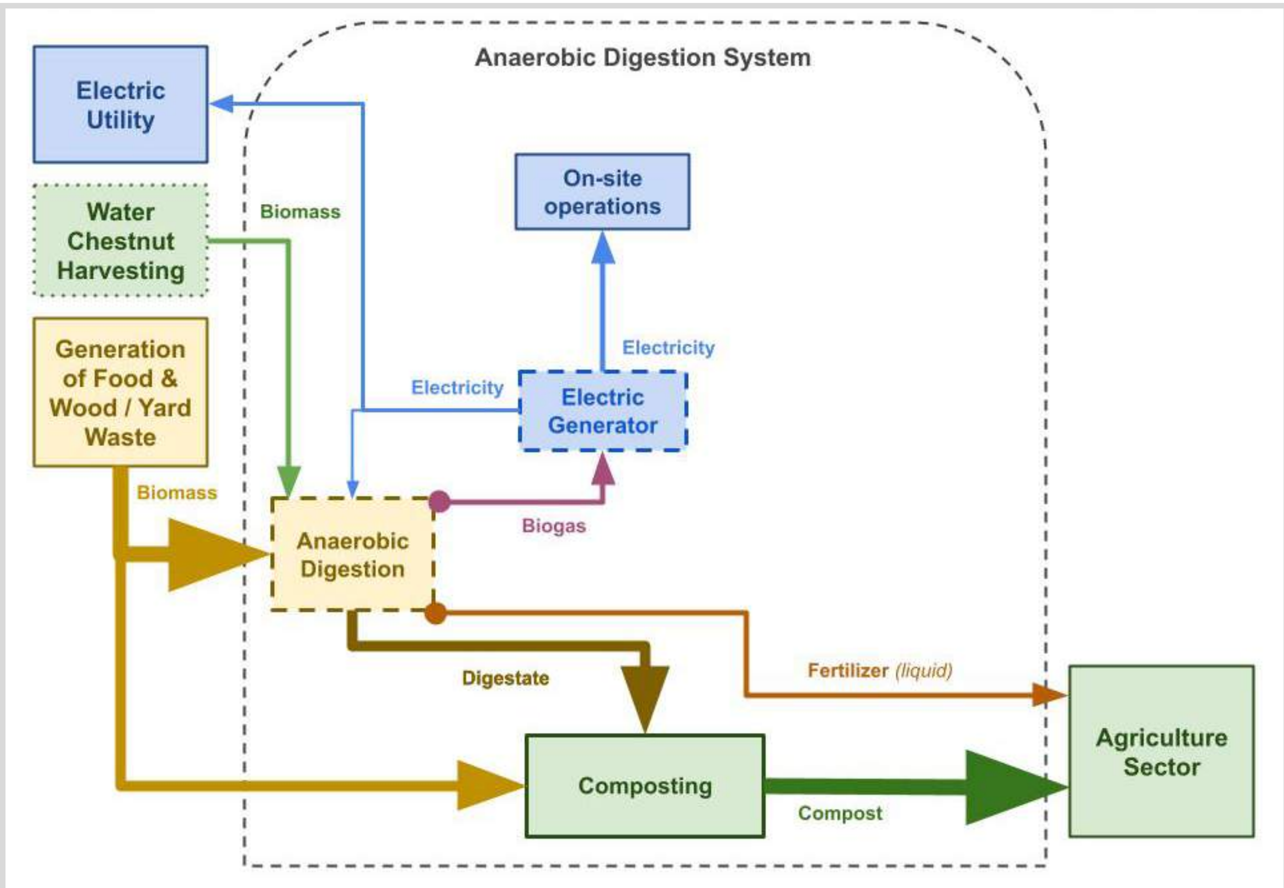
Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE G: ***Space & Circular Economy (Area Overview)***

System design & conditions

The completed matrix analysis offers an outline to the variety of technological drawings and configurations that can be explored with a circular biogas system. Provided that the intent of this research is to offer solutions with biogas as the primary and central technology, a sample system has been created and displayed as SYSTEM A to convey a generalization of this main process and flows involved in a stand-alone setup. This foundational design is present in all of the resulting site proposals and becomes more complex with higher availability of resources and existing infrastructure. Following an explanation of the methodology behind SYSTEM A, a second, more advanced system is presented with the integration of a pyrolysis process. This is an industrial ecology approach which focuses on the synergistic qualities and attributes that multiple technologies can benefit from within a circular system design. Through this form of analysis, process inputs and outputs can be optimized within the facility boundaries of each proposal.

Anaerobic digestion system



SYSTEM A: ***Anaerobic Digestion***

The general biogas proposal has been designed using three basic elements; boxes represent processes, arrows represent material flows, and the dashed line frames all of the activity which would take place within the system boundary of the host facility. In SYSTEM A, 'Generation of Food & Wood Waste' is a process that takes places outside of the site location, and the border of this yellow box is solid which, for this report, indicates that it is an existing process. Biomass feedstock is imported through the facility's system boundary with the corresponding flows represented by yellow arrows which also indicate the direction of the material flow. This 'Biomass' feedstock is assigned to the 'Anaerobic digestion' process as well as the 'Composting' process. In actuality, 'food waste' and 'wood waste' should be separate from each other, and their distribution amongst the two processes could be variable with different proportions based on a variety of parameters; relative flow volumes, potential contamination, moisture content, etc. However, for the purpose of providing a simplified overview of the design, generation of this biomass has been combined.

A brown flow arrow, labeled 'Digestate,' exists from the 'Anaerobic digestion' process and is directed to the on-site 'Composting' process. The subsequent green arrow leaving this process, labeled as 'Compost,' represents the final and cured compost product being exported from the facility, beyond the system boundary, and applied to the 'Agricultural sector." Similarly, an orange arrow exiting the 'Anaerobic digester' displays the nitrogen-rich 'Fertilizer' effluent that is generated from the digestion process. This liquid is also shown to leave the system and be applied to the 'Agricultural sector.'

The third product of the 'Anaerobic digestion' process is the 'Biogas' which is represented by the pink arrow and applied to an 'Electric generator.' Due to the small volumes of biogas associated with these initial proposals, the most economical opportunity is to combust the methane in an electrical generator and apply the resulting 'Electricity' to the parasitic load requirement of the 'ANaerobic digester' as well as 'On-site operations.' Any overflow of 'Electricity production' is then sold back to the 'Electric utility,' which is outside the system, and therefore exported.

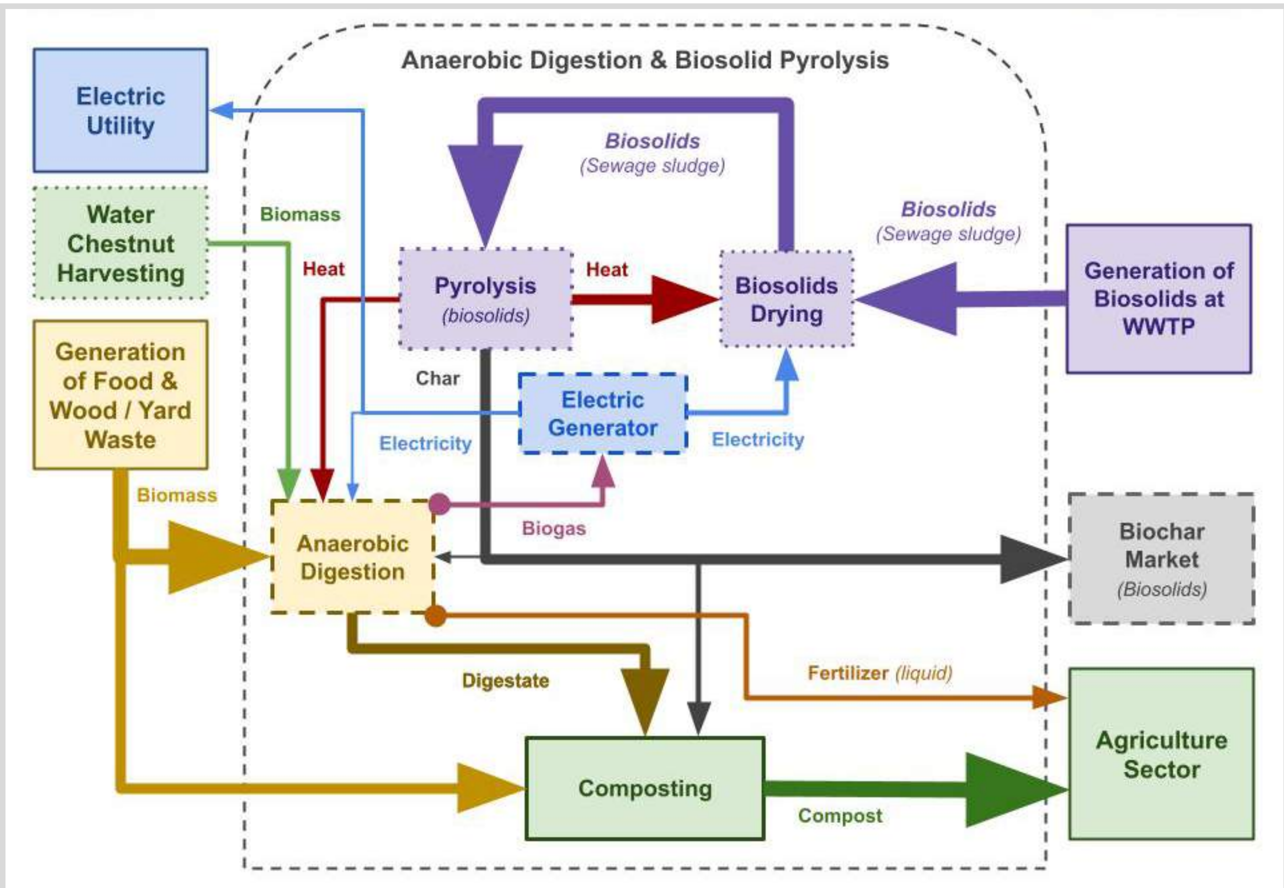
Another attribute to note is the outline style of each process which is unique to the presentations in this report. Three different varieties are presented in the fashion of solid, dashed, and dotted. Processes that are currently established and operational have been assigned a solid border. In the case of SYSTEM A, the 'Composting' process is one example which exhibits this attribute and implies that the site location is actively creating compost. Meanwhile, the dashed border is apparent around the 'Anaerobic digestion' process and indicates that this is proposed infrastructure. The large dashes mean that it should be considered a priority installation when seeking to implement some of the more complex designs. Since the biogas production process is the central feature to these designs, all of the digester and electricity processes have been assigned this dashed border.

Processes with the dotted border should be considered as secondary system components that can be implemented subsequent to the prioritized infrastructure. In SYSTEM A, the 'Water Chestnut Harvesting' is an example of this characterization regardless of its position outside of the system boundary. This marking would indicate that this particular invasive species is in nearby proximity to the proposed site location, but there is no available method to harvest the biomass. However, this harvesting process would receive a dashed border if, for instance, a local community is in possession of water chestnut harvesting machinery that could potentially be made available for a biomass collection operation. Clearly, each scenario will receive a unique interpretation.

Anaerobic digestion & biosolid pyrolysis system

Some WWTPs use anaerobic digestion as a method of treating biosolids which, as previously reviewed, represents one pathway to eliminating potential vector pathogens. However, given the constant concern of hazardous compound contaminants that can be present in these biosolids, which are not destroyed through anaerobic digestion, the safest pathway is to not include this resource as a feedstock with any co-digestion opportunities. To do so would risk the contamination of other hazardous-free waste streams and the resulting digestate. Therefore, any opportunities to include biosolids in the production cycle is always accompanied by a 'Pyrolysis' process. As previously reviewed, pyrolysis above 1,300 degrees F (~700 degrees C) has been shown to destroy all of these potential contaminants.

In SYSTEM B, the two byproducts of the 'Pyrolysis process' are 'Char' and 'Heat.' Some of the 'Char' is directed to 'Anaerobic digestion,' more 'Char' is incorporated into 'Composting,' and most of the 'Char' is exported to a 'Biochar market.' The 'Biochar market' has a dashed outline indicating the lack of a regional market for this product. This is the case for each of the proposals that produce char from biosolids because there doesn't appear to be precedence for this material in the greater Hudson Valley. However, with the development, adaptation, and scaling of these systems, there is an opportunity to introduce this product as long as relevant information, regarding use and education, accompanies a go-to-market strategy.



SYSTEM B: ***Anaerobic Digestion & Biosolid Pyrolysis***

One other aspect of SYSTEM B which requires further elaboration is the 'Biosolids drying' process. Generally, drying is included with 'Pyrolysis' as the 'Heat' that is generated through the pressurization is applied to feedstock to evaporate its inherent water content. According to the specifications of several manufacturers, the threshold for a conducive operation is approximately 25% moisture content. As long as the solids portion is above this threshold, the process is self-sustaining and excess heat is available for other on-site beneficial applications. If this threshold is not met, then pyrolysis may not be conducive for the proposal and some pre-drying technologies would be necessary to justify this technology. When adding these aforementioned components, the resulting depiction can become visually confusing and congested. Therefore, this pre-processing has been excluded and should be assumed to be inherent to the 'Pyrolysis' process. Further elaboration on this aspect is reviewed in the discussion section of this publication.

For all of the presented systems, the thickness of the lines provides some general indication of the flow volumes relative to each other. However, the proportional sizes do not serve as an accurate representation of the amount of material moving between each process. Rather, their thickness has been chosen to provide some proportional insight relevant to flows of different color in the system as well as preference for the allocation of material flow from one stream which is divided into several additional processes. An example of this relative thickness is most apparent with the black 'Char' flow which emanates from the 'Pyrolysis' process; a small portion is added to the 'Anaerobic digestion' process, a larger portion is added to the 'Composting' process, and the majority ends up leaving the system boundary as an export to the biosolids 'Biochar market.'

Environmental justice regions

The United States has recently increased cultural attention to environmental justice initiatives with aspects relevant to sustainability and climate change mitigation. NYS has responded to this heightened awareness by producing a set of maps with geospatial information system (GIS) data sets that identify potential environmental justice areas with details that extend to the local level. This NYS initiative is outlined by the DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29), and it recognizes potential areas with block groups of 250 to 500 households, identified by the US Census, which have populations that meet or exceed at least one of the following statistical thresholds; 1) At least 51.1% of the population in an urban area reports themselves to be members of minority groups; or, 2) 33.8% or more of the population in a rural area reports themselves to be members of minority groups; or 3) at least 23.59% of the population in an urban or rural area have household incomes below the federal poverty level. (The federal poverty level and urban/rural designations for census block groups are established by the U.S. Census Bureau and can be further explored in CP-29.) With each proposal, the nearby identified environmental justice regions have been shown so that implementation of this regional initiative can be designed to integrate with these respective areas and communities.

Building regional capacity

In an effort to maximize program effectiveness and long-term resiliency, a list of relevant stakeholder organizations has been included with each proposal. These results are presented in two categories. A 'General' listing representing regional groups and organizations is the same for every proposal and has been selectively generated throughout the general research for this report. The 'Specific' classification represents groups and associations that are more unique to the particular proposal. The combination of these two classifications is intended to effectively build capacity throughout the Hudson Valley and connect with niche environments within each respective county. These listings do not indicate respective organization support for the proposal or any related endeavors, however, upon pursuing implementation, collaborative arrangements should be investigated and sought after with these groups to facilitate a collaborative initiative. For many of the listed groups, involvement with these Hudson Valley Biogas initiatives would include a general awareness, oversight, and communicative support effort of the circular economy themes. Meanwhile, other stakeholders could be much more involved based on their respective resources.

General stakeholders

One of the primary agencies included in the 'General' listing includes the New York State Department of Environmental Conservation (NYS DEC) as an overseeing regulatory and permitting agency for the state. This government agency is responsible for monitoring activities such as water discharge and waste management which is analogous to their oversight role of WWTPs , recycling facilities, and related permitting. There are a variety of internal departments within this organization that are individually relevant to these proposals and are listed accordingly; Division of Materials Management, Office of Invasive Species Coordination, Environmental Permits, and Climate Change. General insight into this collection of departments has been sourced from the NY DEC's website which can be explored further through the respective web links provided in TABLE_.

Other organizations included in the 'General' list of stakeholders include research and educational institutions such as the New York State Pollution Prevention Institute, or NYSP2I, which as previously described, has served as the primary data source for identifying the distribution of excess food waste generation. Based on this organization's mission and services, it could serve an environmental oversight role which would include generating quantifiable metrics from methods such as life cycle assessment (LCA) and risk analysis. NYSP2I could also help with the regional distribution of educational materials related to aspects of technology and beneficial use. Additional regional groups such as Sustainable Hudson Valley and the Hudson Valley Regional Council (HVRC) have also been added due to their strong community presence and variety of progressive initiatives. Other associations include the American Biogas Council (ABA), International Biochar Initiative, and World Biogas Association (WBA).

Specific stakeholders

Beyond the host municipalities and facilities, there are several stakeholders which are unique to each proposal which can be categorically presented. Land conservancy groups & Land Trust can play an important role in establishing best use practices for the system byproducts. Also, the collective Cornell Cooperative Extensions, which have offices in each respective NY county, are integrated with the farming and recycling aspects of each region. They can work with the land organizations and play a leading role in helping to educate relevant sectors and markets about the benefits of the system's nutrient rich byproducts which are potential substitutes for synthetic solutions that are otherwise being imported into our local ecosystems.

There are also many universities which need to find solutions for their excess food waste in the coming year as mandated by Excess Food Waste legislation. Therefore, these establishments which are within the 25-mile radius of the proposed project location would be required to divert this waste stream. In addition, nearby concentrated animal feeding areas have been included as a potential source of manure feedstock that can be used for co-digestion. While this category typically refers to dairy cows, the Hudson Valley is home to a series of conducive horse feeding facilities.

Stakeholder summary table

TABLE H shows how these 'General' and 'Specific stakeholders are displayed with each proposal. All of the organizations in the column on the left remain consistent throughout the 10 sites while the column on the right will change according to the particular organizations unique to the proposal.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	**New York Department of Environmental Conservation**: Region # Environmental Permit **Host Facility:** **Land Conservancy Groups (Land Trusts):** **Cornell Cooperative Extension(s):** **Universities (Colleges):** **Concentrated Animal Feeding:**

TABLE H: ***Stakeholder Summary Table***

Results: Proposed locations & systems

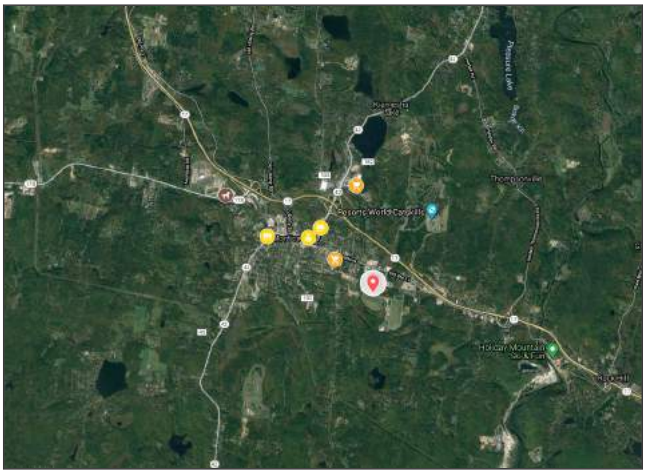
The following 10 Hudson Valley Circular Biogas Systems are presented with supportive reasoning for their implementation in a format according to the prescribed methodology. In this way, the reader can systematically examine the conclusive suggestions for each location. This consistency permits the proposals to be viewed alongside each other for additional comparative analysis:

- Each proposal begins with a short introduction regarding the site's general location in the Hudson Valley and the host municipality. This includes two mapped images: the first displays a general regional feedstock view, and the second shows a closer satellite image. This second image may be from a perspective directly overhead or can be a digital rendering from an angled perspective depending on the available computer generated graphics from the Google Maps platform.
- Following this introduction, the characteristic matrices are shared with corresponding explanations and evidence that support the conclusive aspects. This elaboration highlights the key features and advantages of each proposal as described by the methodology.
- Next, the system design is presented with some descriptive clarifications given for the respective flows and processes. Some comments are provided in regards to the capacities of anticipated technologies based on feedstock availability and associated volumes.
- After these details, regional maps identifying NYS designated environmental justice areas are depicted. Some comments related to job creation and education are also provided as well as justification for regional action.
- Finally, the 'General' and 'Specific' stakeholders are listed in chart form. Complete representation may extend far beyond the presented organizations, however, these lists serve as a foundation for capacity building strategies and should be considered malleable.

While the recent Hudson Valley Biogas assessment of resource potential only examined the 10 counties north of NYC, one additional county, Albany, which is the capital district, has been added to this project scope. Of the total 11 counties reviewed for this study, all, except for 3 of them, have been prescribed a biogas system solution; Columbia, Greene, and Putnam. Each of these exclusions have resulted for different reasons and are offered respective explanations in the discussion section of this report. The 10 resulting proposals have been presented in an order which increases in complexity with the succession of each system. For instance, the first proposal only suggests an anaerobic digestion solution while one of the more advanced proposals suggests pyrolyzing biosolids and setting up a plastics refinery adjacent to the site's facilities to apply the renewable energy to a new and innovative industrial application. Each system represents a potential solution representative of a circular economy production cycle and is intended to be used as a basis for additional discussion and discovery of new beneficial opportunities.

Proposal 1: Monticello Transfer Station

The Village of Monticello is in Sullivan County and is a small community of approximately 6,000 inhabitants (2019 US Census Bureau). In FIGURE 1A, the pink marker shows the satellite view of the Monticello Transfer station amidst a small number of identified excess food waste generators indicated by the yellow and orange markers. It is to the southeast of the village's center and southwest of highway Route 17. This transfer facility accepts many types of solid waste and recyclables and is operated by the Sullivan County Department of Solid Waste & Recycling. FIGURE 1B shows the operational flow chart of MSW, C&D, SSR, and Fiber/Paper and reveals this location as the central transfer point for the county. Materials that pass through here are either directed to various recycling redemption centers or are sent to the Seneca Meadows Landfill which is ~200-miles to the northwest. While this community is relatively small, its position relative to other large cities in the lower Hudson Valley appear to make it an ideal location for biogas production.



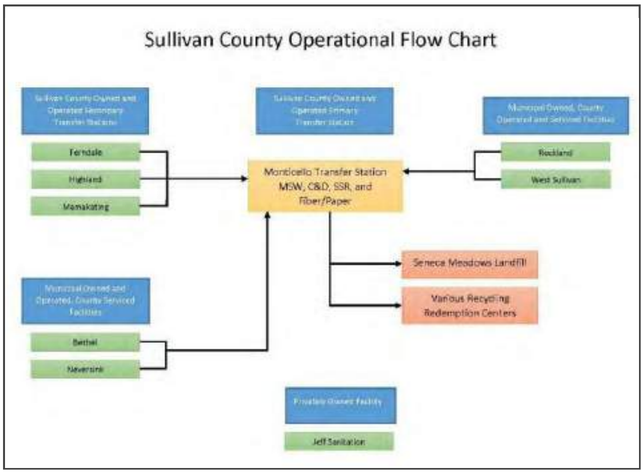


FIGURE 1A: ***Proposal 1 Mapped Feedstocks***

FIGURE 1B: ***Sullivan Operational Flow Chart***

A satellite view of the Monticello Transfer station is shown in FIGURE 1C. This is the site of a former Sullivan County Landfill and identifiable by the grass clearings. The area on the left of the image is about 30-acres while the large area on the right side of the image is about 45-acres. Due to the nature of the existing operations, this site has an ongoing industrial / commercial operation and maintains hauling activities. The corresponding classification matrix is shown in TABLE 1A. Excess food waste is not currently managed by this facility and is therefore being proposed to support a biogas operation and introduce recycling services to this agency. Therefore 'organics' is represented with the colored yellow. While a corresponding composting operation would offer a beneficial accompaniment to the proposal, it is not necessary because the digestate could be dried, pasteurized, bagged and sold directly to the local market.

FIGURE 1C: ***Monticello Transfer Station***

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 1A: ***Proposal 1 Commercial Activities***

FIGURE 1D shows the Monticello Entertainment Center and Raceway which is less than 5-miles from this transfer station. When operating at full capacity, the residing competition horses supply a seasonal supply of manure that could be incorporated into a localized biogas production solution for co-digestion. According to the recent Hudson Valley Biogas assessment on feedstocks, this additive could yield a series of beneficial outcomes inclusive of a healthier microbial environment, increased biogas production, and higher proportions of methane content. Further investigation into the current management practices of this biomass is necessary to determine if an integration with this technology would produce an economically viable intermediary step to current management.

FIGURE 1D: ***Monticello Entertainment Center***

FIGURE 1E: ***Monticello STP***

In TABLE 1B, 'perennial grasses' are also identified as a potential feedstock due to the rural landscape of the region and the large amount of open grass space over the closed landfills. While grasses with deep-root structures such as switchgrass and miscanthus could be implemented with an accompanying land restoration initiative, shallow-root grasses could be introduced onto the capped landfill and harvested for co-digestion. These landfills already have associated maintenance expenses which could be offset through the incorporation of this feedstock.

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE 1B: ***Proposal 1 Feedstocks***

According to the NYS DEC's 2015 Biosolids Survey, the neighboring sewage treatment plant, officially called the Monticello STP (SPDES No: NY0022454), has a flow of 1.3 million gallons per day (designed for up to 3.1 million) and generates approximately 235 dry tons of biosolids on an annual basis. Since this volume is under 1,000 tons per year, an economically viable biosolids pyrolysis solution would require about four times as much material. As such, 'biosolids' is colored green in TABLE 1C and 'pyrolysis' is not colored. While this WWTP can be seen in the upper left corner of FIGURE 1C, a closer satellite view is provided with FIGURE 1E. In 2015, the biomass was sent to the Seneca Meadows Landfill. This represents approximately 30% of Sullivan County's 761 total reported dry tons that year, so aggregating all of this mass to a centralized facility would still not meet an economical threshold for industrialized pyrolysis. However, the neighboring NY counties of Orange and Ulster generate much higher volumes of dry tons. Therefore, if a pyrolysis solution is employed in these nearby regions, the material generated in Sullivan County could potentially be processed and conserved within the Lower Hudson Valley by routing to a facility in an adjacent county. This course of action would significantly reduce transportation distances, reroute material flows for beneficial use, and alleviate some of the economic burden associated with current management practices. The Monticello STP also has a belt filter press which dewaters the biosolids and would be advantageous as a preparation step to a regional pyrolysis solution.

Pyrolysis & biochar		
Biosolids	Wood waste	Heat need

TABLE 1C: ***Proposal 1 Pyrolysis Potential***

The transfer station and respective landfill facilities host a variety of open-space areas that are large enough to introduce biogas infrastructure. While there is some space around the weigh-station at the entrance, the areas shown in FIGURE 1F and FIGURE 1G appear to be more conducive for adding the system components. In FIGURE 1F there is approximately 4- to 5-acres of space around the existing infrastructure which has maintained fields and adequate trucking access. This would allow the systems to be scaled with additional feedstock. The building on the southern point of the property offers an electrical connection for integration with the electricity generator.

FIGURE 1F: ***Sullivan Landfill (Area Estimate)***

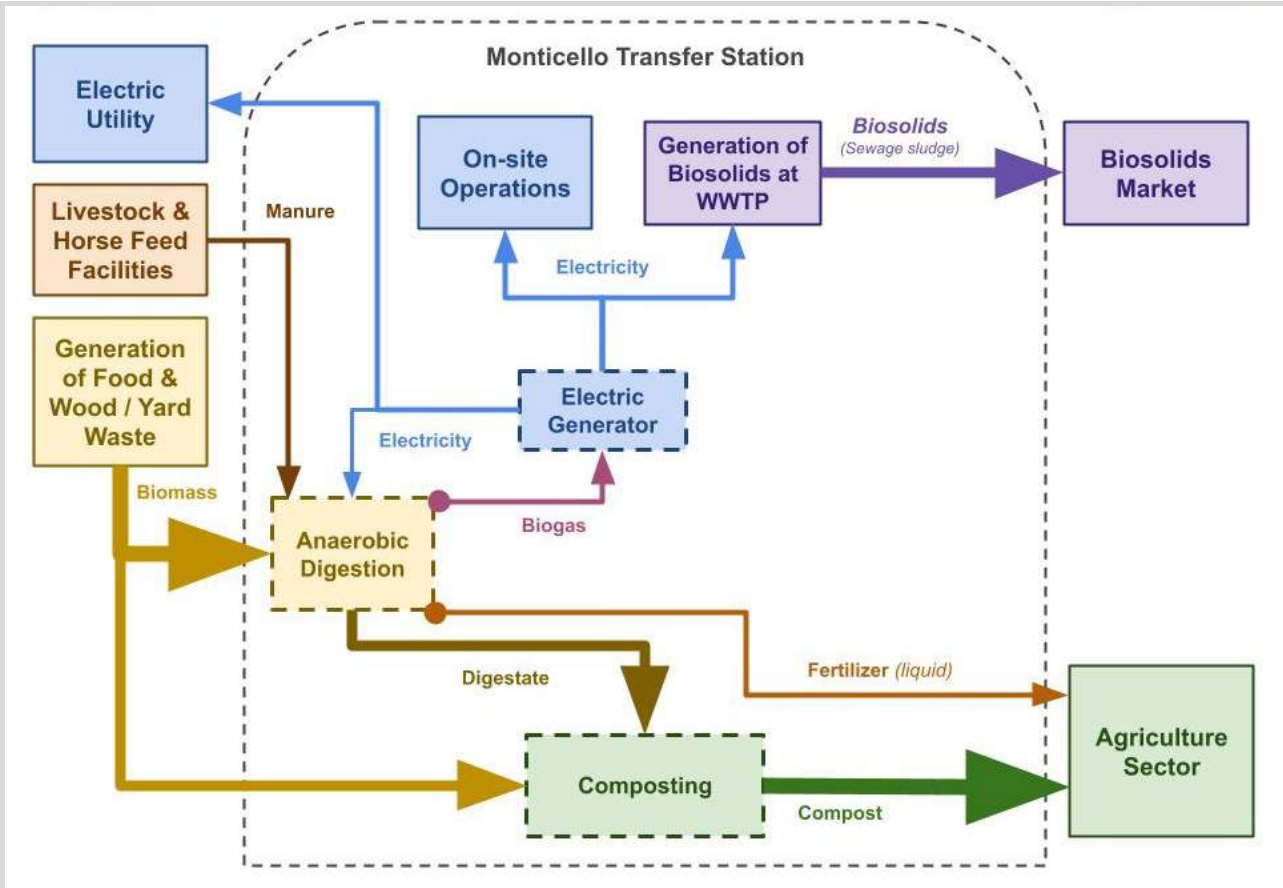
FIGURE 1G: ***Southern Building (Landfill)***

On-site investigation is necessary to determine if there is adequate area to introduce additional technologies, thus 'circular economy' in TABLE 1D has also been colored yellow.

Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE 1D: ***Proposal 1 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 1 and consists primarily of anaerobic digestion and electricity generation processes. The feedstocks are excess food waste and locally available horse manure. As previously mentioned, a composting process will be beneficial, but is not necessary for the proposed design. Another output is the nutrient-rich liquid fertilizer which can be provided to the local agricultural markets and offset the importation of synthetic compounds to the local ecosystem. Installing a biogas production facility at the Monticello Transfer Station can inspire and support an effort to upgrade on-site heavy equipment to electrical power. Implementing this renewable energy design therefore allows for the introduction of innovative expansion projects that can help this county meet the state's low-carbon transition plan.



SYSTEM 1: ***Proposal For Monticello Transfer Station***

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes the City of Monticello as an environmental justice region. FIGURES 1H & 1I are sourced from the state and reveal the expansiveness of this particular region designated with the color purple. FIGURE 1H reveals the span of this area relative to Sullivan County while FIGURE 1I offers a much higher resolution and closer view of the same area. Implementing a circular economy initiative at this location therefore offers an opportunity to introduce investments into this area that would be accessible by the local communities. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the region. Renewable energy in the form of electricity could be applied to the neighboring treatment plant and local electric grid while excess byproduct materials can be sold as a community export for additional revenue.

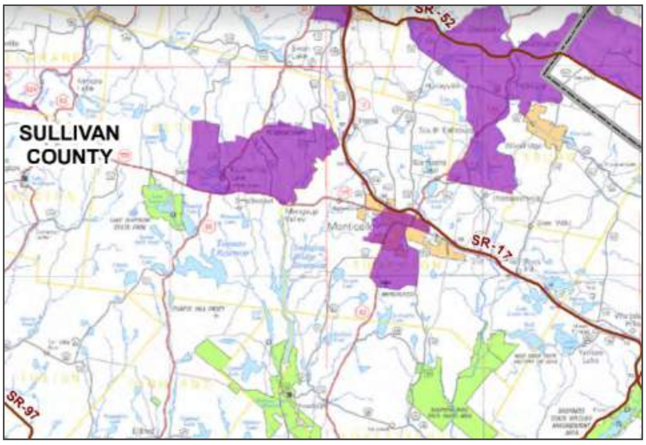


FIGURE 1H: ***Sullivan County Env. Justice***

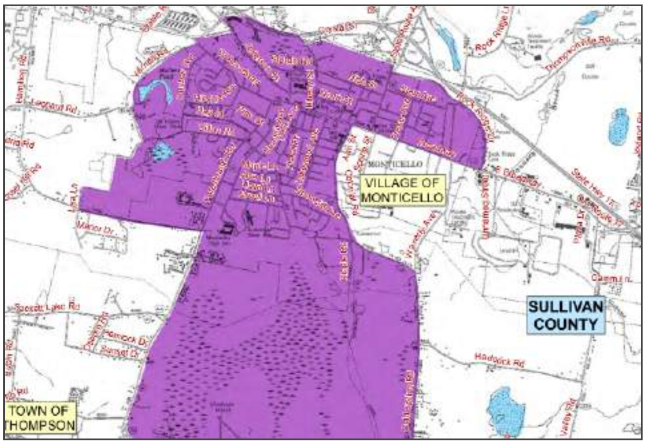


FIGURE 1I: ***Monticello Env. Justice***

TABLE 1E lists a variety of 'general' stakeholders relevant to all 10 Hudson Valley Biogas system proposals. This includes the NYS DEC, with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. 'Specific' stakeholders to this project include the county's Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the transfer station, and some additional regional organizations. In order to maximize community, job creation potential, and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. This is a key location for materials management throughout the lower Hudson Valley and should be valued as a strategic opportunity to introduce renewable practices.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	**New York Department of Environmental Conservation**: Region 3 Environmental Permits **Host Facility:** Sullivan County Transfer Stations / Environmental Facilities **Land Conservancy Groups (Land Trusts):** **Cornell Cooperative Extension(s):** Sullivan County **Universities (Colleges):** SUNY Sullivan **Concentrated Animal Feeding:** Monticello Raceway

TABLE 1E: ***Proposal 1 Stakeholders***

Proposal 2: Taylor-Montgomery LLC

The town of Montgomery is in Orange County, 12-miles west of the Hudson River, and 7- miles west of Stewart International Airport. Taylor-Montgomery LLC is located on Neelytown Rd which is south of the town and Interstate 84. This facility recycles construction and demolition waste materials into new and useful products and can benefit from an integrated circular biogas production system. Their sorting operation extracts metals and separates cardboard for resale to local businesses. They also manage plastics and are continually working with partners to find new ways to recycle. Taylor's mission is to "reduce landfill waste and greenhouse gas emissions by generating useful products from 95%, or more, of the debris brought to [their] site, which were once considered useless." Montgomery has about 24,000 residents and is relatively close to the cities of Newburgh and Middletown which each host approximately 28,000 residents (US Census Bureau). FIGURE 2A shows this site location with the pink map marker in the center. The city of Middletown is on the left and the city of Newburgh is on the right among a variety of identified excess food waste generators.

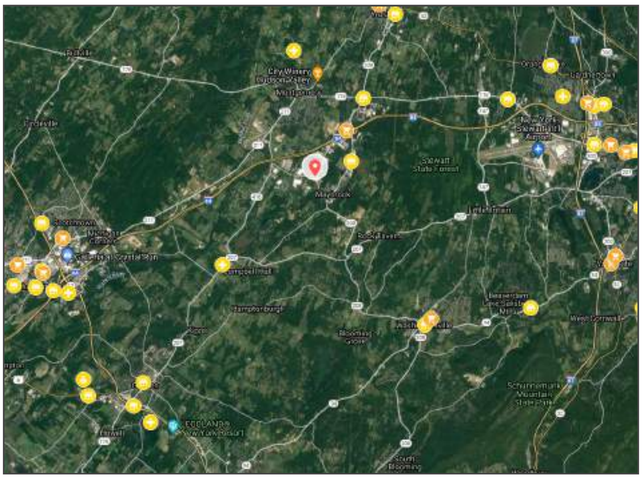


FIGURE 2A: ***Proposal 2 Mapped Feedstocks*** **FIGURE 2B:** ***Taylor-Montgomery LLC***

An aerial image of the Taylor Montgomery facility has been sourced from the company's website and is designated as FIGURE 2B. There are some numbers on this image which identify the on-site location of certain operations. For instance, number 7, in the upper-right corner, shows their topsoil curing. Meanwhile, number 4 is on the left side of the main building and depicts their sorting facility. Excess food waste is not currently managed and is being proposed to support a biogas operation for this populous area. Due to the nature of the existing operations, this site has an ongoing industrial operation conducive for these activities. The corresponding classification matrix is shown in TABLE 2A. Composting is prohibited for commercial application as per the town's zoning laws, however, this process is unnecessary for the system design and would not impede production of other high value products that can be created from locally available organic feedstocks.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 2A: ***Proposal 2 Commercial Activities***

FIGURES 2C & 2D display two locations with water chestnut infestations within Orange County. Algonquin Park is in the town of Newburgh and is shown in FIGURE 2C. This ~2-acre pond is almost completely covered by this invasive aquatic plant (the apparent light-green color). On occasion, local organizations will conduct small-scale removal efforts which is likely the reason for the water surface visibility along the shore. This body of water drains over a dam into a second ½-acre pond that is also completely infested. Meanwhile, FIGURE 2D displays the mouth of the Moodna Creek where it empties into the Hudson River. This location is about 15-miles from Taylor-Montgomery and is also crowded with several patches of water chestnut. Together, these two sites offer biomass which could be extracted and used for co-digestion with excess food waste. It is also important to note that Denning's Point, next to the Beacon Recycling & Transfer Station, is ~16-miles from Taylor-Montgomery and has a much larger water chestnut infestation that would be economically viable to harvest and transport for processing in Montgomery.

FIGURE 2C: ***Algonquin Park Pond***

FIGURE 2D: ***Moodna Creek & Hudson River***

'Livestock manure' is listed in green on TABLE 2B because the Gardnertown Farm is about 12 miles away from the recycling facility and hosts several dozen horses throughout the year. A computer generated satellite image of this area is shown in FIGURE 2E. Their operations include equestrian shows, clinics, and polo games, so there is regular feeding and housing. While they currently sell the horse manure to local residents and farming operations, a partnership could be explored with this family owned and operated business to incorporate their excess biomass into a local co-digestion process for biogas production.

FIGURE 2E: *Gardnertown Farm*

Perennial grasses are proposed as an additional feedstock source for this location provided the amount of open area that the recycling center appears to have throughout the property. For an operation that would support approximately 1,500 tons of silage per year, the storage structure would need to be about 75-ft by 250-ft which is less than ½-acre. A clamp without walls would maximize flexibility and the heaping pile would rise to a little more than 10-ft at the center. Further investigation of the current ground surface is necessary to determine if a respective foundation would be necessary. While concrete or asphalt can be used as a base, it must be designed and treated for the acidic nature of silage. This suggested operation could be integrated with a land restoration initiative that would seek to revitalize regional farmland and increase agriculture productivity potential throughout the county. Logistics for greater Hudson Valley impact should be explored through local land conservancies and educational institutions to secure supply chains and establish a consistent feedstock. As a cellulosic plant, grinding and mashing machinery is crucial to enable the most efficient digestion process and generate byproducts with the highest value. Provided these uncertainties, yet viable potential, this feedstock has been colored 'yellow' in TABLE 2B.

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE 2B: ***Proposal 2 Feedstocks***

Taylor-Montgomery LLC does not manage any biosolids, however there may be an opportunity to introduce pyrolysis of this biomass from locally sourced WWTP's into a greater circular economy initiative. According to the NYS DEC's 2015 Biosolids Survey, there are two WWTPs nearby: The Montgomery-T STP Dist #1 (SPDES No: NY0247782) has a flow of 0.119 MGD (designed for up to 0.15 million) and generates approximately 31 dry tons of biosolids on an annual basis, and the Village Of Montgomery STP (SPDES No: NY0026433) has a flow of 0.331 million gallons per day (designed for up to 0.5 MGD) and generates approximately 172 dry tons of biosolids on an annual basis. Both facilities employ aerobic digestion processes, and, at the time of the survey, the latter was sending the resulting biomass to incineration in Connecticut. In order to reach a 1,000 ton annual volume that would facilitate an economically viable pyrolysis treatment operation, biosolids would have to be sourced from other treatment plants as well. Upon examination of the mapped data points, there are several nearby locations which generate a significant amount of biomass and should be considered prime candidates for collaboration. As such, 'pyrolysis and biochar' potential is identified in yellow in TABLE 2C.

FIGURE 2F: ***Goshen WWTF***

FIGURE 2G: ***New Windsor STP***

The Goshen WWTF, in FIGURE 2F (SPDES No: NY0031518), is located in Goshen, NY and approximately 10 miles away from the recycling center. It has a flow of 1.108 million gallons per day (designed for up to 2 million), generates approximately 442 dry tons of biosolids on an annual basis, and, at the time of the survey, was sending this biomass to Pennsylvania for land application. In addition, the New Windsor STP, in FIGURE 2G (SPDES No: NY0022446), is located in New Windsor, NY and approximately 14 miles away from the recycling center. It has a flow of 3.4 MGD (designed for up to 5 MGD), generates approximately 525 dry tons of biosolids on an annual basis, and at the time of the survey was also sending its biomass to Connecticut for incineration. This treatment center is located along the northern bank of the Moodna Creek, which is visible at the bottom of FIGURE 2G, and is only a short distance upstream from the aforementioned water chestnut infestation where this watershed enters the Hudson River. Combined, these four treatment WWTPs generate over 1,000 dry tons of biosolids on an annual basis which would justify a financial investment in local pyrolysis treatment for beneficial applications and remove thousands of miles of hauling activities, and the respective carbon emissions, from the described management practices.

FIGURE 2H: ***Wallkill STP***

FIGURE 2I: ***Newburgh WWTP***

It would also be possible to scale these proposed pyrolysis operations with additional biosolids sourced from Orange County that lie within the same approximate radial distance. For instance, the Wallkill STP, in FIGURE 2H (SPDES No: NY0024422), is located in Middletown, NY along the Wallkill River, and is approximately 14-miles from the recycling center. It has a flow of 2.5 MGD (designed for up to 4 MGD), generates approximately 454 dry tons of biosolids on an annual basis, and at the time of the survey was sent outside of the state for incineration. Also, the Newburgh WWTP, in FIGURE 2I (SPDES No: NY0026310), is located in Newburgh, NY along the Hudson River, and approximately 15-miles from the recycling center. It has a flow of 4.9 MGD per day (designed for up to 8.8 MGD), but the amount of generated biosolids was not reported. Provided that this is almost twice the volume of the Wallkill STP, it produces a significant amount of biomass.

Pyrolysis & biochar		
Biosolids	**Wood waste**	**Heat need**

TABLE 2C: ***Proposal 2 Pyrolysis Potential***

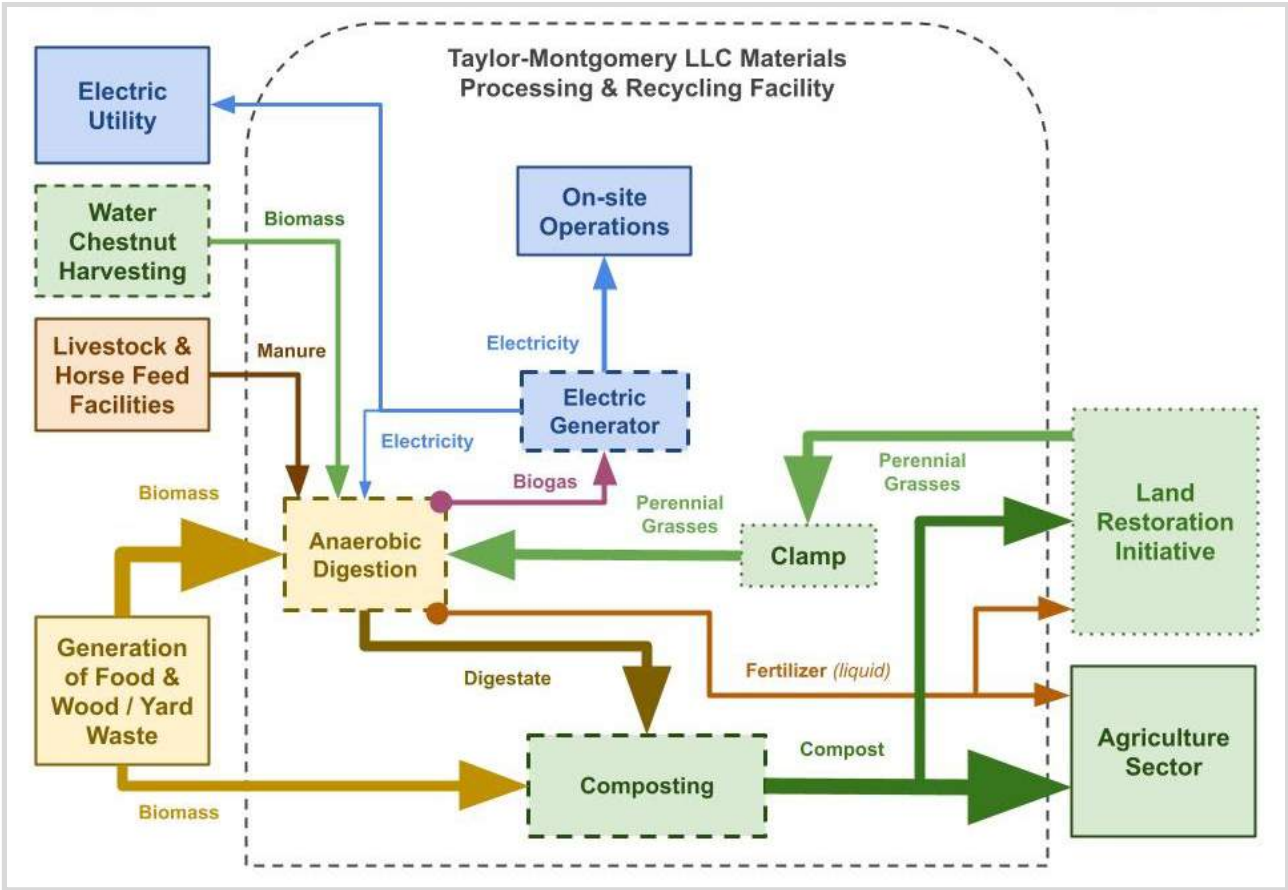
FIGURE 2J: ***Two Land Parcels (~95-acres)*** **FIGURE 2K:** ***North Land Parcel (~45-acres)***

Taylor-Montgomery LLC maintains ownership of two land plots which are shown in FIGURE 2J and have a combined area of about 95-acres. Their current operations are on the north parcel which is about 45-acres (FIGURE 2K). The southern plot is approximately 55-acres and has no infrastructure except for some road access to the northern parcel on the eastern end of the property. It has sufficient space to support this biogas proposal, scale with increased feedstock, and introduce additional innovative initiatives. As such, the corresponding area TABLE 2D is completely green.

Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE 2D: ***Proposal 2 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 2 and displays the primary anaerobic digestion process. The feedstocks for co-digestion are excess food waste, the locally available horse manure, and the regionally available water chestnut. 'Water chestnut harvesting' has a dashed border because there aren't any nearby communities that currently have a harvesting machine. A composting process is also shown, but is not necessary for the proposed design (it can have some complications with town zoning). Another process depicted is clamp storage which can store regionally produced perennial grasses and be used as an additional feedstock for anaerobic digestion. The outputs of the digester are reapplied to a respective land restoration initiative. While this proposal has thoroughly explored the potential feedstock origins for a biosolids pyrolysis process, it has not been included in this diagram. This is because Taylor-Montgomery doesn't currently manage this biomass and implementation would require the collaboration of many stakeholders. However, an implementation of this system should be explored and can complement their existing on-site management of plastics. Similar to proposal 8 for the Ulster County Resource & Recovery Agency, heat generated from pyrolysis can offer on-site drying and grinding of sorted plastics and invite additional innovative on-site manufacturing of plastic products directly from recycled materials. Installations that remove the transportation aspects are necessary for economic viability and essential for the Hudson Valley to meet the state's low-carbon transition plan.



SYSTEM 2: ***Proposal for Taylor-Montgomery LLC***

The owners of Taylor-Montgomery LLC also own Taylor Biomass Energy, LLC which is headquartered at the same location. They are actively proposing a biomass gasification process that produces medium Btu and has a heating value approximately half that of natural gas. It would be a multi-million dollar facility, built at this location, which would intake MSW, produce syngas, and reduce waste otherwise destined for landfills. The installation would provide a direct substitute for natural gas and could be used as a fuel for turbine engines as a synthesis gas for a large variety of products related to biofuels, chemicals, and hydrogen. Taylor Biomass claims that integrating the Taylor Gasifier with their current sorting and separating process can reduce emissions generated from ‘business-as-usual’ by an order of magnitude. Through this process, material input mass would be reduced by approximately 90% and contaminants in the gas, such as nitrogen producing compounds and sulfur compounds, would be removed to improve overall process emissions.

This gasification initiative can complement the biogas circular system that Hudson Valley Biogas is proposing. These production cycles can be integrated with combined infrastructure facilitating generation, storage, and transfer of heat. A coordinated planning effort would therefore increase the respective benefits and economical opportunities associated with each independent installation. It would create an inspirational, renewable production center setting precedents for innovative energy generation and novel material processing that could have its benefits shared and replicated throughout the world. Orange County and the greater Hudson Valley can greatly benefit from this system thinking mentality and promote the establishment of relevant new business opportunities.

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes the nearby City of Newburgh as an environmental justice region as well as several areas around the neighboring community of Middletown. FIGURES 2L & 2M are sourced from the state and reveal the expansiveness of these regions which are designated with the color purple. FIGURE 2L reveals the span of this area relative to Orange County while FIGURE 2M offers a much higher resolution and closer view of the same area. Implementing a circular economy initiative at this location therefore offers an opportunity to introduce investments into this region that would be accessible by the local communities. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the community. Renewable energy in the form of electricity could be applied to the local electric grid while excess byproduct materials can be sold as a community export thereby generating additional revenue opportunities for the county.

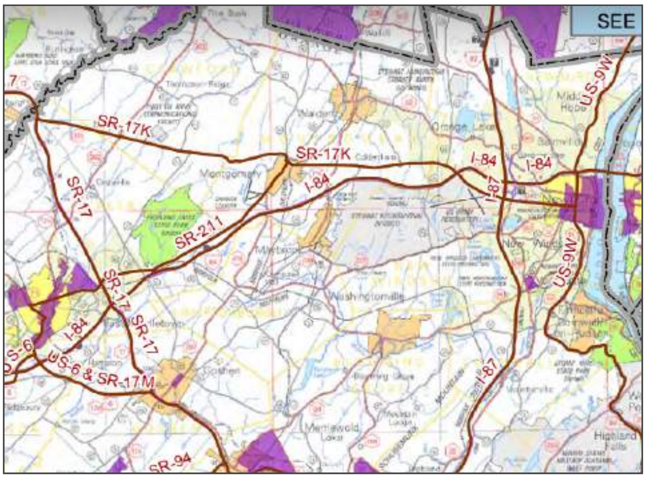


FIGURE 2L: *Orange County Env. Justice*

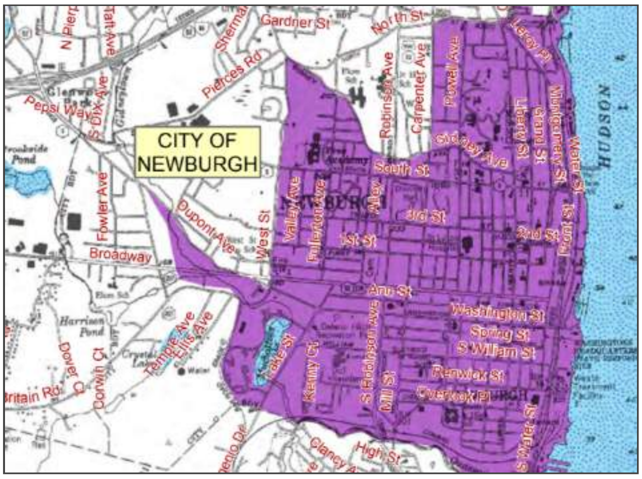


FIGURE 2M: City Of *Newburgh Env. Justice*

TABLE 2E lists a variety of ‘general’ stakeholders relevant to all 10 Hudson Valley Biogas system proposals. This includes the NYS DEC, with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. ‘Specific’ stakeholders to this project include the local land conservancies and land trust, the county’s Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. Due to the potential for the invasive water chestnut to be used as a feedstock at this site location, some of the ‘specific’ organizations also include PRISM, Scenic Hudson, and the Hudson River Watershed Alliance. These groups are therefore in common with the other proposals which exhibit the same potential to utilize this aquatic feedstock. In order to maximize community and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. With Taylor-Montgomery residing near the intersection of two federal highways (I-87 and I-84), this facility is ideal for coordinating material flows throughout the Greater Hudson Valley.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	**New York Department of Environmental Conservation**: Region 3 Environmental Permits **Partnerships for Regional Invasive Species Management:** Capital Region PRISM Lower Hudson PRISM St Lawrence Eastern Lake Ontario (SLELO) PRISM New York-New Jersey Trail Conference **Host Facility:** Taylor-Montgomery, LLC Taylor Biomass Energy, LLC **Land Conservancy Groups (Land Trusts):** Dutchess Land Conservancy Hudson Highlands Land Trust Orange County Land Trust Stony Kill Foundation Wallkill Valley Land Trust **Cornell Cooperative Extension(s):** Dutchess County Orange County **Universities (Colleges):** Mount Saint Mary College SUNY Orange **Concentrated Animal Feeding:** Gardnertown Farm **Regional Organizations:** Beacon Institute for Rivers & Estuaries (Clarkson University) Hudsonia (Bard College) Hudson River Sloop Clearwater Hudson River Watershed Alliance Scenic Hudson

TABLE 2E: ***Proposal 2 Stakeholders***

Proposal 3: Beacon Recycling & Transfer

The city of Beacon is in Dutchess County and lies along the eastern coast of the Hudson River. This community is to the south of Interstate 84 and the Hamilton-Fish Newburgh-Beacon bridge. The Recycling & Transfer Station is located at the southern end of the Beacon Train Station and is on the east side of the railroad tracks. This facility provides city residents with garbage, recyclables, and yard waste drop-off services. Beacon has about 14,000 residents as provided by the US Census Bureau. FIGURE 3A shows this high density area on the right with the city of Newburgh (~30,000 people) on the left side of the image. The variety of biogas production feedstocks available in this area make it an ideal location to introduce a circular biogas system.

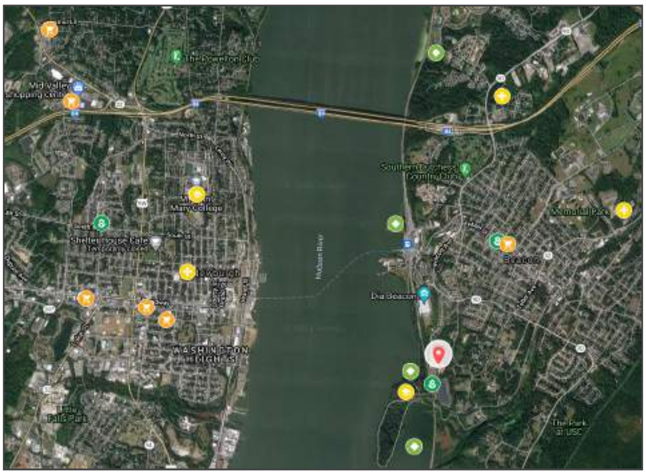


FIGURE 3A: ***Proposal 3 Mapped Feedstocks***

FIGURE 3B: ***Beacon Recycling & Transfer***

A computer generated image of the recycling facility is provided by FIGURE 3B. On the left side of the image, there are brown piles which represent a composting operation. Yard waste material is collected from area households and residents twice per year within the city limits and brush is picked up year round. Excess food waste is not currently managed by this facility and is therefore being proposed to support as a biogas feedstock. The city's wastewater treatment facility can also be seen in FIGURE 3A with infrastructure designed for aerobic treatment of biosolids. Immediately to the south of the aeration tanks and clarifiers, there is a closed landfill which now hosts a solar panel installation (past the field of view to the right). Due to the nature of the existing operations, this site has an ongoing industrial operation and maintains hauling activities. The corresponding classification matrix is shown in TABLE 3A with 'organics' in yellow and 'composting' in green.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 3A: ***Proposal 3 Commercial Activities***

FIGURE 3C displays another satellite image with the Beacon Recycling & Transfer station located in the top right corner. The prominent peninsula extending into the Hudson River is Denning's Point State Park and hosts Clarkson University's Beacon Institute for Rivers and Estuaries. Water chestnut infestations are very apparent across this image as the light green vegetation surrounding the tree-covered landmass. To the north, there are approximately 50-acres of this invasive plant, and to the south, at the mouth of the Fishkill Creek, there are approximately 85-acres (calculated with Google's area measurement tool). This represents a total of 135-acres of biomass in the immediate vicinity that are available for harvesting as a feedstock for anaerobic digestion. Because hauler transportation is not needed to the adjacent station, this feedstock offers an economically attractive opportunity for the proposed system. In the following feedstock chart, TABLE 3B shows 'invasive species' in yellow because Beacon does not have a water chestnut harvester. However, the Village of Wappingers Falls is approximately 10-miles north of this location and has a harvester which is used to manage their own infestation. A shared use agreement could be explored between both of these communities to maximize local benefit.

FIGURE 3C: ***Denning's Point***

Variation of feedstock				
Excess food waste	**Wood / yard waste**	**Invasive species**	**Livestock manure**	**Perennial grasses**

TABLE 3B: ***Proposal 3 Feedstocks***

According to the NYS DEC's 2015 Biosolids Survey, the one-site WWTP, officially referred to as the Beacon Water Pollution Control Plant (SPDES No: NY0025976), has a flow of 2.8 MGD (designed for up to 6 MGD) and generates approximately 1,600 dry tons of biosolids on an annual basis. At the time of the survey, the great majority of this mass was being landfilled in Chemung & Ontario which are in the western part of the state. Since this volume is over 1,000 tons per year, a biosolids pyrolysis solution would be appropriate for on-site installation to accompany the proposed biogas infrastructure. There is also a belt filter press in place to dewater the biosolids, so pyrolysis technology would be able to exploit additional energy efficiency as a result of the removed water content. An installation with this capacity would generate excess heat which could be applied to the anaerobic digestion operation as well as create opportunities for additional infrastructure that can benefit from this renewable energy. For instance, a partnership with the Beacon Institute for Rivers and Estuaries to provide renewable heat to their anticipated educational center expansion project. Another option would be to install community greenhouses and vertical farming projects in cooperation with the city, community groups, and this educational institution. Given the expansiveness of these opportunities, the 'heat need' attribute in TABLE 3C has been color-coded to yellow. The resulting char can be beneficially applied to the local production cycle as well as distributed to the local community to promote backyard gardening and food security.

Pyrolysis & biochar		
Biosolids	**Wood waste**	**Heat need**

TABLE 3C: ***Proposal 3 Pyrolysis Potential***

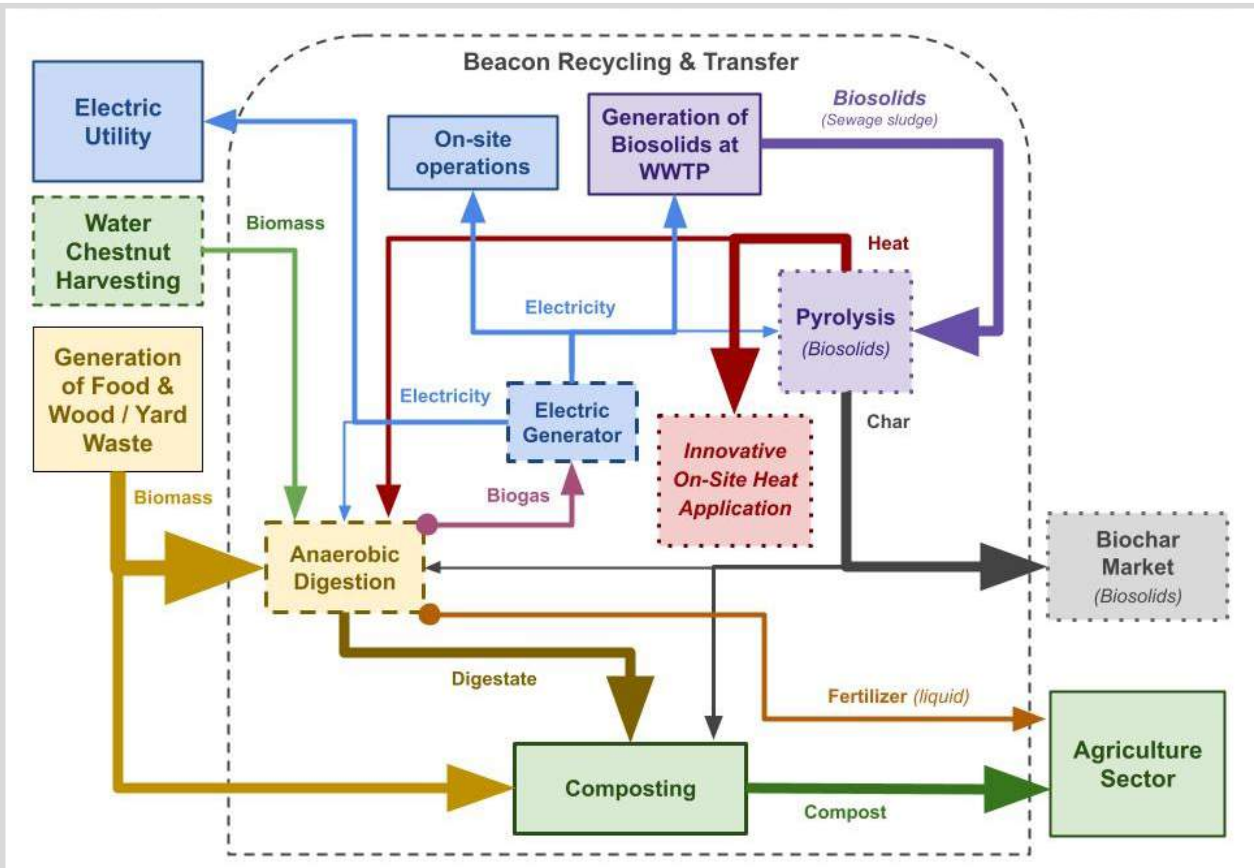
An aerial estimation of available area at the site suggests that there may be up to 6-acres of space which could be utilized for the proposed system. Therefore, TABLE 3D lists this as a sufficient amount of area to install these types of technologies. Space to expand the system appears limited, but could be explored with the adjacent institution's property. Irrespective of this constraint, there are opportunities for additional innovative circular economy initiatives.

FIGURE 3D: ***Examination Of Area***

Space to host the proposed system		
Sufficient to support proposal	**Space to scale-up the proposed system with increased feedstock**	**Available area to introduce innovative circular economy initiatives**

TABLE 3D: ***Proposal 3 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 2 and consists of three primary processes; anaerobic digestion, pyrolysis (biosolids), and composting. Excess food waste and the invasive water chestnut are depicted as feedstocks for anaerobic digestion while the outflow of biogas is converted to electrical energy. The nutrient-rich fertilizer is supplied to the local agricultural sector and the digestate is composted on site or directly sold to market. Biosolids generated from the on-site WWTP becomes a feedstock for pyrolysis, while resulting heat is applied



SYSTEM 3: ***Proposal For Beacon Recycling & Transfer***

applied to an innovative application. Some potential integrated technologies could be agriculture related infrastructure. A black arrow indicated the majority of the resulting char being sold to a respective market while a small portion would be allocated to both the anaerobic digestion and the potential composting process to catalyze beneficial microbe activity.

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes the City of Beacon as an environmental justice region and Beacon Recycling & Transfer happens to be located within this identified area. FIGURES 3E & 3F are sourced from the state and reveal the expansiveness of this particular region which is designated with the color purple. FIGURE 3E reveals the span of this area relative to the Dutchess and Putnam Counties, and FIGURE 3F offers a higher resolution depiction of the same area. Implementing a circular economy initiative at the transfer station offers a significant opportunity to introduce investments into this local community. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the community. Renewable energy in the form of electricity and heat could be applied to the treatment plant and local electric grid while excess byproduct materials can be sold as a community export thereby generating additional revenue municipal opportunities.

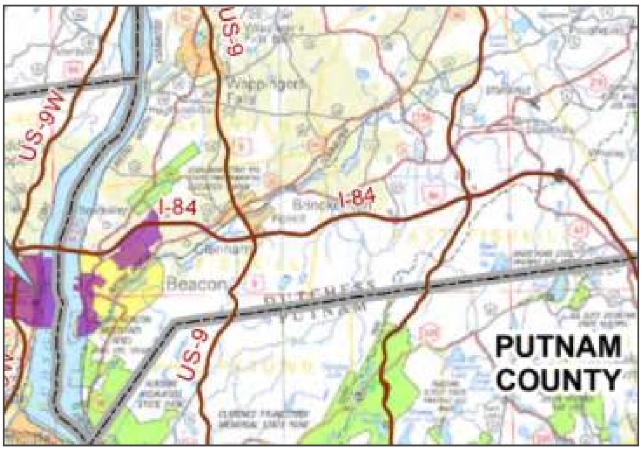


FIGURE 3E: ***Dutchess County Env. Justice***

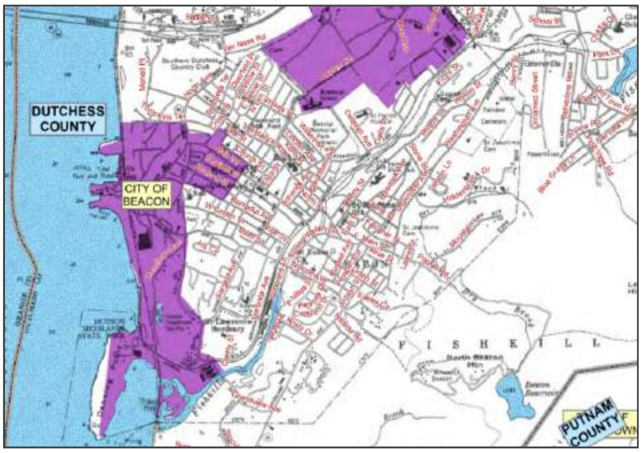


FIGURE 3F: City Of *Beacon Env. Justice*

TABLE 3E lists a variety of 'general' stakeholders relevant to all 10 Hudson Valley Biogas system proposals. This includes the NYS DEC with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. 'Specific' stakeholders to this project include the local land conservancies and land trust, the county's Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. Due to the great potential for the invasive water chestnut to be used as a feedstock at this site location, some of the 'specific' organizations also include PRISM, Scenic Hudson, and the Hudson River Watershed Alliance. These groups are therefore in common with the other proposals which exhibit the same potential to utilize this aquatic feedstock. In order to maximize community and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	**New York Department of Environmental Conservation:** Region 3 Environmental Permits **Partnerships for Regional Invasive Species Management:** Capital Region PRISM Lower Hudson PRISM St Lawrence Eastern Lake Ontario (SLELO) PRISM New York-New Jersey Trail Conference **Host Facility:** Beacon Recycling & Transfer Station **Land Conservancy Groups (Land Trusts):** Dutchess Land Conservancy Hudson Highlands Land Trust Stony Kill Foundation **Cornell Cooperative Extension(s):** Dutchess County Orange County **Universities (Colleges):** Mount Saint Mary College **Concentrated Animal Feeding:** **Regional Organizations:** Beacon Institute for Rivers & Estuaries (Clarkson University) Hudsonia (Bard College) Hudson River Sloop Clearwater Hudson River Watershed Alliance Scenic Hudson

TABLE 3E: *Proposal 3 Stakeholders*

Proposal 4: WeCare Denali | Rockland County

The city of Hillburn, NY is in Rockland County and home to [WeCare Denali](). It is east of Interstate 87, less than 3-miles from the state's border with New Jersey, and about 13-miles west of the Tappan-Zee Bridge. Denali has many facilities throughout the US and this is one of three within [Rockland County](). FIGURE 4A shows the WeCare Hillburn's location identified by the pink marker among many yellow and orange data points identifying nearby excess food waste generators. WeCare manufactures compost mulch and soils, and depending on the end use market, they will often incorporate biosolids in their production process. These products are sold to both the public and private sectors throughout the landscape, construction, and agricultural industries. All of Rockland County is within 25-miles of his facility which is home to over 325,000 residents (US Census Bureau) which makes this an ideal location to implement a circular biogas system.

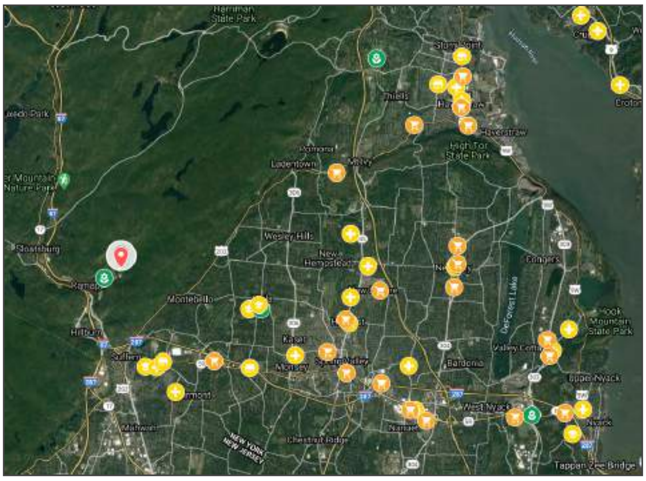


FIGURE 4A: ***Proposal 4 Mapped Feedstocks***

FIGURE 4B: ***WeCare Denali | Rockland***

A satellite view of the Hillburn facility is depicted in FIGURE 4B. This site is also the location of the Rockland County Solid Waste Management Authority which is a recycling center that processes and composts a variety of feedstocks, but does not include excess food waste. Adjacent to the operation buildings is a closed landfill, and there isn't any on-site energy production at this time. The corresponding commercial matrix is shown in TABLE 4A with 'composting,' and 'recycling facilities,' color-coded green. Biogas production through anaerobic digestion is being proposed to generate electrical energy for the facility and contribute to their organics processing. This would also help to expand the waste authority's operating potential and represent green infrastructure.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 4A: ***Proposal 4 Commercial Activities***

According to the Cornell Waste Management Institute's survey, brush and branches, logs, stumps and other wood along with animal manure are currently composted at this location in vessels and sold to the local market. However, in response to NY's food waste law, Denali is now considering collection of this additional biomass to incorporate into their current organics management practice.

In TABLE 4B, 'perennial grasses' are identified as a potential biogas production feedstock because of the rural areas located within 25-miles north of this facility in Orange County. A respective land restoration initiative can be explored with neighboring communities to revitalize depleted farm soils and improve local agricultural districts. The open grass areas over the closed landfill can also be harvested for co-digestion with the aforementioned organics. This landfill already has associated maintenance expenses which could be offset with the incorporation of this potential feedstock.

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE 4B: *Proposal 4 Feedstocks*

According to the NYS DEC's 2015 Biosolids Survey, 3,250 tons of biosolids are managed within Rockland County on an annual basis. The primary source of this biomass is generated at the Rockland County Sewer District No 1 (SPDES No: NY0031895) which has a flow of 15.9 MGD (designed for up to 28.9 MGD) and generates approximately 2,122 dry tons of biosolids annually. This is an anaerobic digestion facility, depicted in FIGURE 4C, and all of the digestate is managed within the local area. Organic Recycling Inc can be seen adjacent to the treatment plant, on the right side of the image, which produces a variety of landscape products. The county's second highest generator of biosolids is located less than ½ mile from this sewer district and is called Orangetown SD #2 STP (SPDES No: NY0026051). It has a flow of 7.84 MGD (designed for up to 12.75 MGD) and is depicted in FIGURE 4D. This facility generates approximately 1,216 dry tons annually, however, in 2015, approximately 50% of this mass was sent to the Seneca Meadows Landfill. Subsequent generators are Haverstraw Joint Regional STP (SPDES No: NY0028533). in West Haverstraw (FIGURE 4E), and Western Ramapo Advanced WWTP (SPDES No: NY0270598), in Hillburn, NY (FIGURE 4F) which, on an annual basis, generate ~330 and ~185 dry tons, respectively. The Biosolids Survey does not identify how much of this mass ends up at the WeCare Denali facility, however, the company receives a large portion of the total amount.

FIGURE 4C: *Rockland SD No 1 (Anaerobic)*

FIGURE 4D: *Orangetown SD No 2 STP*

Denali WeCare also accepts biosolids that are generated throughout the greater Hudson Valley. One of the current origins of this additional biomass is the Ulster County Resource & Recovery

Facility (UCRRA) which is an aggregate point for about 3,600 tons of biosolids per annum. (Only about half of this is generated by WWTPs in Ulster County according to the biosolids survey.) While Ulster County formerly sent this biomass to landfill, Denali has recently acquired a contract to haul this material 70-miles south to their processing facilities throughout Rockland.

FIGURE 4E: ***Haverstraw Joint Regional STP***

FIGURE 4F: ***Western Ramapo WWTP***

Because WeCare Denali appears to processes thousands of tons of biosolids per year, pyrolysis could be introduced as a carbon sequestration technology that could help provide their facility with some of the necessary heat that is required to upgrade and dry this biomass to Class B and Class A materials, as required by the EPA, for their respective markets. While significant heat is naturally created through the compost curing process, an additional renewable source can expedite this process. TABLE 4C therefore indicates ‘heat need’ with the color ‘green’ and ‘pyrolysis’ in yellow. Instead of using electricity produced from fossil fuels or natural gas to process the biosolids and destroy potential pathogens, a pyrolysis installation would divert some of this material to create a marketable char product while alleviating the company of some of these other energy costs. This on-site renewable energy can be implemented as a system that is parallel to the current processing methods. In this way, Denali can maintain their current business practices and customers while increasing the economic value of their operations through energy efficiency and additional products.

Pyrolysis & biochar		
Biosolids	**Wood waste**	**Heat need**

TABLE 4C: ***Proposal 4 Pyrolysis Potential***

The amount of available area around these facilities appears to have some space limitations because there is not a significant amount of free space around the current buildings. The WeCare Denali biosolids processing center is shown in FIGURE 4G and a large compost pile can be seen on the back side of the building at the top of the image. According to one manufacturer, a pyrolysis unit that manages between 1,000- and 3,500-tons per year can be the equivalent size of a 2- to 4-car garage. Provided these dimensions, there appears to be sufficient space around the outside of the buildings, and WeCare may even have space inside the building that can be allocated to this infrastructure. Further investigation is necessary to determine the extent of scaling potential.

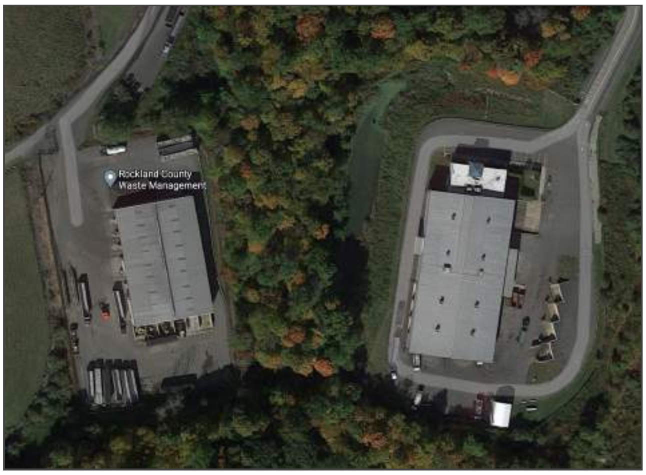


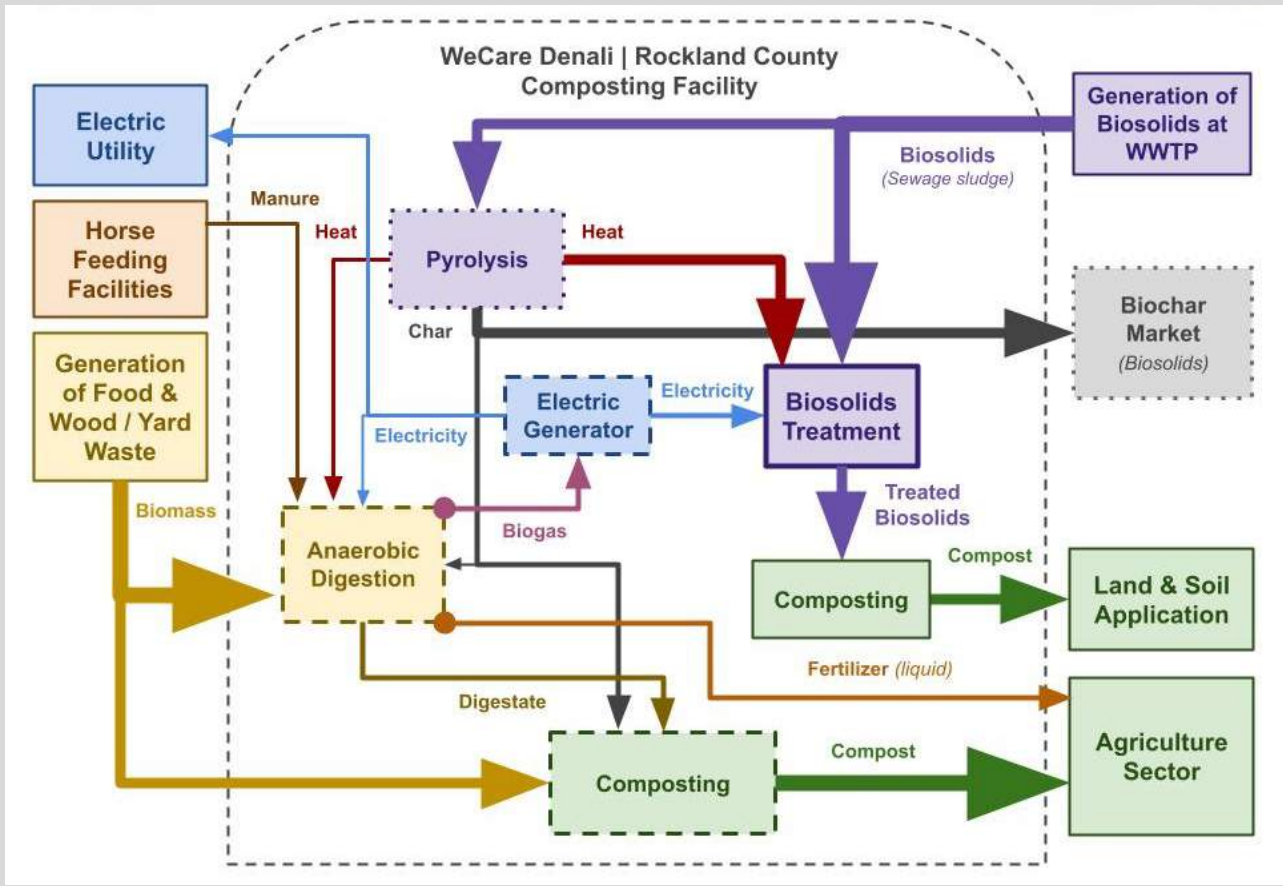
FIGURE 4G: ***WeCare Denali Facility*** **FIGURE 4H:** ***Rockland County Waste Mgmt.***

There also appears to be some available area around the Rockland County Waste Management buildings (FIGURE 4H). Due to separation, this would not be ideal for establishing the proposed circular system, however, the anaerobic digestion portion of the design may be able to be placed outside of these buildings and still provide an electricity offset for both the town and WeCare. The respective 'space' matrix is displayed in TABLE 4D and indicates potential for system expansion.

Space to host the proposed system		
Sufficient to support proposal	**Space to scale-up the proposed system with increased feedstock**	**Available area to introduce innovative circular economy initiatives**

TABLE 4D: ***Proposal 4 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 4 and consists of several existing and suggested flows & processes. The primary feedstocks for anaerobic digestion are excess food waste and livestock manure. The majority of biosolids received by this facility would continue with the current soil production practice while a portion would be diverted for pyrolysis. These flows are depicted with purple flow arrows. Heat produced from the pyrolysis process would be applied to WeCare's current treatment practices and is displayed with a red arrow. Most of the char produced would be sold to market, however, a portion of this material would be incorporated into the anaerobic digestion process to improve the microbial environment and methane production potential (black arrows). If the digestate byproduct is composted, it should be separate from the other composting activities due to the difference in quality as well as potential market value. The soil end product and liquid fertilizer effluent would be sold to the agriculture, community, and residential sectors. These flows are represented by the green and orange arrows, respectively. As previously described, biogas created from the anaerobic digestion process would be converted to electricity through an electrical generator and applied to the one-site operations with abundances sold to the electric utility. This is one example of integrating innovative and renewable energy technologies into an existing operation to increase overall resource recovery rates while upcycling material value. Denali can set a bold precedent for these types of operations by establishing this technology at their Hillburn location. They can also replicate this model at their many facilities throughout the county.



SYSTEM 4: ***Proposal For Denali We-Care Rockland***

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes the Village of Spring Valley as an environmental justice region as well as the nearby Village of Hillburn. FIGURES 4I & 4J are sourced from the state and reveal the expansiveness of this particular region which is designated with the color purple. FIGURE 4I reveals the span of this area relative to Rockland County,while FIGURE 4J offers a much higher resolution and closer view of the Village Of Spring Valley and the neighboring towns of Ramapo and Clarkstown. Implementing a circular economy initiative at this Rockland location therefore offers an opportunity to introduce investments to the local communities and build capacity with the local residents. This approach can educate the local citizens on the benefits of a regenerative production cycle.

FIGURE 4I: ***Rockland County Env. Justice***

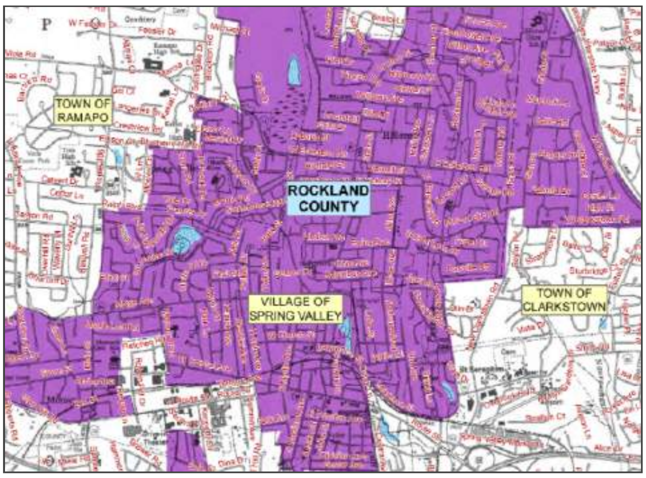


FIGURE 4J: ***Spring Valley Env. Justice***

TABLE 4E lists a variety of 'general' stakeholders relevant to all 10 Hudson Valley Biogas system proposals. This includes the NYS DEC with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. 'Specific' stakeholders to this project include the local land conservancies and land trust, the county's Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. In order to maximize community and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. Hillburn is a key location for materials management throughout the lower Hudson Valley due to its position amidst the highly populated areas just outside of NYC. Coordinating a regional operation at this site offers a strategic opportunity to introduce renewable practices at a transportation gateway to the NY counties north of Manhattan.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	**New York Department of Environmental Conservation**: Region 3 Environmental Permits **Host Facility:** Denali Water Solutions WeCare Denali | Rockland County **Land Conservancy Groups (Land Trusts):** **Cornell Cooperative Extension(s):** Rockland County Orange County **Universities (Colleges):** Rockland Community College SUNY Orange **Concentrated Animal Feeding:** **Regional Organizations:**

TABLE 4E: ***Proposal 4 Stakeholders***

Proposal 5: Ulster County Resource Recovery Agency

Kingston is in Ulster County along the western coast of the Hudson River. The Ulster County Resource Recovery Agency (UCRRA) is located ~3-miles northeast of the city center and south of the entrance to the Kingston-Rhinecliff Bridge. This facility is a solid waste authority, public benefit corporation and a permitted solid waste facility. There are about 23,000 residents in this community according to the US Census Bureau, and FIGURE 5A shows this site with a pink map marker among a collection of identified excess food waste generators to the west and to the south (orange and yellow ions). This site is an ideal location to implement a circular biogas system due to the large variety of materials involved in the current waste management operations.

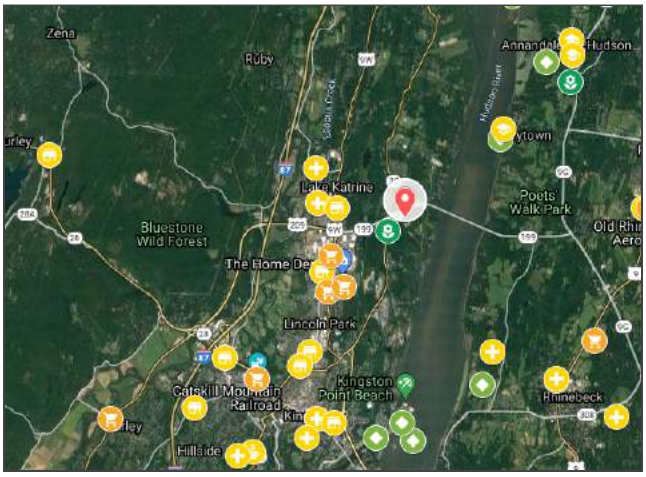


FIGURE 5A: ***Proposal 5 Mapped Feedstocks***

FIGURE 5B: ***Ulster County RRA***

A satellite view of UCRRA is pictured in FIGURE 5B with the compost facilities visible in the bottom and right sides of the image. This industrial composting operation (TABLE 5A) opened in 2012 and processes food scraps from commercial partners. From these organics, the agency manufactures a high quality, sustainably-produced compost that is for sale in bulk. UCRRA is a member of the United States Composting Council, and their Grow Ulster Green Compost is STA certified. On site, they have a Material Recovery Facility (MRF) which processes dual stream recycling. Here, mixed paper and cardboard is kept separate from commingled plastic/glass/metal. Only commercial businesses are allowed to deposit recyclables while residents must use a curb-side service.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 5A: ***Proposal 5 Commercial Activities***

The existing organic flows through their agency make it an ideal facility to implement an innovative biogas production cycle. Between 2017 and 2019, UCRRA composted 11,202 metric tons of food waste. They claim that diverting this biomass from MSW flows to the Seneca Meadows Landfill has resulted in a reduction of 53,600 transport miles and an offset of 30,400 gallons of diesel fuel. Through the current industrial management practice, the food scraps are combined with wood chips through a method that utilizes an Extended Aerated Static Pile (EASP) for 90 days.

FIGURES 5C & 5D display two locations on the Hudson River, north of Kingston, that are inundated with water chestnut infestations. Both are located in the town of Saugerties which is about 9 miles to the north of UCRRA. This neighboring community has a water chestnut harvester which they use to remove about 75 tons of this biomass from the watershed on an annual basis. FIGURE 5C shows an area coverage of about 60-acres, and it is to the north of Ruth Reynolds Glunt Nature Preserve, the Saugerties Lighthouse, and the mouth of the Esopus Creek. FIGURE 5D is directly south of FIGURE 5C and has an infestation that spans over 100-aces. There are also several sections of the Esopus Creek where this aquatic plant has become established. Saugerties current method of management is to send the collected biomass to landfill, however, a more beneficial alternative would be to apply this material to a biogas production operation (TABLE 5B).

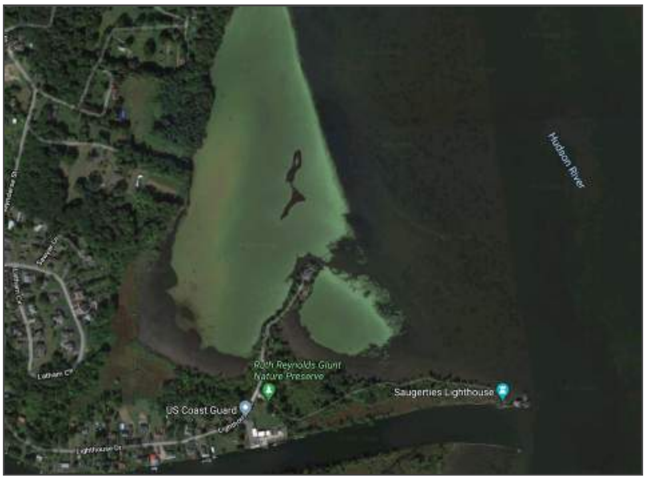


FIGURE 5C: ***North Of Esopus Creek***

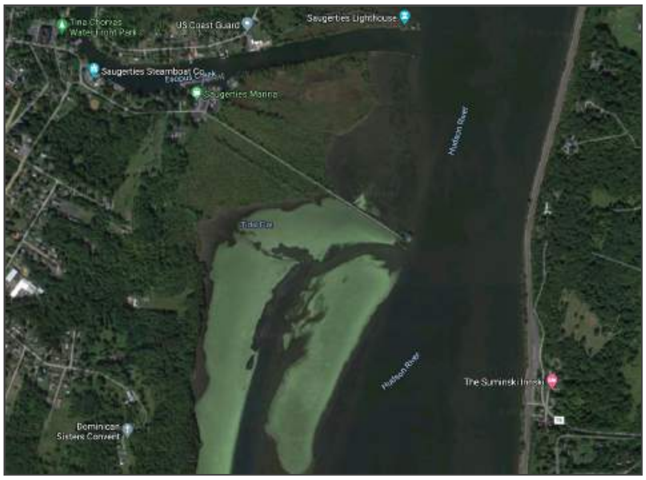


FIGURE 5D: ***South Of Esopus Creek***

Another nearby infestation on the Hudson River is shown in FIGURE 5E. It is less than 5-miles away, to the northeast, in Tivoli South Bay. This patch spans over 200-acres and is part of the Tivoli Bays Wildlife Management Area. It is on the eastern side of the Hudson River and adjacent to Bard College in Annandale-On-Hudson, NY. Also, about 8-miles south of the UCRRA, on the western side of the Hudson River, is another infestation that spans over 100-acres (FIGURE 5F). This is along the coast of Esopus Meadows Preserve and west of Esopus Meadows Lighthouse. This collection of infestation areas has the ability to provide Ulster County and the surrounding area with significant quantities of renewable products while incentivizing restoration of the local ecosystem.

FIGURE 5E: ***Tivoli South Bay***

FIGURE 5F: ***Esopus Meadows Preserve***

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE 5B: ***Proposal 5 Feedstocks***

Approximately 3,600 tons of biosolids pass through UCRRA per annum. Almost half of this amount is aggregated from WWTPs within Ulster County with the remainder coming from the surrounding counties. While this biomass was once sent to the Seneca Meadows Landfill (2015 Biosolids Survey), it is now contracted to Denali Water Solutions and transported about 70-miles south to their WeCare Composting facility in Rockland County. However, this quantity of material would justify a financial investment in an on-site pyrolysis treatment solution. This can remove thousands of miles of hauling from downstream processing along with the respective carbon emissions. In addition, the thousands of tons of wood chips and brush recycled at this site each year could be integrated into the char production process and offer additional carbon sequestration. The heat produced from this process that exceeds the need for drying the biosolids would invite other innovative technologies to be incorporated on site. Both 'biosolids' and 'wood waste' are identified in green in TABLE 5C because of their substantial quantities currently available at the agency while 'heat need' does not have any coloring because there is no immediate need for this renewable energy source.

Pyrolysis & biochar		
Biosolids	Wood waste	Heat need

TABLE 5C: ***Proposal 5 Pyrolysis Potential***

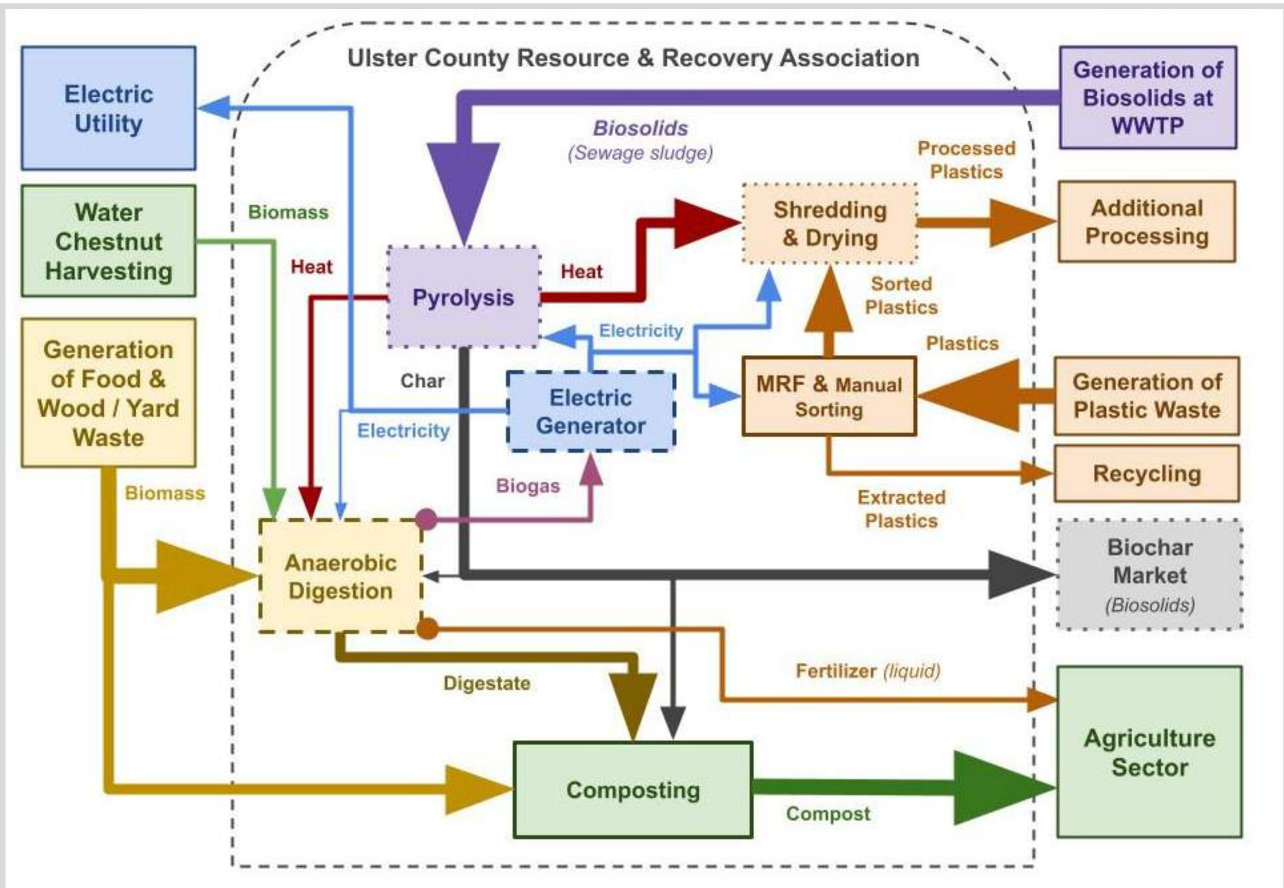
An aerial satellite view of UCRRA is displayed in FIGURE 5G. Visual inspection reveals that there is space available to implement the proposed system components. However, this facility may be at capacity with its current volume of material flows, so the 'scale-up' category has been color-coded to yellow in TABLE 5D. Regardless of this potential constraint, this location is positioned to introduce a variety of innovative circular economy initiatives related to waste management and upcycling to create products with higher value. These implementations can offer alternative beneficial solutions for the agency while offering additional job opportunities and higher economic value of byproducts. This mentality is necessary for the Hudson Valley to meet the state's low-carbon transition plan.

FIGURE 5G: ***Ulster County Resource & Recovery Agency (Aerial View)***

Space to host the proposed system		
Sufficient to support proposal	**Space to scale-up the proposed system with increased feedstock**	**Available area to introduce innovative circular economy initiatives**

TABLE 5D: ***Proposal 5 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 5 and consists of several existing and suggested flows & processes. The primary feedstocks for anaerobic digestion are excess food waste and the invasive aquatic water chestnut. The digestate end product is added to the current composting process and the nutrient-rich liquid fertilizer can be sold to the agriculture, community, and residential sectors. These material flows are represented by the green and orange arrows, respectively. Biogas created from the anaerobic digestion process can be converted to electricity through a combined heat and power unit and applied to the agency's one-site operations with abundances sold to the electric utility. Biosolids received by UCRRA are directed to pyrolysis and this flow is designated by the purple arrow. Most of the char would be sold to market, however, a portion of this material can be incorporated into the anaerobic digestion process to improve the microbial environment and methane production potential. Heat produced from the pyrolysis process can be applied to an innovative circular economy initiative related to downstream recycling of plastics. With respect to this concept, a plastics shredding and drying process is offered as an option to upcycle this waste stream with flows indicated with the color orange. According to an equipment manufacturer, third-party companies would be very interested in operating this aspect.



SYSTEM 5: ***Proposal For Ulster County Resource & Recovery Agency***

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes two sections of the City Of Kingston as an environmental justice region. FIGURES 5H & 5I are sourced from the state and reveal the expansiveness of this particular region which is designated with the color purple. FIGURE 5H reveals the span of this area relative to Ulster County, while FIGURE 5I offers a much higher resolution and closer view of Kingston. Implementing a circular economy initiative at this Ulster location therefore offers an opportunity to introduce investments into this area that would be accessible by the local communities. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the community. Also, byproducts sold as community exports can create additional revenue and opportunities for residents. Installations that remove the transportation aspects from waste management are necessary for economic viability and essential for the Hudson Valley to meet the state's low-carbon transition plan. The renewable electricity can also power an electric vehicle fleet and eliminate the pollution otherwise caused by hauling equipment operating throughout the city.

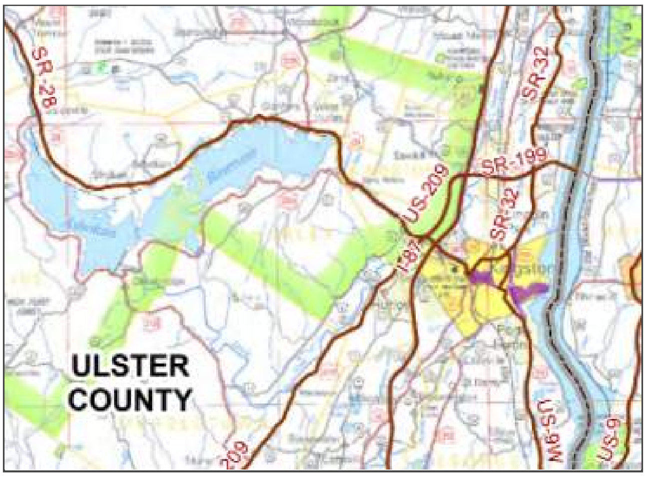


FIGURE 5H: ***Ulster County Env. Justice***

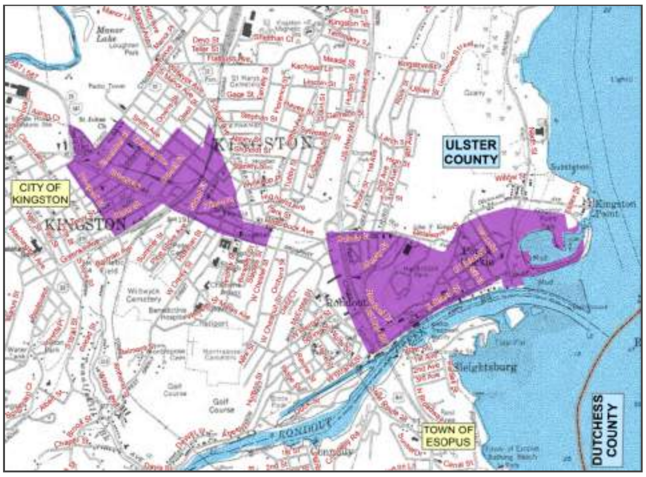


FIGURE 5I: ***City Of Kingston Env. Justice***

TABLE 5E lists a number of 'general' stakeholders relevant to this project as well as each of the 10 individual system proposals. This includes the NYS DEC with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. 'Specific' stakeholders to this project include the local land conservancies and land trust, the county's Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. Due to the great potential for the invasive water chestnut to be used as a feedstock at this site location, some of the 'specific' organizations also include PRISM, Scenic Hudson, and the Hudson River Watershed Alliance. These groups are therefore in common with the other proposals which have the potential to utilize this same feedstock. In order to maximize community and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. This is one example of integrating innovative and renewable energy technologies into an existing operation to increase recovery rates and set higher standards for local waste management.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	**New York Department of Environmental Conservation:** Region 3 Environmental Permits **Partnerships for Regional Invasive Species Management:** Capital Region PRISM Lower Hudson PRISM St Lawrence Eastern Lake Ontario (SLELO) PRISM New York-New Jersey Trail Conference **Host Facility:** Ulster County Resource & Recovery Agency (UCRRA) **Land Conservancy Groups (Land Trusts):** Dutchess Land Conservancy Hudson Highlands Land Trust Stony Kill Foundation **Cornell Cooperative Extension(s):** Dutchess County Columbia & Greene Counties Ulster County **Universities (Colleges):** Bard College SUNY New Paltz **Concentrated Animal Feeding:** **Regional Organizations:** Beacon Institute for Rivers & Estuaries (Clarkson University) Hudsonia (Bard College) Hudson River Sloop Clearwater Hudson River Watershed Alliance Scenic Hudson

TABLE 5E: ***Proposal 5 Stakeholders***

Proposal 6: Delaware County Solid Waste Management Center

The Delaware County Landfill is operated by the Solid Waste Management Center & Compost Facility in Walton, NY. This community has a population of ~5,000 people (2019 US Census Bureau). It is approximately 60 miles west of the Hudson River and 150 miles northwest of Manhattan. FIGURE 6A shows the facility's location identified by the pink marker near the bottom of the image. The town of Walton is positioned to the left of the landfill in FIGURE 6A and has a few yellow and orange markers indicating nearby sources of excess food waste. Meanwhile the aggregation of markers in the upper right of the image is where SUNY Delhi is located. This college is ~12-miles to the northeast of the landfill and hosts approximately 3,000 students. The capacity of this facility and integrated operations makes it ideal for implementing a circular biogas system.

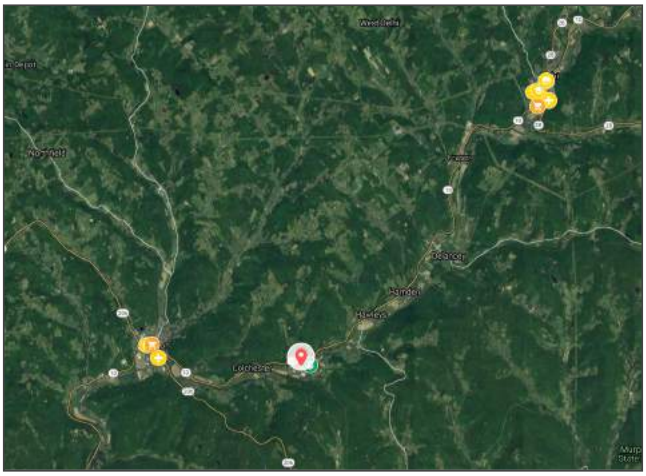


FIGURE 6A: ***Proposal 6 Mapped Feedstocks***

FIGURE 6B: ***Delaware County Landfill***

A satellite view of the landfill and compost center is pictured in FIGURE 6B. This facility hosts an organics recovery program that addresses food scraps, food processing wastes, biosolids, small animal mortalities, food and MSW (TABLE 6A). The biomass is captured by an advanced separation technology which incorporates dewatered biosolids into the processing activity. This infrastructure is one of only several facilities of its kind in the US and Canada where organics from the MSW waste stream are meticulously sorted and diverted from landfilling. First, select MSW is fed into this system, and it is aerated in a moisture controlled and biologically active tumbler for three days. An aggressive mechanical screening for both the inputs and finished product effectively removes metal, glass, plastics, sharps, and oversized particles. Following this stage, the pre-compost material is directed to a second maturation area. Here, it is combined with the dewatered biosolids and fed into an aerated IPS / Siemens automated system. The final step requires the compost to cure for a minimum 56-days. During this time, it is turned every 3 days and it is supplied with water to optimize the final breakdown of compounds and pathogens. The finished compost is available for sale to the local community and meets or exceeds the standards for Class A material. Analytical tests are regularly conducted to ensure the quality and purity of the end product. Regular inspections by the NYS DEC and US EPA have found the operation of this facility to be in compliance with applicable state and federal regulations (Delaware SWMP, 2017).

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 6A: ***Proposal 6 Commercial Activities***

This solid waste management facility doesn't have a separate food waste processing stream and relies on their advanced technology to divert organics from select MSW. However, source separation is typically the most effective and efficient and will become more relevant as commercial entities throughout NYS will be required to comply with the new diversion legislation. Therefore, it would be reasonable for the authority to consider a separate beneficial treatment pathway. Leaf and yard waste is not currently managed at the landfill either which is due to a Delaware County program decision from 1992 that excluded this material from the landfill. The primary reason for this was to preserve expensive landfill airspace and wastes with higher pollution control demands. Also, due to the rural nature of this region, there isn't an apparent need for this type of centralized service as this biomass is already adequately managed in or near the village's limits. Both 'excess food waste' and 'wood / yard waste' are designated with the color yellow TABLE 6B indicating potential.

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE 6B: ***Proposal 6 Feedstocks***

Following a memorandum of agreement between NYC and the upstate watershed communities, regional WWTPs went through a substantial growth over the past decade, and all of the upgrades are near to completion. With respect to this increased capacity, and according to the Delaware County Solid Waste Management Plan, biosolids are anticipated to continue to be part of the facility's operations for at least the next 10 years and continue at approximately the same rates. There is no land application of biosolids in Delaware due to restrictions associated with the NYS Watershed Rules and Regulations, and the higher volume of the material was the county's main motive to develop their mixed biosolids composting facility. However, this infrastructure can only treat a portion of this biomass intake with a significant quantity still directed to landfill (FIGURE 6C). Since 2013, this respective landfilled tonnage has been greater than 2,000 tons per year (FIGURE 6D). Therefore, pyrolysis offers an economically viable opportunity to manage this excess biomass.

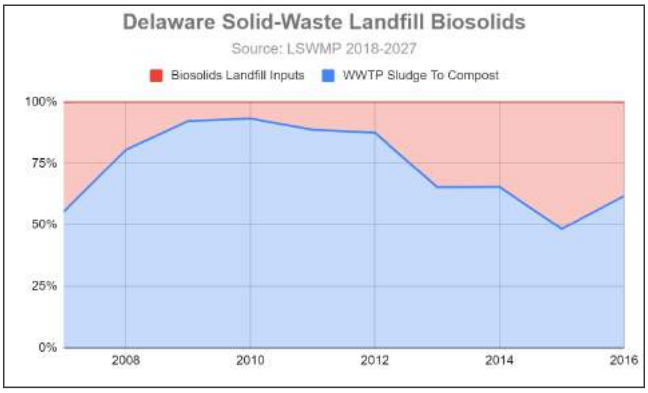


FIGURE 6C: ***Biosolid Compost Vs Landfill***

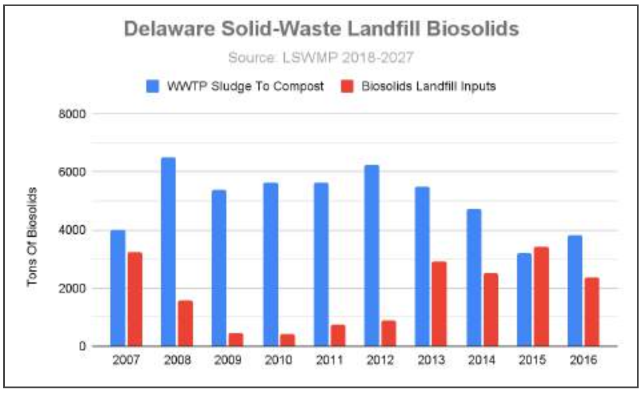


FIGURE 6D: ***Biosolid Mgmt Quantities***

The MSW sorting and composting installation can greatly benefit from a parallel pyrolysis operation. The generated pre-compost material routinely achieves temperatures in excess of 131 degrees F and thus successfully destroys pathogens. However, this process can be accelerated through the application of the heat created during pyrolysis. TABLE 6C indicates ‘biosolids’ in green due the existing management of this material and ‘heat need’ in green for the compost curation.

Pyrolysis & biochar		
Biosolids	Wood waste	Heat need

TABLE 6C: ***Proposal 5 Pyrolysis Potential***

FIGURES 6E and 6F display two satellite images of buildings which are at the site of the landfill. The first image is near the facility’s entrance off of Neale Road near to the weigh station. FIGURE 6E is an area located further into the waste management facility along the West Branch Delaware River. The building housing the organic waste sorter is depicted on the left of this figure. Each of these buildings appears to have sufficient space around their perimeters which would be sufficient for the proposed installation. There also seems to be space to scale the system with increased feedstock. Provided the perceived flexibility of this area, it should also be possible to introduce additional innovative circular economy initiatives that would serve as extensions to these processes. As such, the classification matrix in TABLE 6D is green for each respective category.

FIGURE 6E: ***Landfill Entrance / Weigh Station***

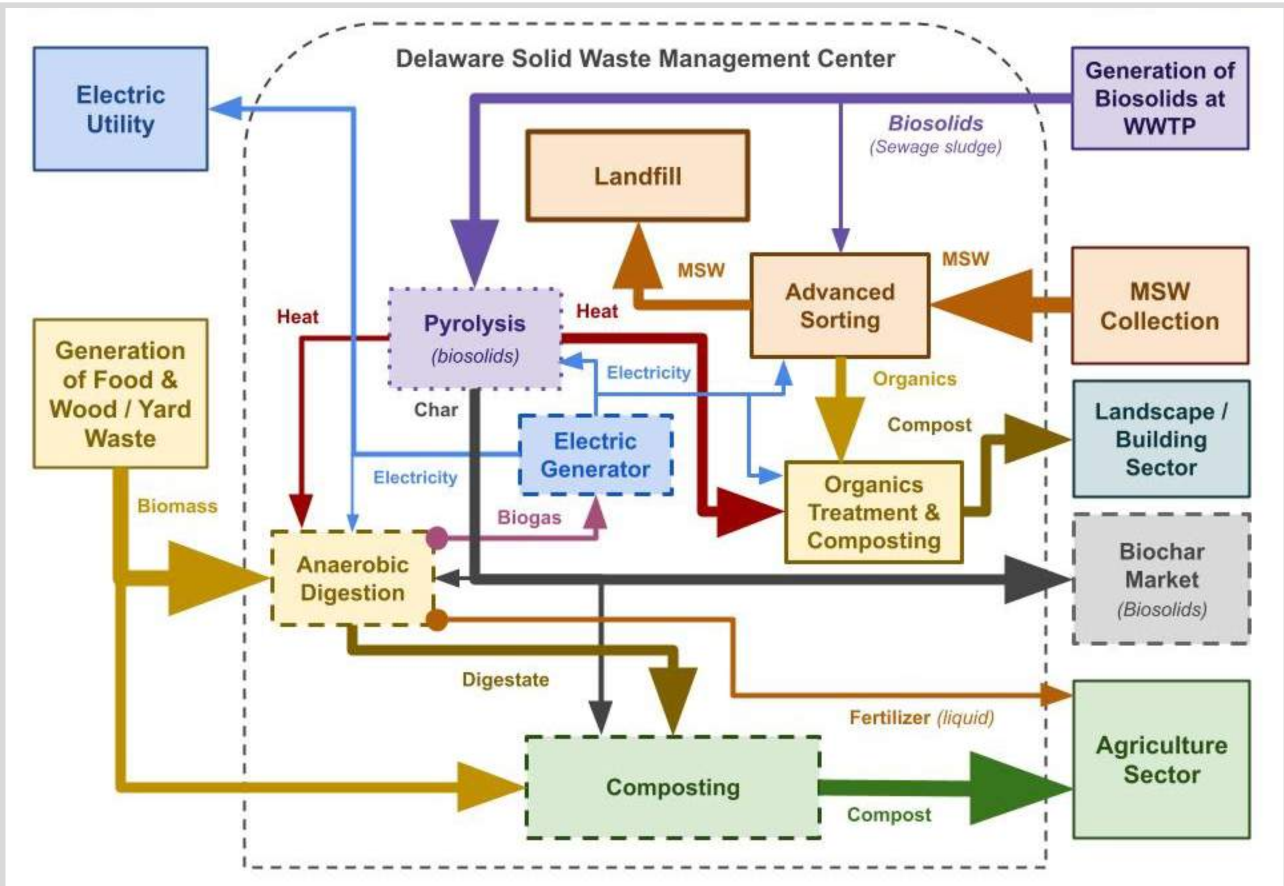
FIGURE 6F: ***Organic Waste Sorting***

Further analysis is necessary to determine the optimal installation locations that can invite more green infrastructure. This form of locally produced renewable energy can invite the establishment of related manufacturing and bring more economic opportunities to the municipality. For instance, the heat from pyrolysis can be applied to a plastics refining operation and promote local industry development. The existing supply of feedstock materials lowers the investment risk of introducing these new forms of associated sustainable business practices.

Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE 6D: ***Proposal 6 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 6 and consists of several existing and suggested flows & processes. The primary feedstock for anaerobic digestion is excess food waste which must be from a source separated stream. The digestate end product is composted and the liquid fertilizer effluent is sold to the agriculture and residential sectors. These flows are represented by the green and orange arrows, respectively. Biogas created from the anaerobic digestion process is converted to electricity through a combined heat and power unit and applied to the one-site operations with abundances sold to the electric utility. It is important that the feedstock for anaerobic digestion remains separate from the extracted MSW organics. This prevents any potential risk of contamination and the waste management center can offer different qualities of compost products to the market. Biosolids received at the landfill are represented with a purple arrow. A portion of this biomass serves as a feedstock for pyrolysis while the remainder is added to their sorting operation to continue business as usual. Ideally, these biosolids are completely consumed and avoid landfilling. Most of the char produced from this pyrolysis can be sold to market, however, a portion can be incorporated into both the anaerobic digestion and composting processes to improve their microbial environments. These respective flows are represented with the black arrows. Heat produced from the pyrolysis process can help dry the incoming feedstocks, keep the digester warm throughout the colder seasons, and treat the compost before it is returned to the landscape and building industries. Any remaining energy can then be applied to more innovative circular economy initiatives that can continue to divert MSW from the landfill. This method of accountability can help the greater Hudson Valley meet its ambitious zero-waste goals.



SYSTEM 6: Proposal For Delaware Solid Waste Management Center

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) does not recognize any communities in the immediate area of the landfill as environmental justice regions. FIGURE 6G is sourced from the state and reveals that none of the surrounding region is designated with the color purple. However, this proposal still offers a significant opportunity to introduce investments into this rural area that would be beneficial to the local communities. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the surrounding region. Renewable energy in the form of electricity can be applied to new technologies and the local electric grid while excess byproduct materials can be sold for additional revenue.

FIGURE 6G: ***Delaware County Env. Justice***

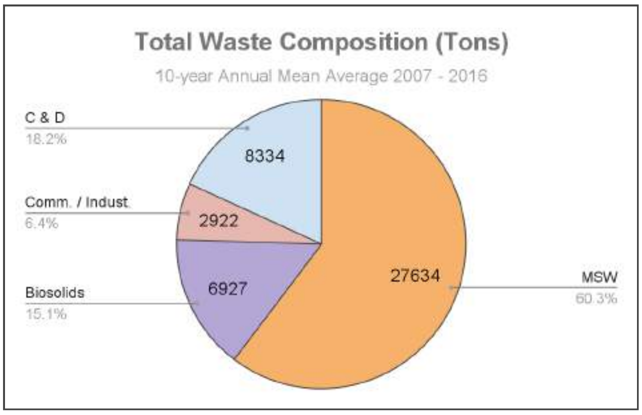


FIGURE 6H: ***Average Waste Composition***

The Delaware County Solid Waste Management Plan also provides a summary of status and recommendations in regards to their organic waste streams. It states that their compost facility should continue operating with mixed waste from biosolids inclusive of ongoing maintenance and capital repairs to retain capacity. Accompanying this is a suggestion to expand the marketing program for varying grades of compost products. The proposed anaerobic digestion and pyrolysis products would therefore help the facility to meet this goal. In regards to wood waste capture, the equipment and site capacity for grinding as a supplemental bulking agent should be maintained. There may also be an opportunity to incorporate these chips into the biosolids pyrolysis process to increase the carbon sequestration potential of the resulting char. Finally, the facility anticipates that incoming MSW volumes will decrease over time and that there is a need to reduce the amount of biosolids and respective moisture content of compost. Pyrolysis offers a viable solution that can meet these needs in an economical and sustainable manner. While it would be best for WWTP operators to decrease water content prior to transportation, a portion of the heat energy from the pyrolysis process can be allocated to drying the biomass and attaining an ideal moisture content. The annual mean average waste composition (2007-2016) is displayed in FIGURE 6H and provides some additional insight into this facility's historical material intake. Meanwhile, FIGURE 6I reveals the composition of the landfilled waste which is about 48% of the total. The composition of diverted waste is also shown in FIGURE 6J. The proposed Hudson Valley circular biogas system offers an innovative solution to improving upcycling of this waste and increasing resource recovery rates.

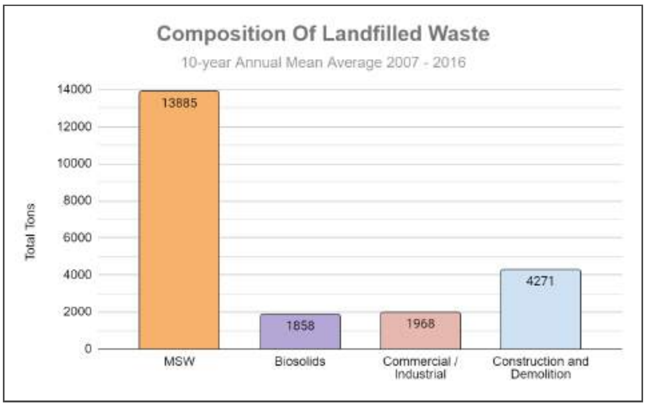


FIGURE 6I: ***Landfilled Waste Composition***

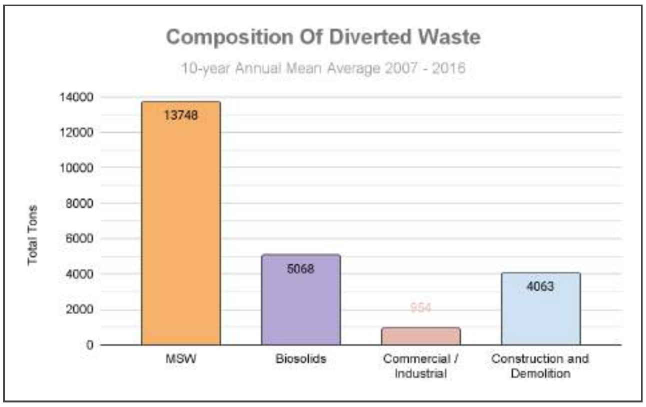


FIGURE 6J: ***Diverted Waste Composition***

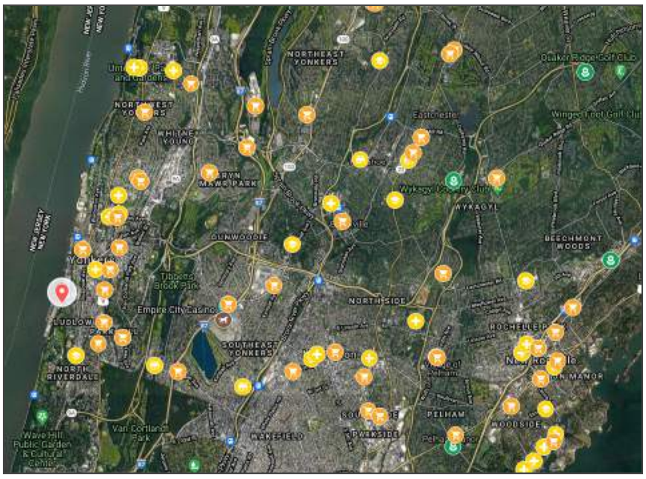
TABLE 6E lists a variety of 'general' stakeholders relevant to all 10 Hudson Valley Biogas system proposals. This includes the NYS DEC with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. 'Specific' stakeholders to this project include the host facility, the county's Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. In order to maximize community and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. The Delaware County Landfill offers a unique opportunity to unify regional support and bring more attention to materials management throughout the greater Hudson Valley. As a landfill, this is the end-of-life point for thousands of tons of materials and represents the final opportunity to enact upcycling technologies. Reducing waste is essential to meeting the state's ambitious climate change mitigation goals and transitioning to a sustainable, low-carbon future.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	New York Department of Environmental Conservation: Region 4 Environmental Permits **Host Facility:** Solid Waste Management Center & Compost Facility **Land Conservancy Groups (Land Trusts):** **Cornell Cooperative Extension(s):** Delaware County **Universities (Colleges):** SUNY Delhi **Concentrated Animal Feeding:** **Regional Organizations:**

TABLE 6E: ***Proposal 6 Stakeholders***

Proposal 7: Westchester County Wastewater Treatment Plant

Yonkers is in Westchester County and lies along the eastern side of the Hudson River. The Westchester County Wastewater Treatment Plant is in this city which is located on the river's shoreline and to the west of the railroad tracks. It is about 7- miles north of the George Washington Bridge which connects New Jersey to NYC. This densely populated area has about 200,000 residents (2019 US Census Bureau) and is approximately 12-miles north of central Manhattan. FIGURE 7A shows the location of this site designated with a pink map marker. The region to the east has many excess food waste generators that are identified with yellow and orange markers and span into Connecticut. In 2020, the Westchester County Food Waste Study recommended an anaerobic digestion solution at this location to help manage this organic material. Hudson Valley Biogas has also come to the same conclusion and recommends a unique circular economy solution.



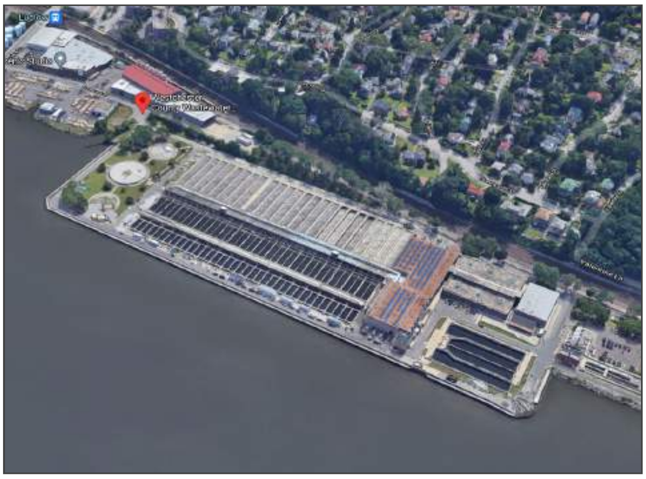


FIGURE 7A: ***Proposal 7 Mapped Feedstocks*** **FIGURE 7B:** ***Westchester County WWTP***

A computer generated image of the WWTP is provided by FIGURE 7B. Food waste and other organics are not part of the current operations and neither is composting. The corresponding characteristic matrix in TABLE 7A represents these attributes with the color yellow for their potential to develop and become an established component of ongoing operations. This is an anaerobic digestion facility, as identified by the USDA, which conducts a mesophilic biosolids treatment method. The biogas is used to heat the building, heat the digeser, and drive machinery with any excess flared. Therefore, the proposed biogas infrastructure may be able to be integrated with the current system to lower installation capital costs and realize a combined economic benefit.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 7A: ***Proposal 7 Commercial Activities***

The size of the local population and the number of identified excess food waste generators suggests that there is a large quantity of food waste available for a biogas expansion project. This proposed processing stream should be operated parallel to the sewage sludge digester. Keeping these feedstock separate is necessary to ensure that the highest quality compost product is produced. About 4-miles to the east, the Yonkers Raceway operates a horse racing facility as part of their casino resort and entertainment center. A satellite image of this site is shown in FIGURE 7C. The respective abundance of animal manure can be transported to this WWTP and co-digested with food waste (TABLE 7B) to facilitate the digestion process and provide the benefits associated with this consistent substrate; acidity stabilization, nutrient balancing, higher methane content, etc.

FIGURE 7C: ***Yonkers Raceway***

Variation of feedstock				
Excess food waste	**Wood / yard waste**	**Invasive species**	**Livestock manure**	**Perennial grasses**

TABLE 7B: ***Proposal 7 Feedstocks***

According to the NYS DEC's 2015 Biosolids Survey, this WWTP, officially referred to as the Yonkers Joint WWTP (SPDES No: NY0026689), has a flow of 75 MGD (designed for up to 120 MGD) and generates approximately 7,355 dry tons of biosolids on an annual basis. FIGURE 7D offers another perspective of this facility by focusing on the southern end where the large anaerobic digestion tanks are installed. At the time of the survey, all of the resulting biomass was transported to Pennsylvania for land application. However, this volume is well over 1,000 tons per year, so a biosolids pyrolysis solution is recommended for integration with the proposed circular system (TABLE 7C). A centrifuge is used to dewater the biosolids, so pyrolysis can exploit additional energy efficiency as a result of the removed water content (ideal below 30% moisture). Because the total annual amount of generated biosolids is close to 10,000 tons per year, a high-volume technological solution is more appropriate than the 3,000 tons per year unit. Instead of the heat byproduct, this higher capacity solution generates syngas (carbon monoxide and hydrogen) which can be sold to many industries inclusive of transportation and manufacturing. Alternatively, the company that produces this solution has a proprietary technology to reform the gas to renewable methane, or RNG. Another option is to separate the green hydrogen from the syngas, however syngas from sewage sludge only contains about 29% hydrogen and may not be economically viable. For reference, syngas produced from wood pyrolysis at this same processing temperature contains about 49% hydrogen. Further exploration of local market needs and potential revenue outcomes are necessary to determine which solution is the most desirable and beneficial for Westchester County.

FIGURE 7D: ***Westchester WWTP (anaerobic)***

Pyrolysis & biochar		
Biosolids	Wood waste	Heat need

TABLE 7C: ***Proposal 7 Pyrolysis Potential***

Another satellite image of the Westchester County Wastewater Treatment Plant is displayed in FIGURE 7E. This extension into the Hudson River spans almost ½-mile long with the width around 500-ft for the larger area and about 270-ft for the smaller area. From this picture, it is apparent that the infrastructure is extremely compact and there is not too much space available other than around the clarifiers on the north end (the left side of the image), the parking area near the center, and the digesters on the south end (the right side of the image). For reference, a local digester solution could consist of a series of shipping containers which, depending on the manufacturer, has some flexibility in regards to installation arrangement. Meanwhile, a pyrolysis solution designed for 10,000 tons per year would have a construction footprint of approximately 5,000-square-ft (0.12-acres). Therefore, only the anaerobic digestion portion may be able to be configured at this site. A complete installation should still be explored to be able to eliminate all relevant transportation costs and have the greatest economic and energy efficient technology configuration.

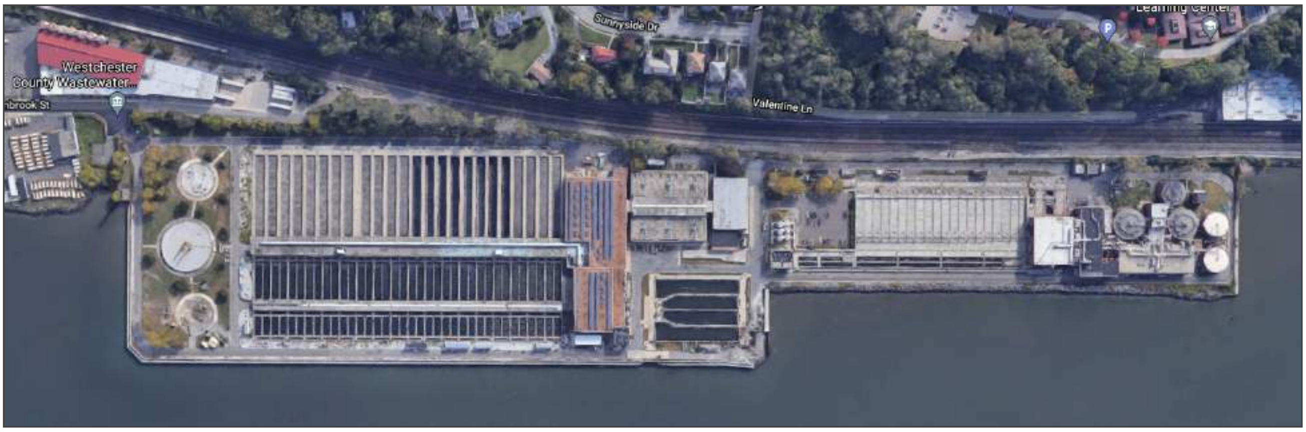


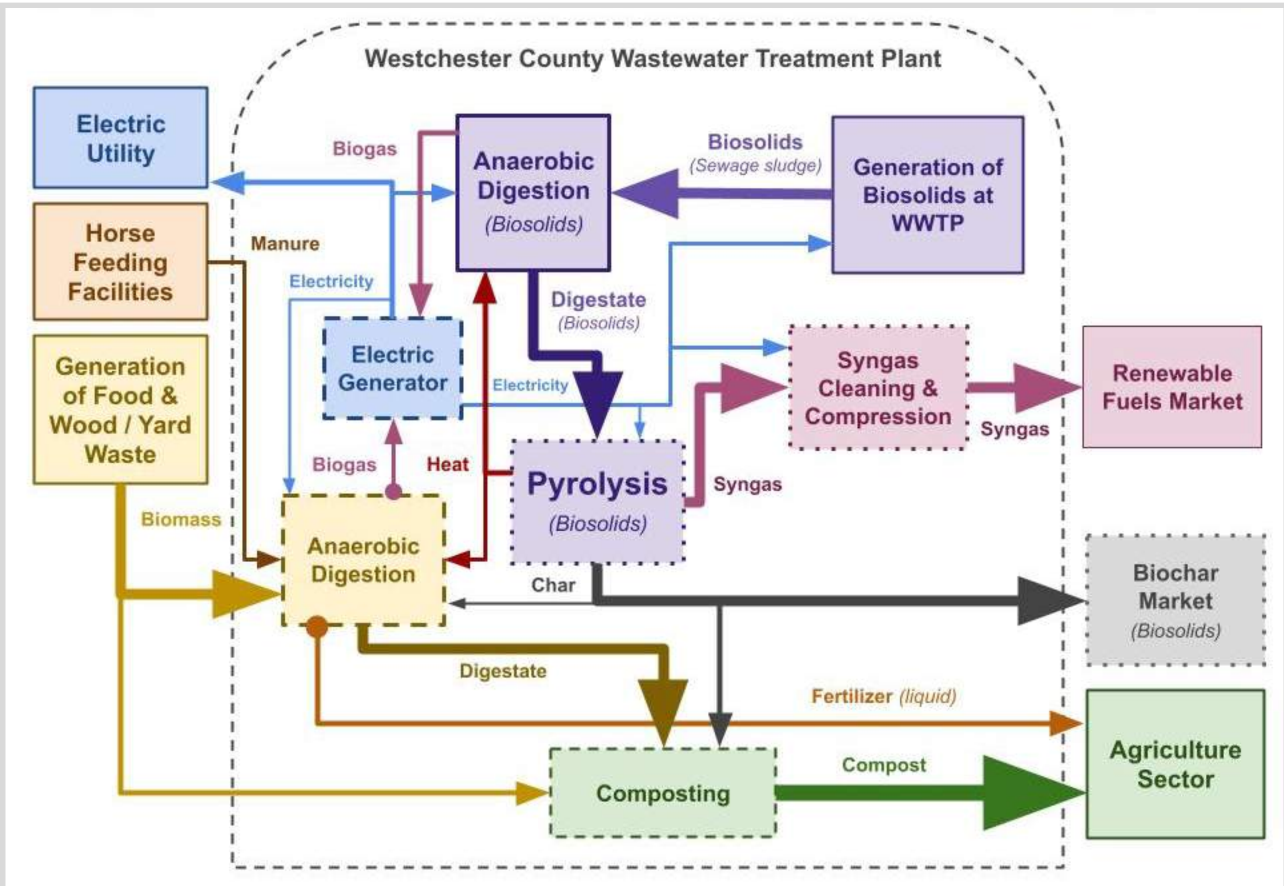
FIGURE 7E: ***Westchester Wastewater Treatment Plant (complete aerial view)***

The space availability matrix is displayed in TABLE 7D with two of the three categories represented in yellow due to the aforementioned constraints. However, the third item regarding innovative circular economy initiatives is shown in green due to the diversity of existing infrastructure that could invite new solutions and efficiency upgrades. For instance, the limited available area could support a smaller version of the described setup, and, for instance, manage a portion of the biosolids on site through the smaller pyrolysis solution that generates heat for use instead of syngas. This method of approach would still offer the benefits of a reduced carbon footprint and potentially build capacity with other local facilities which do have the space to install infrastructure that would accommodate full capacity. Even a series of small-satellite locations could be initiated as a regional solution.

Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE 7D: ***Proposal 7 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 7 and consists of several processes inclusive of the existing anaerobic digestion process which intakes the sewage sludge. This flow is represented by the purple material flow arrow. An important note is that the biogas produced from this process currently operates a boiler to heat the facility as well as the digester, so the electrical generator is also suggested with this configuration. Because a second anaerobic digester system is proposed for excess food waste and manure, represented with the yellow and brown arrows, respectively, a combined gas collection and cleaning technology can be annexed to the current system. The digestate end product is composted (not necessary), and the liquid fertilizer effluent is sold to the agriculture and residential sectors. In SYSTEM 7, the high volume pyrolysis receives the digested biosolids indicated with the purple arrow. This process produces syngas, represented by the pink arrows, which enters the cleaning and compression process, and it is then exported to the renewable fuels market. Most of the char produced from the pyrolysis can be sold to market, however, a portion can be incorporated into both the anaerobic digestion and composting processes to improve their microbial environments. These respective flows are represented with the black arrows. If the alternative smaller pyrolysis technology is revealed to be the favored technology, then the generated heat can take the place of current biosolid heating and drying methods. Then, the biogas would no longer be needed for this process and could be applied to an electricity generation process. Biogas from both digestion processes can combine these gas flows and serve as a feedstock to the same generator. The renewable electricity would then be applied to the on-site operational componentes with abundances sold to the electric utility for local distribution.



SYSTEM 7: ***Proposal For Westchester County Wastewater Treatment Plant***

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes the City Of Yonkers as an environmental justice region and the Westchester County WWTP happens to be located within this identified area. FIGURES 7F & 7G are sourced from the state and reveal the expansiveness of this particular region which is designated with the color purple. FIGURE 7F reveals the span of this area relative to Westchester County, while FIGURE 7G offers a much higher resolution and closer view of Yonkers. Implementing a circular economy initiative at this WWTP therefore offers a significant opportunity to introduce investments into this local community. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the community. Renewable energy in the form of electricity and heat can be applied to the treatment plant and local electric grid while excess byproduct materials can be sold as a community export thereby generating additional revenue municipal opportunities.

FIGURE 7F: ***Westchester County Env. Justice***

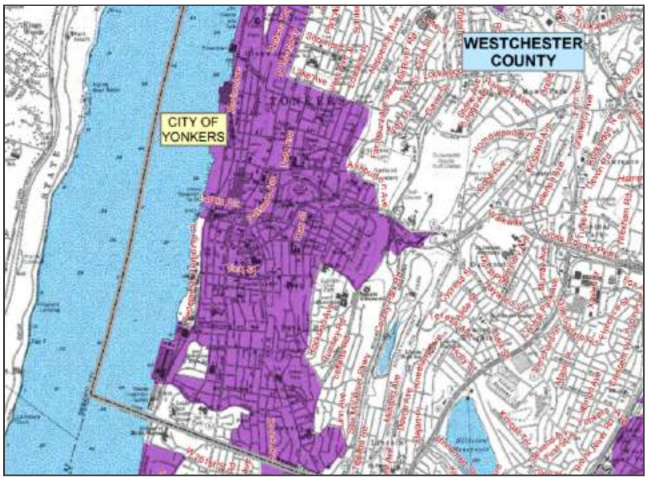


FIGURE 7G: ***City Of Yonkers Env. Justice***

TABLE 7E lists a variety of 'general' stakeholders relevant to all 10 Hudson Valley Biogas system proposals. This includes the NYS DEC with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. 'Specific' stakeholders to this project include the local land conservancies and land trust, the county's Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. In order to maximize community and county benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. This WWTP represents a significant location for materials management throughout the lower Hudson Valley due to its position amidst the highly populated areas just outside of NYC. Coordinating a regional operation at this site offers a strategic opportunity to introduce renewable practices at a transportation gateway to the NYS counties north of Manhattan and create a strong precedent for upcycling biomass with higher economic value and more beneficial use applications. This mentality and creative system design is necessary to meet the state's ambitious climate change mitigation goals and transition to a low carbon future.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	New York Department of Environmental Conservation: Region 3 Environmental Permits **Host Facility:** Westchester County Wastewater Treatment Plant (Yonkers) **Land Conservancy Groups (Land Trusts):** Westchester Land Trust **Cornell Cooperative Extension(s):** Westchester County **Universities (Colleges):** College of Mount Saint Vincent Mercy College (Dobbs Ferry Campus) Purchase College (SUNY) Westchester Community College **Concentrated Animal Feeding:** Empire City Casino: Yonkers Raceway **Regional Organizations:** Sustainable Westchester

TABLE 7E: ***Proposal 7 Stakeholders***

Proposal 8: Wheelabrator Westchester

The city of Peekskill is in Westchester County and lies along the eastern side of the Hudson River and has about 24,000 residents (2019 US Census Bureau). Wheelabrator Westchester is the county's waste-to-energy facility which is situated on the coast a few miles north of Haverstraw Bay. This incinerator began operations in 1984 and manages up to 2,250 tons per day of household and business waste. This process generates 60 MW of electricity for sale to the local utility which powers over 60,000 homes. FIGURE 8A shows the location of Wheelabrator designated by the pink map marker. Several with excess food waste generators are identified to the northeast of this location with yellow and orange markers. While this area is densely populated, it is positioned among the iconic Hudson Valley scenery with Bear Mountain State Park across the river to the west and Hudson Highlands State Park to the north. A circular biogas system can complement the environmental character of this community and serve as a model for regenerative technologies and upcycling innovations throughout the region. The following proposal offers some possible solutions.

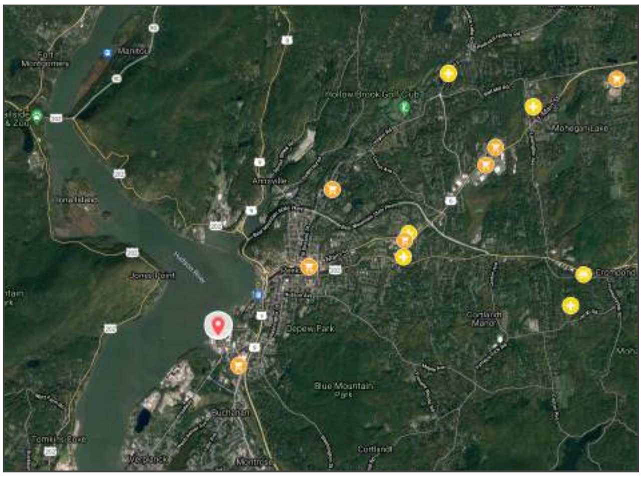


FIGURE 8A: ***Proposal 8 Mapped Feedstocks***

FIGURE 8B: ***Wheelabrator Westchester***

Wheelabrator technologies (FIGURE 8B) classifies their infrastructure as a recycling operation and renewable energy facility (TABLE 8A). In addition to incineration, they extract metals from the processed waste stream which, in 2016, exceeded 12,000 tons. They also provide green steam to White Plains Linen (a commercial laundry operation). There aren't any separated organics as part of their logistics nor are there any composting facilities, however, this facility is within a 25-mile transportation distance of several high population cities and can offer a respective biogas solution. Stony Point and West Haverstraw are across the river, in Rockland County, and collectively host around ~25,000 people. Meanwhile, Ossining is located to the south in Westchester County with a population of ~38,000 people. Thus, a significant amount of excess food waste is generated throughout this region and can be collected and processed for beneficial application (TABLE 8B).

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 8A: ***Proposal 8 Commercial Activities***

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE 8B: ***Proposal 8 Feedstocks***

According to the NYS DEC's 2015 Biosolids Survey, Peekskill Wastewater Treatment Facility (SPDES No: NY0100803), shown in FIGURE 8C, has a flow of 6.3 MGD (designed for up to 10 MGD) and generates approximately 773 dry tons of biosolids on an annual basis. The USDA lists its treatment method as a mesophilic anaerobic digestion process which uses the biogas to heat the building and the digester with excess gas flared. Nearby, the Ossining Wastewater Treatment Plant (SPDES No: NY0108324), depicted in FIGURE 8D, has a flow of 4.1 MGD (designed for up to 7 MGD) and generates approximately 905 dry tons of biosolids on an annual basis. Both of these plants discharge their treated water into the Hudson River. Also, close by the incinerator, there is the Buchanan STP (SPDES No: NY0029971) which has a flow of 0.3 MGD (designed for up to 0.5 MGD) and generates approximately 89 dry tons of biosolids on an annual basis. At the time of the survey, all of the biomass from these three treatment centers was being land applied in New Jersey. However, this collective generation of 1,700 dry tons per annum is sufficient for an economically viable pyrolysis process, and it would remove the carbon-intensive out-of-state transportation.

FIGURE 8C: ***Peekskill WWTF***

FIGURE 8D: ***Ossining WWTP***

There are two more high volume biosolids generators that are located in the southwest region of Westchester County. The New Rochelle STP (SPDES No: NY0026697), shown in FIGURE 8E, has a flow of 12.4 MGD (designed for up to 20.6 MGD) and generates approximately 5,408 dry tons of biosolids on an annual basis. Also, the Port Chester WWTF (SPDES No: NY0026786), shown in FIGURE 8F, has a flow of 4.3 MGD (designed for up to 6 MGD) and generates approximately 1,509 dry tons of biosolids on an annual basis. In 2015, both of these facilities were sending their biosolids to an incinerator in Connecticut. Wheelabrator Westchester is about 40-miles and 30-miles from these plants, respectively, and could offer the renewable benefits of a pyrolysis treatment process to the local county. Collectively, the four described facilities, in addition to the ~7,300 annual tons produced in Yonkers, generate a total of about 16,000 dry tons per year. A centralized management facility can be explored as a viable option to manage all of this biomass locally. This is about 80% of the more than 20,000 dry tons of biosolids generated in Westchester County on an annual basis. According to one manufacturer, a pyrolysis solution that can manage this amount would have a construction footprint of about 9,000-square-ft, or 0.2-acre. Proposal 7 for the Westchester County WWTP revealed that the area available in Yonkers is limited, so transporting the biosolids to Wheelabrator, which is 30-miles to the north, may offer an alternative location for the proposed infrastructure that can accommodate the entire county.

FIGURE 8E: New Rochelle STP

FIGURE 8F: *Port Chester WWTF*

TABLE 8C shows the characterization matrix with 'biosolids' in yellow because they are not currently available on site of Wheelabrator Westchester. 'Heat need' is colored green because it is already required to pre-treat the incoming MSW feedstock for the incinerator.

Pyrolysis & biochar		
Biosolids	**Wood waste**	**Heat need**

TABLE 8C: *Proposal 8 Pyrolysis Potential*

The satellite view of Wheelabrator Westchester reveals that there may be some limitations regarding the available area to construct a complete county biosolids pyrolysis solution on site. However, there is also a possibility to integrate some of the proposed infrastructure into the current facility to optimize use of the heat energy already being produced by the incinerator. The categories of 'scale-up' and additional 'innovative circular economy initiatives' have been color-coded to yellow due to these potential constraints (TABLE 8D). Expanding into the lawn area next to the parking lot on the east side of the building may be an option for consideration although it may be deemed undesirable and too congested for the existing activities. Further exploration of the site is therefore necessary to form an accurate assessment as to the viability for implementing this technology and at what scale.

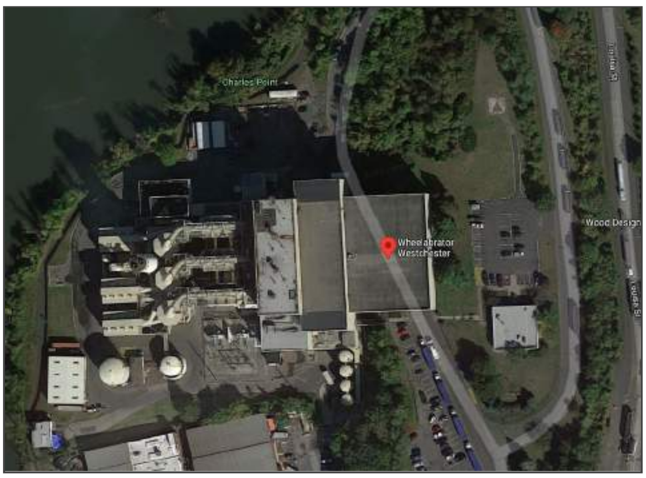
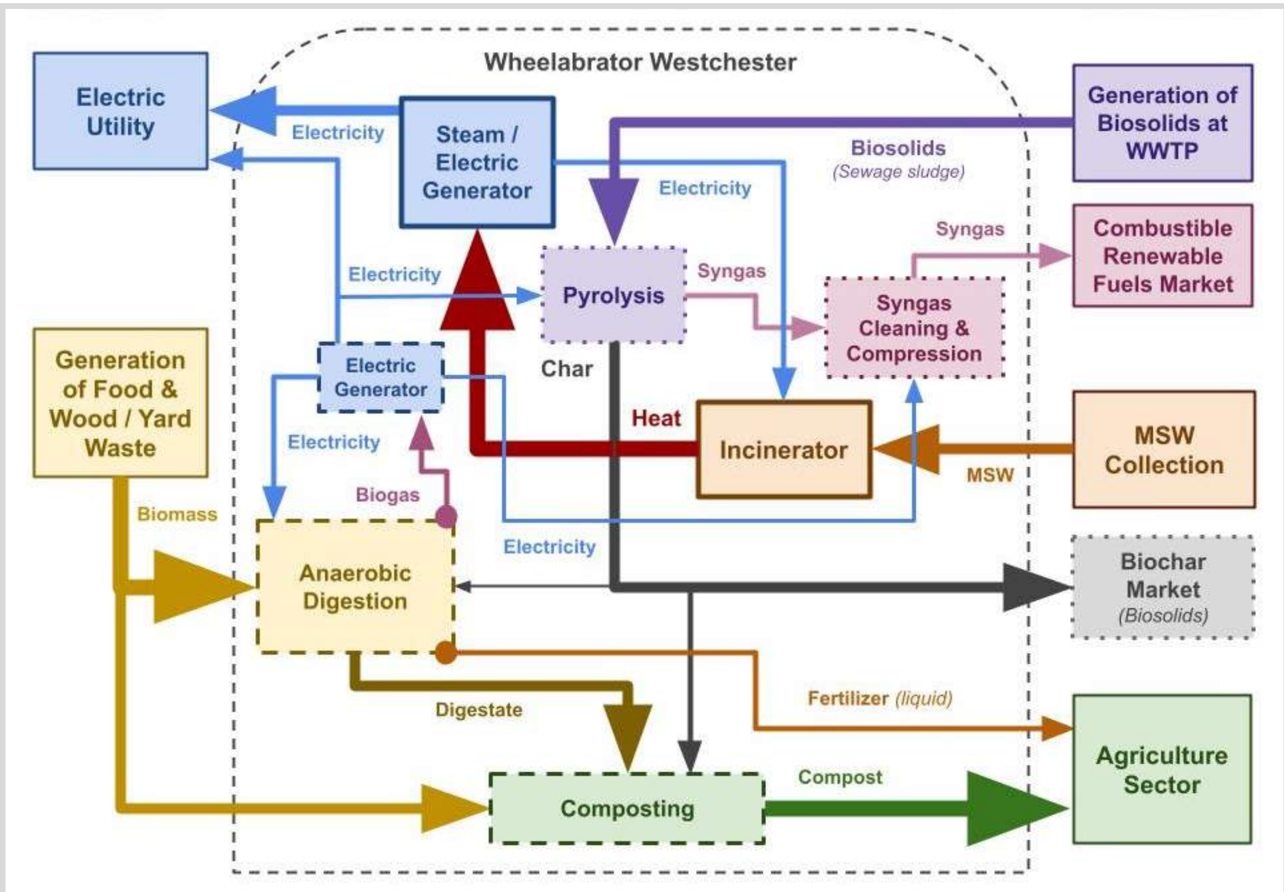


FIGURE 8G: *Wheelabrator (Satellite View)*

Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE 8D: ***Proposal 8 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 8 and consists of several processes. MSW is brought to the facility and fed into the incinerator (orange flow). Incineration produces heat which drives a series of steam turbines to generate electricity. (Ash and metals also exit the incinerator process, but are not displayed in the following chart.) Food waste is the primary input for anaerobic digestion (yellow flow) with any overflows and indigestible wood / yard waste directed to a potential composting process. Digestate is combined with this compost (brown flow) or sold directly to market. Biogas also exits the digester and is fed to an electric generator which can power the proposed on-site operations with abundances added to the utility sales pathway. Liquid fertilizer (orange flow) that is separated from the digestate is sold to the local agricultural market. Biosolids generated from the county's WWTPs are the primary feedstock for pyrolysis (purple flow). Some char output is applied to the digestion and potential compost processes with the majority being sold to the local market (black flows). Due to the nature of this proprietary pyrolysis technology, renewable syngas is created and a separate cleaning and compression process is displayed. Heat from the incinerator could be applied to drying imported biosolids and increase overall system efficiency, but these flows and processes are not displayed in the diagram.



SYSTEM 8: ***Proposal For Wheelabrator Westchester***

The Indian Point Energy Center is located less than one mile southwest of Wheelabrator Westchester and is worth mentioning as a strategic opportunity for this proposal. This three-unit, 2,000 MW nuclear power plant has recently been shut down and is in the process of being decommissioned. Given the industrial nature of this facility, the most valuable future use of this area could be the development of a new energy center that is focused on renewables and circular economy solutions. Therefore, the proposed process of high volume biosolids pyrolysis may be able to be hosted on this site and serve as the catalyst for inviting additional innovative technologies. FIGURE 8H shows a satellite view of Indian Point and its coastal access to the Hudson River. With this geographical position, biosolids can be shipped up the Hudson River from Westchester WWTP in Yonkers and substantially reduce the carbon footprint that would otherwise be created from typical hauling activities. Also, Port Chester and New Rochelle WWTPs are on the Long Island Sound and their generated biosolids can be transported by water via the East River (on the eastern side of Manhattan) which connects to the Hudson River. These suggestions are a far extension from the current management practices, but represent an ambitious opportunity to make valuable use of this decommissioned property and otherwise incinerated biosolids. The syngas produced from pyrolysis can be upgraded to RNG, and this volume of production would justify pipeline injection into the regional grid. FIGURE 8I reveals the approximate position of the existing natural gas pipelines in purple with the northern line passing through the southern end of the Indian Point property. The lower Hudson Valley region is highly dependent on electricity produced from this fossil fuel and is unable to access the high proportion of renewable energy that is available north of Albany. Reimagining possibilities for this highly populated area can yield a novel solution to the renewable energy bottleneck that exists due to the constraints of the current electricity grid. It would allow local power plants and respective communities to benefit from this renewable technology and help the state meet its aggressive climate change mitigation goals. A project of this scale requires significant stakeholder acceptance inclusive of the utility companies and regional power plants. However, these actions can be facilitated by positive dialogue regarding local sustainability and regional independence. In this way, citizens can take greater responsibility for their carbon footprints and build a foundation for continuous innovation.

FIGURE 8H: ***Indian Point Energy Center***

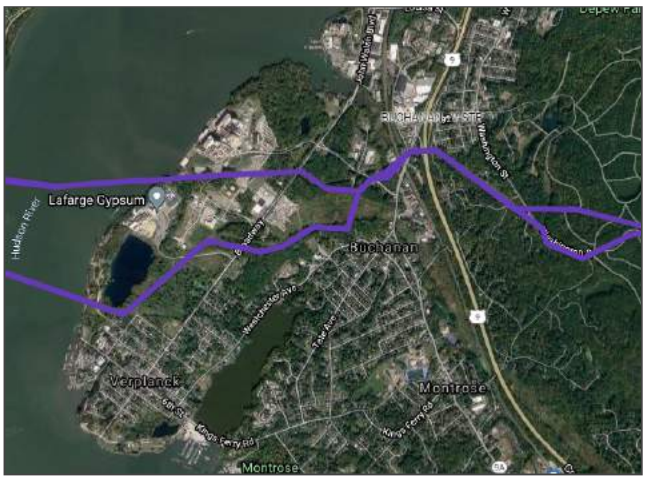


FIGURE 8I: ***Natural Gas Pipeline, Buchanan***

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes the Village of Spring Valley as an environmental justice region as well as the nearby Village of Hillburn. FIGURES 8J & 8K are sourced from the state and reveal the expansiveness of this particular region which is designated with the color purple. FIGURE 8J reveals the span of this area relative to Westchester County, while FIGURE 8K offers a much higher resolution and closer view of the city. Wheelabrator Westchester is less than a mile south of this region along the shore of the Hudson River. Implementing a circular economy initiative at this location therefore offers an opportunity to introduce investments into this area that would be accessible by the local communities. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the community. Renewable energy in the form of electricity could be applied to the treatment plant and local electric grid while excess byproduct materials could be sold as a community export and generate additional revenue.

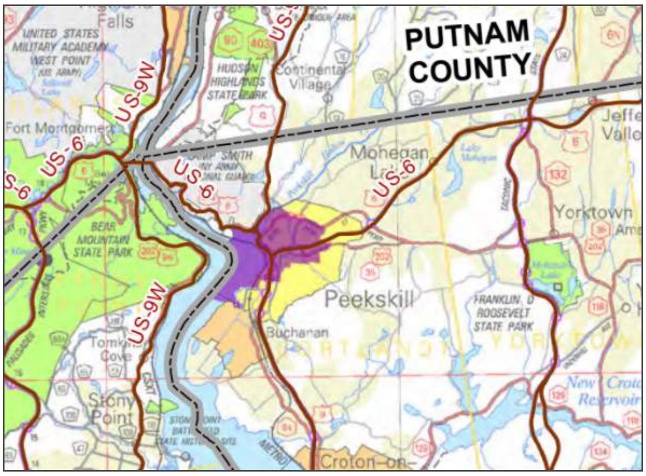


FIGURE 8J: ***Westchester County Env. Justice***

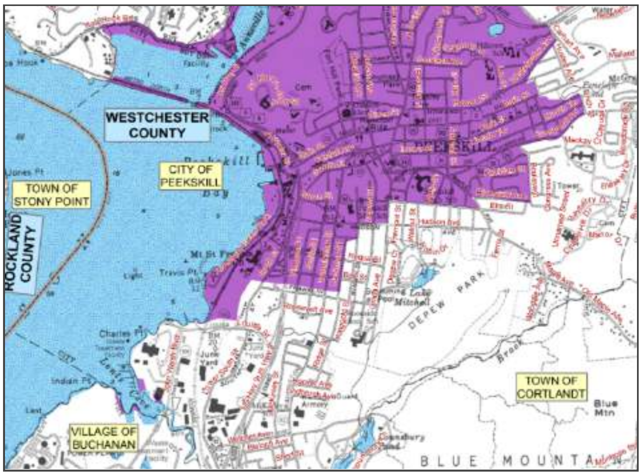


FIGURE 8K: ***City Of Peekskill Env Justice***

TABLE 8E lists a variety of 'general' stakeholders relevant to all 10 Hudson Valley Biogas system proposals. This includes the NYS DEC with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. 'Specific' stakeholders to this project include the local land conservancies and land trust, the county's Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. In order to maximize community and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. The scale of this proposal requires significant local and regional acceptance. These discussions should be grounded in the need to become energy independent as well as the need to actively address environmental justice. Coordinating a regional operation at this site offers a strategic opportunity to introduce renewable practices at a transportation gateway to the NYS counties north of Manhattan and create a strong precedent for upcycling biomass with higher economic value and more beneficial use applications.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	New York Department of Environmental Conservation: Region 3 Environmental Permits **Host Facility:** Wheelabrator Westchester **Land Conservancy Groups (Land Trusts):** Dutchess Land Conservancy Hudson Highlands Land Trust Stony Kill Foundation Westchester Land Trust **Cornell Cooperative Extension(s):** Dutchess County Westchester County **Universities (Colleges):** **Concentrated Animal Feeding:** **Regional Organizations:** Sustainable Westchester

TABLE 8E: ***Proposal 8 Stakeholders***

Proposal 9: Dutchess County Resource Recovery Agency

Poughkeepsie is in Dutchess County and lies along the eastern coast of the Hudson River. The Dutchess County Resource Recovery Agency (Dutchess RRA) is located in the town portion of this municipality approximately 5 miles south of the Mid-Hudson Bridge and to the east of the railroad tracks. This facility is a public benefit agency that was established by the NYS Legislature in 1982 and opened in 1989 as a waste-to-energy center. It has a capacity of processing 164,000 tons per year and has a turbine which converts the energy to electricity which is sold to Central Hudson Gas & Electric. The approximate 450 tons of annually processed MSW generates ~9.3 MW and powers over 9,000 homes. Throughout this process, the facility also recovers 10 to 14 million pounds of ferrous materials which are extracted from the incinerator's ash byproduct and sold to market. Poughkeepsie is home to approximately 44,000 residents (~30,000 which are in the city) and hosts over 15,000 households (2019 US Census Bureau). In FIGURE 9A, the pink map marker identifies the location of the resource recovery agency. The yellow and orange markers to the north are in the city and identify excess food waste generators. This facility's location within the greater Hudson Valley makes it an ideal place to implement a circular biogas system solution for regional benefit.

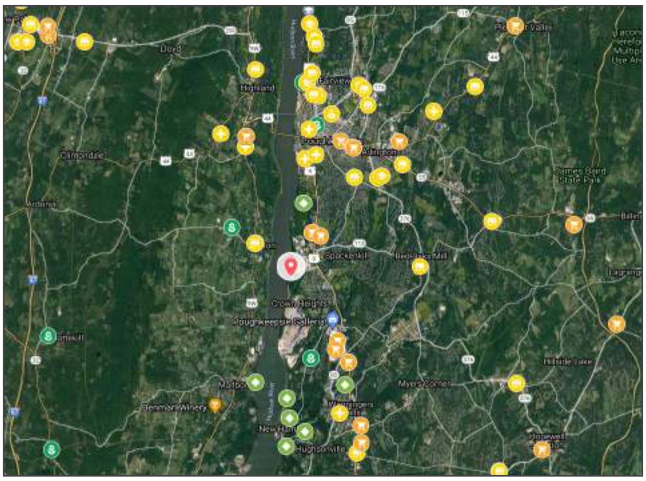


FIGURE 9A: ***Proposal 10 Feedstock Map***

FIGURE 9B: ***Dutchess County RRA***

A computer generated image of Dutchess County RRA is provided by FIGURE 9B. The city's wastewater treatment facility can also be seen in this figure with infrastructure accommodating aerobic treatment of biosolids. Due to the nature of the existing operations, this site has an ongoing industrial operation and maintains hauling activities. The general public is not permitted to bring trash to the facility as this service is only offered to municipalities and licensed haulers. The corresponding classification matrix is shown in TABLE 9A. Excess food waste is not currently managed by this facility and is therefore being proposed to support a biogas operation. Composting is also not necessary for this proposal, but it is a suggested complementary process.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 9A: ***Proposal 9 Commercial Activities***

This area of Dutchess County has several severe water chestnut infestations. FIGURES 9C & 9Dshow the Wappinger Lake and Wappinger Creek which are located in the [Village of Wappingers Falls]() about 5 miles south of the incinerator. This invasive species is very apparent across the two images as the light green vegetation covering these bodies of water. Their combined area is estimated to be over 100-acres as calculated using Google's area measurement tool. In the following feedstock chart, TABLE 9B shows 'invasive species' in green because the Village of Wappingers Falls has a water chestnut harvester that they regularly use to clear out some of this biomass. While the removed material has traditionally been left to decompose on shore, it can be allocated to this proposed biogas system as a valuable feedstock. It is also important to note that there are an additional 40 acres of water chestnut located on the eastern side of the Hudson River along [Bowdoin Park](), however, accessibility could be challenging because there limited land access

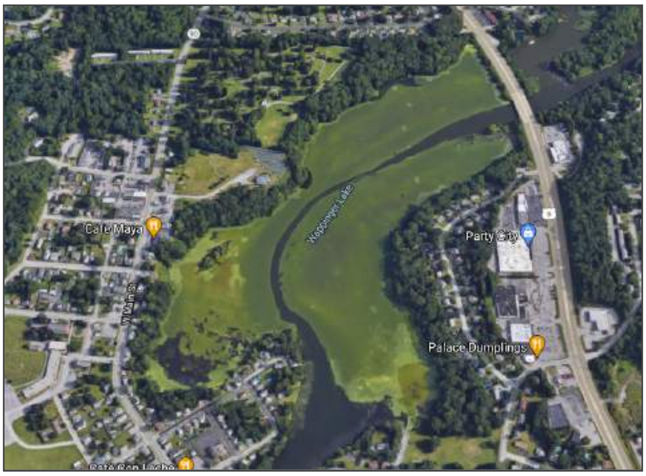


FIGURE 9C: ***Wappinger Lake***

FIGURE 9D: ***Wappinger Creek***

Perennial grasses are proposed as an additional feedstock source for this location provided the large parking lot that is located on the adjacent property north of the WWTP. This is currently the store-front of [Supply Technologies]() and adjacent to [IBM](). FIGURE 9E shows an aerial view of this space which has three distinct sections that span approximately 12-acres. The section on the left, on the west end, represents about 4-acres or 1/3rd of this space and would therefore serve as enough space to host clamp storage. For an operation that would support approximately 1,500 tons of silage per year, the structure would need to be about 75 x 250 ft which is less than ½-acre. A clamp without walls would maximize flexibility and the heaping pile would rise to a little more than 10-ft at the center. The existing surface would serve as a great economic benefit to an installation, however, the surface may require some additional treatment. The source of this feedstock can be arranged with a regional land restoration initiative and possibly facilitated through the county's various land conservancies.

FIGURE 9E: ***Adjacent Parking Lot (Private)***

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE 9B: ***Proposal 9 Feedstocks***

According to the NYS DEC's 2015 Biosolids Survey, the one-site WWTP, officially referred to as the Poughkeepsie Arlington WWTP, in FIGURE 9E (SPDES No: NY0026271), has a flow of 2.3 million gallons per day (designed for up to 4 million) and generates ~780 dry tons of biosolids on an annual basis. Since this volume is under 1,000 tons per year, an economically viable biosolids pyrolysis solution would require about 25% more material. However, there are several additional WWTPs within the nearby area which generate an annual mass that would help to meet this threshold. For instance, the Tri-Municipal WWTP in Wappingers Falls, in FIGURE 9G (SPDES No: NY0149209), generates approximately 200 dry tons of biosolids on an annual basis. It is located ~5 miles to the south of the incinerator, on the eastern side of the railroad tracks, and next to the coast of the river. Both of these facilities have belt filter presses in place to dewater the biosolids, so pyrolysis technology would be able to exploit additional energy efficiency as a result of the removed water content and effectively treat this approximately 1,000 aggregate tons per year.

FIGURE 9F: ***Poughkeepsie Arlington WWTP***

FIGURE 9G: ***Tri-municipal WWTP***

An installation with this capacity will generate excess heat which can be applied to the anaerobic digestion process and have excess renewable energy available for additional innovative infrastructure. This heat may also be capable of being coupled with the incinerator to realize further benefit. Another option would be to allocate this energy to drying additional biosolid feedstock prior to processeccing. For instance, the Poughkeepsie Solids Treatment Plant (SPDES No: NY0026255), which does not have a belt filter press, has a flow of 6.1 million gallons per day (designed for up to 10 million) and generates approximately 1,400 dry tons per year. This facility is about 7 miles north of the incinerator and also along the eastern side of the railroad tracks. In the corresponding 'pyrolysis and biochar' matrix, TABLE 9C represents 'biosolids' in green due to the sufficient volume of locally available feedstock. 'Heat need' is also 'green' because the incinerator requires this form of energy to pre-heat and dry incoming MSW feedstock. The table header is 'yellow' to convey the potential of implementing this technology into an effective production cycle.

Pyrolysis & biochar		
Biosolids	Wood waste	Heat need

TABLE 9C: ***Proposal 9 Pyrolysis Potential***

The amount of available space is one factor which may pose a challenge for this proposed location. FIGURE 9H displays an aerial view of the resource recovery agency and through the Google area measurement tool, there appears to only be about 0.5- to 1-acre available for an installation. However, there may be areas along the exterior of the building in which several shipping container style digesters could be situated that would also benefit from the heat generated within the building. FIGURE 9I displays the adjacent WWTP which appears to have up to 2.5-acres that may also be a suitable nearby location available to host the whole system or a design extension.

FIGURE 9H: ***RRA Area Calculation***

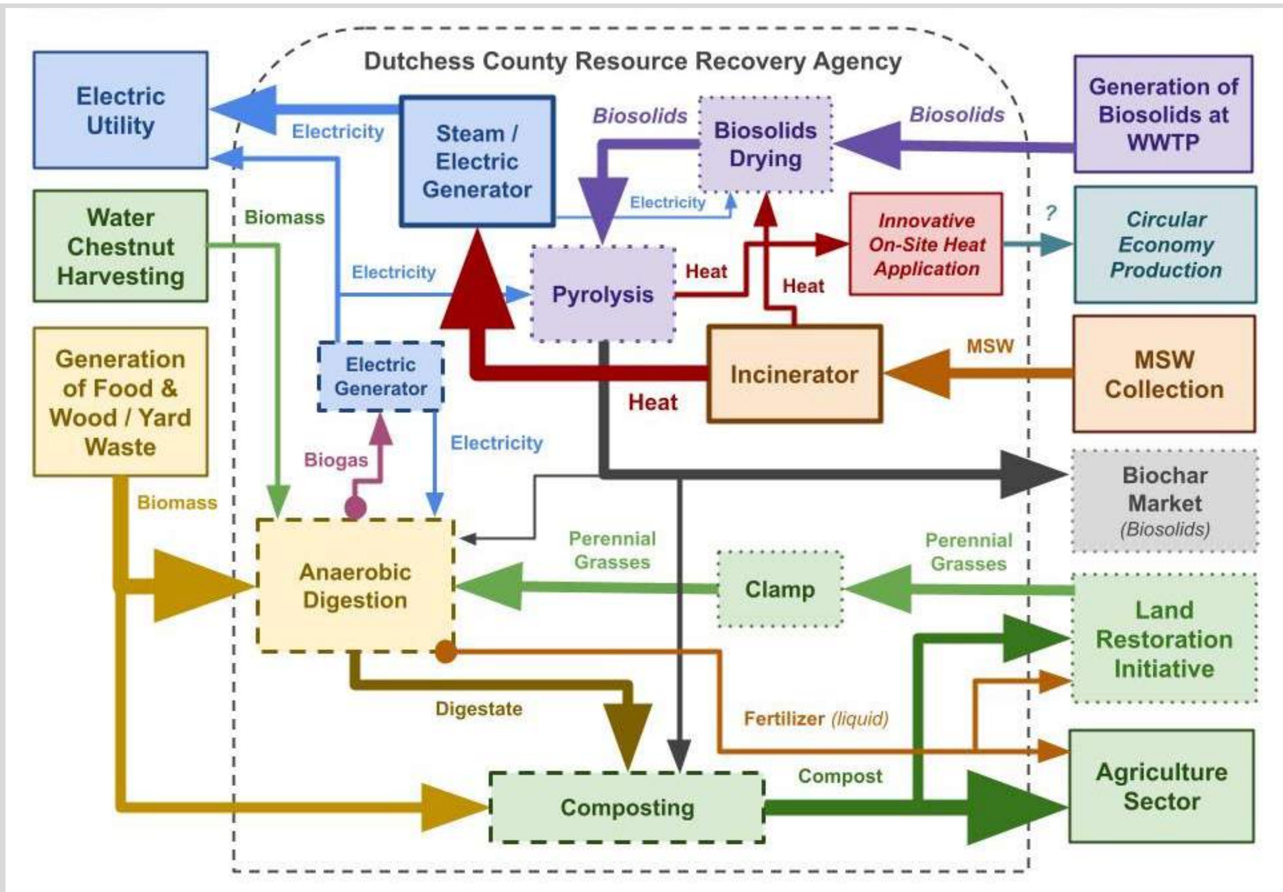
FIGURE 9I: ***WWTP Area Calculation***

The corresponding area matrix is presented in TABLE 9D with the first category suggesting that there is sufficient area to support a basic installation. However, further upgrades that would maximize system production potential may be limited due to the required cooperation with the adjacent WWTP and owners of the property to the north. These potential constraints require further exploration as this system can develop into a valuable asset for Dutchess County. Scaling and additional opportunities will therefore likely depend on the cooperation of all stakeholders.

Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

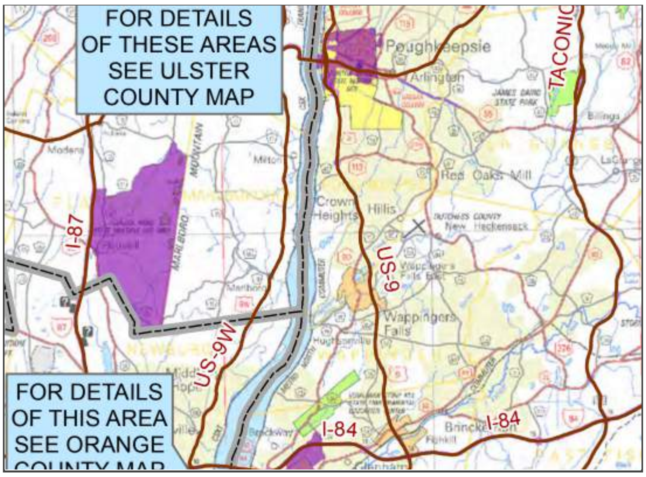
TABLE 9D: ***Proposal 9 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 9 and consists of several processes and flows. MSW is brought to the facility and fed into the incinerator (orange flow). Incineration produces heat which drives a series of steam turbines to generate electricity. (Ash and metals also exit the incinerator process, but are not displayed in the following chart.) Food waste (yellow flow) and the invasive water chestnut (green flow) are the primary inputs for anaerobic digestion with any overflows and indigestible wood / yard waste directed to a potential composting process. Perennial grasses are also depicted as a feedstock for co-digestion and would be stored on the adjacent property's parking lot and extracted throughout the year to supply a consistent substrate additive to the biogas production process. Clamp storage is depicted with respective flows in green entering the system. Meanwhile, the outputs of the digester are reapplied to a respective land restoration initiative. Digestate is combined with this compost (brown flow) or sold directly to market. Biogas also exits the digester and is fed to an electric generator which can power the proposed on-site operations with abundances added to the utility sales pathway. Liquid fertilizer (orange flow) that is separated from the digestate is sold to the local agricultural market as well as supplied to the land restoration initiative. Biosolids generated from the county's WWTPs are the primary feedstock for pyrolysis (purple flow). Some char output is applied to the digestion and potential compost processes with the majority is sold to the local market (black flows). Heat from the incinerator and the pyrolysis process could be applied to drying imported biosolids and increase overall system efficiency (red flows). Another option is to apply this heat to an on-site innovative heat application that would upcycle products for and contribute to a local circular economy initiative. For instance, there may be an opportunity to introduce a plastics shredding and drying process for manufacturing plastics into new products. According to one equipment manufacturer, third-party companies would be very interested in operating this aspect and bringing this technology to the Hudson Valley. Initiatives like this would increase job opportunities for the region and be able to build upon the system proposal which has been presented. Therefore, this foundation serves an effective role at inspiring new solutions for the region and creating new economic opportunities for the area.



SYSTEM 9: ***Proposal For Dutchess County Resource Recovery Agency***

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes the City Of Poughkeepsie as an environmental justice region as well as the nearby Village of Wappingers Falls. FIGURES 9J & 9K are sourced from the state and reveal the expansiveness of this particular region which is designated with the color purple. FIGURE 9J reveals the span of this area relative to the Dutchess and Ulster Counties, while FIGURE 9K offers a much higher resolution and closer view of the same area. Implementing a circular economy initiative at this Dutchess location therefore offers an opportunity to introduce investments into this area that would be accessible by the local communities. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the community. Renewable energy in the form of electricity could be applied to the treatment plant and local electric grid while excess byproduct materials could be sold as a community export and generate additional revenue for these municipalities. Building working relationships among many stakeholders is key to creating long-standing and resilient business models that offer the greatest community impacts and skill development of the local citizen workforce.



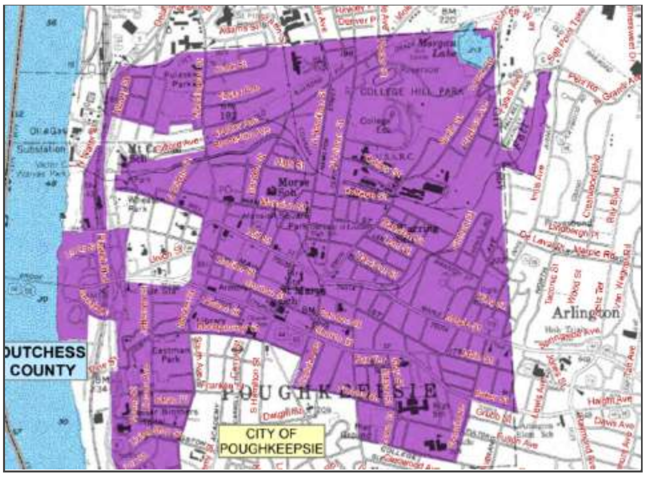


FIGURE 9J: ***Dutchess County Env. Justice*** **FIGURE 9K:** ***Poughkeepsie Env. Justice***

TABLE 9E lists a variety of 'general' stakeholders relevant to all 10 Hudson Valley Biogas system proposals. This includes the NYS DEC with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. 'Specific' stakeholders to this project include the local land conservancies and land trust, the county's Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. Due to the great potential for the invasive water chestnut to be used as a feedstock at this site location, some of the 'specific' organizations also include PRISM, Scenic Hudson, and the Hudson River Watershed Alliance. These groups are therefore in common with the other proposals which have the potential to utilize this same feedstock. In order to maximize community and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. This mentality and creative system design is necessary to transition to a low carbon future.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	**New York Department of Environmental Conservation:** Region 3 Environmental Permits **Partnerships for Regional Invasive Species Management:** Capital Region PRISM Lower Hudson PRISM St Lawrence Eastern Lake Ontario (SLELO) PRISM New York-New Jersey Trail Conference **Host Facility:** Dutchess County Resource Recovery Agency **Land Conservancy Groups (Land Trusts):** Columbia Land Conservancy Dutchess Land Conservancy Hudson Highlands Land Trust Stony Kill Foundation **Cornell Cooperative Extension(s):** Dutchess County **Universities (Colleges):** Vassar College Dutchess County Community College Marist College The Culinary Institute of America **Concentrated Animal Feeding:** **Regional Organizations:** Beacon Institute for Rivers & Estuaries (Clarkson University) Hudsonia (Bard College) Hudson River Sloop Clearwater Hudson River Watershed Alliance Scenic Hudson

TABLE 9E: ***Proposal 9 Stakeholders***

Proposal 10: Town Of Colonie Landfill

Cohoes has a population of approximately 17,000 inhabitants (2019 US Census Bureau). It is located in Albany County along the Mohawk River and hosts the Town Of Colonie Landfill. In FIGURE 10A, the pink marker shows the satellite view of this site which is situated off of Route 9 on a peninsula surrounded by the river and adjacent Erie Canal. It is approximately 9 miles northwest of Troy (population ~49,000) and 11 miles north of the city of Albany, the state's capital (population ~96,000). The landfill is operated by Capital Region Landfills, Inc and accepts waste generated from the surrounding communities allowing removal costs to remain low for the entire area. Collection occurs through the use of their Department Of Public Works crews as well as third party markets for the management of recyclable materials emanating from within the city. While a 2006-07 plan determined that the landfill would reach capacity in 2018 and cause all operations to cease, the NYS DEC recently granted an approval for the development of an additional area which would extend the lifespan by 20-years. A pumping system is used to collect and transport leachate to the Town Of Colonie sanitary sewer system which flows to the Mohawk View Wastewater Treatment Plant. This landfill's position relative to the surrounding cities, existing infrastructure, and industrial character make it an ideal place to expand biogas production capacity and implement a circular economy production cycle that can upcycle locally available organic material.

FIGURE 10A: ***Proposal 10 Mapped Feedstocks***

FIGURE 10B: ***Colonie Solid Waste Landfill***

Town Of Colonie Landfill (FIGURE 10B) currently captures the landfill biogas generated by the decomposing organic matter and converts this to electrical power. The methane content tends to remain between 48- and 52%. In 2005-06, four 1,600 kW generators were installed by Innovative Energy System Inc, and, today, this infrastructure is owned and operated by Aria Energy. Each engine is designed to accept 500-600 scfm of biogas per day, and, typically, only three of the four engines are in operation. Therefore, the aggregate daily total is an intake between 1,500-1,800 scfm. This equates to ~100 to 110 MW generated per day. All of this electricity is sold back to the utility and distributed on the local power grid with an equivalent amount equal to the consumption of ~3,000 homes. Aria Energy has expressed interest in converting this system to an RNG upgrade facility for pipeline injection, however, there are no plans at this time to pursue this technology shift.

TABLE 10A identifies the associated industrial and commercial site activities. Food waste organics are not currently processed here, but an anaerobic treatment method is being proposed due to the close proximity of several high population areas. This site also hosts the Town Of Colonie Yard Waste Composting Facility which is owned by the local government. The major feedstock to this operation is yard waste which includes leaves, grass, brush & branches, logs, stumps, and other wood (Cornell WMI survey). Additional operations permitted at this site include material recycling, and these respective categories are colored 'green' on both TABLES 10A and TABLE 10B.

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE 10A: ***Proposal 10 Commercial Activities***

The Mohawk River and integrated Erie Canal waterway are inundated with the aquatic invasive water chestnut. The degree of this infestation is easily recognizable from FIGURE 10C which depicts a computer generated satellite image of the peninsula. The bright green around this area indicates the pervasiveness of this destructive plant. However, herein lies an opportunity to extract this biomass and use it as a feedstock for biogas production. The Albany Marine Service Marina, established in 1972, is positioned along the northeastern part of this peninsula and an area estimate through Google's measurement tools indicates that there are roughly 75-acres of coverage here. Meanwhile, the northwest side of the peninsula (FIGURE 10D) has an infestation that covers more than 40-acres and is mostly along the Erie Canal corridor. As a result of this plant's decades of establishment and growth, this waterway has become unusable for recreation and local biodiversity is greatly diminished. Thick growth and sediment accumulation also contribute to this destruction.

FIGURE 10C: ***Albany Marine Service Marina***

FIGURE 10D: Peninsula's *Northwest Area*

On the opposite bank of the Mohawk, the Crescent Boat Club, in Clifton Park / Halfmoon, NY, is also plagued by this plant. (By water, it is located between Erie Canal Lock 6 and 7, approximately midway between Interstate 87, Twin Bridges, and State Route 9.) This private club, shown in FIGURE 10E, has a water chestnut harvester which they use on an annual basis to clear their boat area. This extracted material can be integrated for co-digestion with the proposed biogas operation.

In addition to the 100+ acres of harvestable water chestnut around the peninsula, other areas like the 7.5-acres at the Crescent Boat Club and the 4-acres at the Flightlock Rd Boat Launch, shown in FIGURE 10F, hardly represent the hundreds of acres of this plant biomass that extend up this valuable waterway and National Heritage Corridor. This represents an extremely significant opportunity to generate electricity from a locally available nuisance species while economically incentivizing the repair and restoration of this valuable and historic waterway. Boats and barges could effectively be used to transport the harvested material to the biogas production area and offer a low-intensity carbon emission alternative to vehicle transport.

FIGURE 10E: ***Crescent Boat Club, Inc.*** **FIGURE 10F:** ***Flightlock Rd Boat Launch***

Perennial grasses are not identified as an available feedstock in TABLE 10B, however, it is worth highlighting that the landfill's location on the Mohawk River make this a very strategic site for the large-volume importations of this biomass to contribute to the production cycle and provide renewable energy to the local residents and industries. This supply could be orchestrated at a future time to facilitate land restoration initiatives that are up stream along the river valley in more rural and agricultural districts. Byproducts and other goods could then be returned upstream. These grasses are typically harvested twice per year, in the early summer and fall, which would fall outside the peak harvesting time for the water chestnut in late summer. Therefore, a coordinated supply of these two potential feedstock has the potential to supply a consistent and sustainable amount of biomass to be used for almost half the year and potentially more if storage clamps are implemented into the supply chain management. This feedstock is therefore yellow in TABLE 10B.

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE 10B: ***Proposal 10 Feedstocks***

According to the NYS DEC's 2015 Biosolids Survey, the nearby Colonie WWTP has a flow of 3.5 million gallons per day (designed for up to 6 million) and generates approximately 1,064 dry tons of biosolids on an annual basis. This facility is located upstream on the Mohawk River in Latham, NY (FIGURE 10G) which is about 5-miles to the southwest of the landfill (almost 10-miles by driving). At the time of this survey, all of this biomass was going to the Town Of Colonie landfill and this method of management is still being employed today. Since this volume is over 1,000 tons per year, a biosolids pyrolysis solution would be appropriate for on-site installation to accompany the proposed biogas infrastructure. These biosolids are treated through aerobic digestion, and because there is a belt filter press in place for dewatering, this technology would be able to exploit additional energy efficiency as a result of the removed water content. Due to the large volume of wood materials that enter the Town Of Colonie Yard Waste Composting Facility, a wood pyrolysis system could also be considered to be set up parallel to this proposed biosolids management stream. These feedstocks are therefore identified with the color 'green' in TABLE 10C along with 'pyrolysis & biochar' represented with the color 'yellow.' An installation with this capacity could generate excess heat which can be applied to an innovative on-site technology. Aria Energy can explore the implementation of a CO2 capture technology to collect this gas that is produced from their generators. There is a market need for this gas with various industries and there are manufacturers which provide solutions that are capable of refining this gas with a purity that can be applied to the food and beverage industry.

FIGURE 10G: ***Colonie WWTP***

Pyrolysis & biochar		
Biosolids	**Wood waste**	**Heat need**

TABLE 10C: ***Proposal 10 Pyrolysis Potential***

There appears to be sufficient space at the landfill to employ both anaerobic digestion and pyrolysis technologies. FIGURE 10H shows a large staging area on the left that is approximately 3.5-acres. This is adjacent to the yard waste compost piles on the right of the image, so this location could be convenient for installation of the proposed system. Alternatively, for the purpose of integrating with existing infrastructures, it might be more conducive to choose a space around the existing buildings,

FIGURE 10H: ***Staging & Compost Area***

FIGURE 10I: ***Landfill Building Facilities***

shown in FIGURE 10I, near the main entrance of the landfill. However, upon consideration of capturing the CO2 produced from the electric generators, it would make the most sense to incorporate an installation around these units which are located at the southeastern corner of the landfill and have their own access road. FIGURE 10J shows the building which houses the generators and each of the 4 units can be identified protruding from the back side of the building. The lawn area in the foreground of the picture spans approximately 1.5-acres which includes some area along the entrance road. While this space may appear to be limited, all of the proposed technologies could be designed to fit within this confined area. The CO2 capture element would take up the most area, which, according to one manufacturer, would require approximately 100- by 100-ft according to the estimated volume of exhaust gas produced by the generators. Given the size and flexibility of the area around the landfill that is available for this engineering, all of the categories identified in TABLE 10D are marked with the color 'green.' For example, one solution may be to construct the proposed biosolids pyrolysis unit next to the generators while a wood pyrolysis unit could be introduced at one of the other landfill's sites. There is viable space at this location and the large variety of daily operations and material inflows make it an ideal place to introduce many circular economy initiatives that could bring more economic value to this site.

FIGURE 10J: ***Aria Energy's 4 Generators***

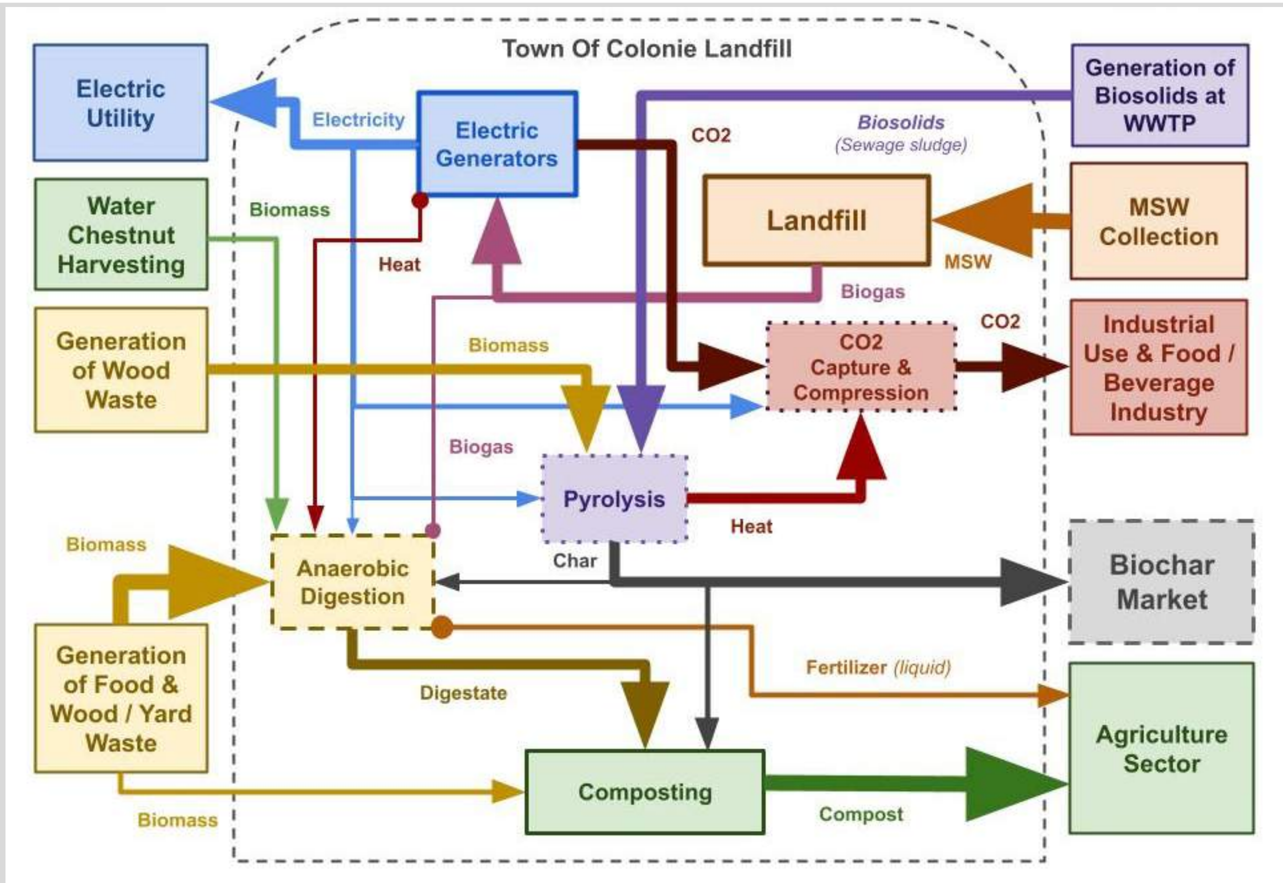
FIGURE 10K: ***Colonie WWTP Area***

Another option to highlight is the possibility of introducing the proposed anaerobic digestion and pyrolysis technologies on site of the Colonie WWTP. This would involve less stakeholders and may be more conducive to introducing this technology to the region. FIGURE 10K shows an overhead view of this facility and an area calculation through Google reveals that there is more than 4-acres of cleared space. This is suitable in size to host these operations. This solution would not include the carbon dioxide capture technology from the generators, however, this aspect may become irrelevant if Aria decides to convert their systems for RNG pipeline injection at a later time. The added benefit of the WWTP location would be an elimination of the biosolid transport component.

Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE 10D: ***Proposal 10 Area Overview***

The proposed circular biogas solution is presented in SYSTEM 10 and consists of several processes and flows. The primary feedstocks for digestion are excess food waste (yellow flow) and the abundance of locally available water chestnuts (green flow). 'Water chestnut harvesting' has a solid border because of the active harvesting done by the Crescent Boat Club. The digestate end product (brown flow) would be added to their current composting process and the nutrient-rich liquid fertilizer (orange flow) can be sold to the agriculture, community, and residential sectors. A composting process is also shown, but is not necessary for the proposed design, and therefore provides some greater flexibility relative to installation location. Biogas created by decomposition of organics within the landfill is currently collected and directed to the 'electric generators' as represented by the pink flow. Heat created by the electricity generation process can be captured and applied to the anaerobic digester to help maintain a consistent year-round temperature that is conducive for the microbial environment (red flow). Only one pyrolysis process is shown, but in actuality, a dual stream is the best solution with separate processing of biosolids (purple flow) and wood (yellow flow). Likewise, their respective chars would be sold to different markets. In the system, some of this material is applied to anaerobic digestion and composting to improve the quality of these processes. The CO2 from the electricity generation process is directed into the CO2 capture & compression process. Heat from pyrolysis is the main catalyst for this compression technology so it can be seen as a red flow connecting to this process. The combined processes and flows of this proposal are indicative of a circular economy production cycle and offer some insight into Cohoes' potential for adopting innovative renewable solutions with maximized benefits.



SYSTEM 10: ***Proposal For Town Of Colonie Landfill***

The NYS DEC Commissioner Policy 29 on Environmental Justice and Permitting (CP-29) recognizes the City of Cohoes as an environmental justice region as well as several areas around the cities of Troy and Albany. FIGURES 10L & 10M are sourced from the state and reveal the expansiveness of this particular region which is designated with the color purple. FIGURE 10L reveals the span of this area relative to Albany County, while FIGURE 10M offers a much higher resolution and closer view of the same area. Implementing a circular economy initiative at this location therefore offers an opportunity to introduce investments into this area that would be accessible by the local communities. Corresponding educational initiatives can be designed and executed to build capacity with the local residents and reveal the benefits of a regenerative production cycle. In addition, a system of this design would allow for waste to be reclassified as beneficial use material and become maintained within the community. Renewable energy in the form of electricity could be applied to the local electric grid while excess byproduct materials can be sold as a community export thereby generating additional revenue opportunities.

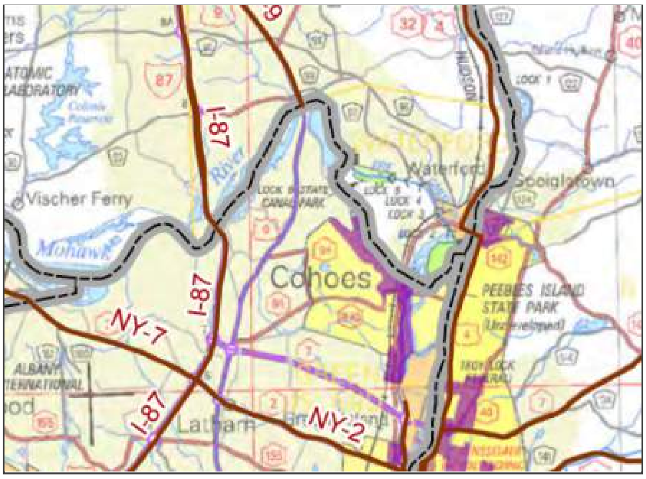


FIGURE 10L: ***Albany County Env. Justice***

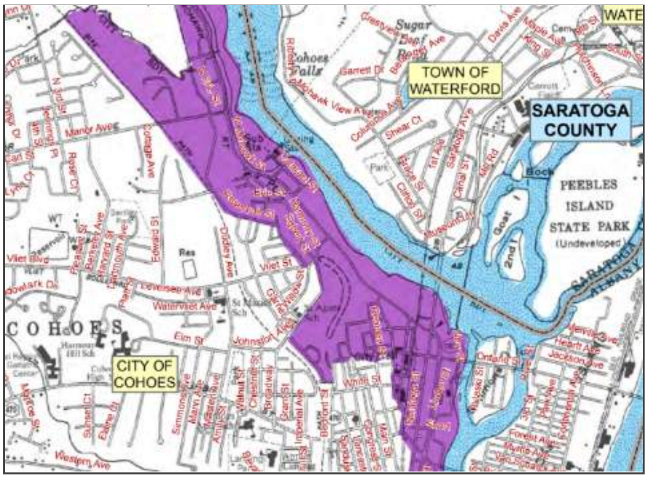


FIGURE 10M: **City Of *Cohoes Env. Justice***

TABLE 10E lists a number of ‘general’ stakeholders relevant to this project as well as each of the 10 individual system proposals. This includes the NYS DEC with its respective divisions, a variety of research & education institutions, select regional organizations, and several professional associations. ‘Specific’ stakeholders to this project include the local land conservancies and land trust, the county’s Cornell Cooperative Extension, higher educational institutions within a 25-mile radius of the facility, and some additional regional organizations. Due to the potential for the invasive water chestnut to be used as a feedstock at this site location, some of the ‘specific’ organizations also include PRISM, Hudsonia (Bard College), and the Beacon Institute for Rivers & Estuaries. These groups are therefore in common with the other proposals which exhibit the same potential to utilize this feedstock. Also, this proposal is relevant for the Erie Canal National Heritage Corridor and would relate to this waterways preservation of access and important historical significance. In order to maximize community and regional benefit, each of these organizations should be contacted and coordinated to form a network of support and oversight. This strategic opportunity for the greater Hudson Valley is a viable solution to reducing waste and meeting the state’s ambitious goals of transitioning to a sustainable, low-carbon future.

GENERAL	SPECIFIC
New York Department of Environmental Conservation: Division of Materials Management Climate Change Invasive Species Council & Advisory Committee US Army Corps of Engineers (USACE) **Research & Educational Institutions:** NYS Pollution Prevention Institute (NYSP2I) NYS Energy Research & Development Authority (NYSERDA) Cornell Waste Management Institute (Cornell University) C-Change (Iowa State University) Ithaka Institute for carbon intelligence Cary Institute **Regional Organizations:** Sustainable Hudson Valley Hudson Valley Regional Council **Associations:** American Biogas Council International Biochar Initiative World Biogas Association	**New York Department of Environmental Conservation**: Region 4 Environmental Permits **Partnerships for Regional Invasive Species Management:** Capital Region PRISM Lower Hudson PRISM St Lawrence Eastern Lake Ontario (SLELO) PRISM New York-New Jersey Trail Conference **Host Facility:** Town Of Colonie Landfill Aria Energy **Land Conservancy Groups (Land Trusts):** **Cornell Cooperative Extension(s):** Albany County Rensselaer County Schenectady County **Universities (Colleges):** Rensselaer Polytechnic Institute (RPI) Russell Sage College SUNY Albany Union College **Concentrated Animal Feeding:** **Regional Organizations:** Beacon Institute for Rivers & Estuaries (Clarkson University) Hudsonia (Bard College) Erie Canalway: National Heritage Corridor

TABLE 10E: *Proposal 10 Stakeholders*

Discussion: Additional considerations

The results of this study provide site-specific roadmaps for development with respect to feedstocks, process requirements, and feasibility. Their order of presentation has also revealed the potential progression of technological advancement from a stand-alone anaerobic digester to an integrated system which also includes processes such as pyrolysis, syngas production, and carbon capture. However, this does not provide a strategy for regional action and implementation. Therefore, elements of regional coverage and development pathways will now be explored to provide further comment on which installations should be prioritized and which can return the most immediate accomplishments regarding regional area coverage (maps in APPENDIX 3). Since environmental justice initiatives have been highlighted as important aspects of these systems, comments with respect to the regional placement and population density are also discussed. Some possible avenues and opportunities for financing are also mentioned to help public action groups begin to embark on pathways which can offer viable funding in accordance with economic development.

Area coverage

Starting January 1st of 2022, according to the NYS Food Donation and Food Scraps Recycling Law, all large generators of food scraps (more than 2 tons per week on average) have to redirect this biomass for beneficial use as long as there is a facility within 25-miles from the point of origin. These specific generators have already been identified by the NYS DEC, therefore, they are required by law to divert this organic material from their MSW stream with respect to the food waste hierarchy. The 10 Circular Biogas System Proposals have been located at facilities throughout the Hudson Valley taking this condition into consideration. Thus, one objective of the collective proposals has been to locate each proposal within approximately 25- to 50-miles of each to offer networked regional coverage. FIGURE F displays the location of each proposal with a pink map marker. The large circle around each point is equivalent to approximately a 25-mile radius. Clearly, there is significant continuous coverage provided by the collection of installations with the primary gap located in Greene and Columbia Counties below the installation in Albany County. The resulting radial coverage spans an area over much of the selected 11 NY counties with corresponding infrastructure investments in 8 of them.

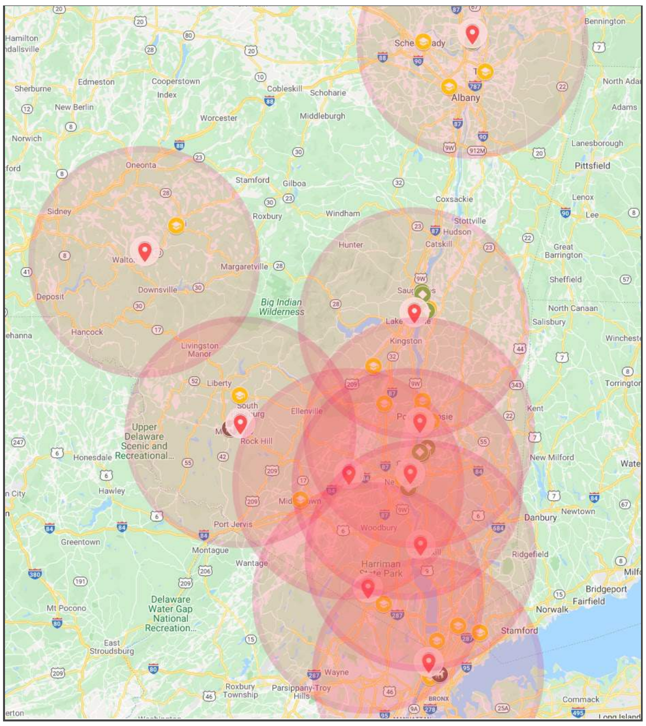


FIGURE F: ***10 Proposals (~25-mile radii)***

Strategy for prioritization

Achieving simultaneous installations of all the proposed facilities may not be realistic from both management and funding perspectives. Therefore, strategies should be explored that can prioritize implementation of these systems in a manner that is the most effective and conducive to continuous regional coverage with the least number of systems. FIGURE G displays a map with five of the system proposals that appear to cover a significant portion of the Hudson Valley. There are 25-mile radiuses extending from each site location; Town Of Colonie SWL, Delaware SWMC, Ulster County RRA, Dutchess County RR, and Wheelabrator Westchester. FIGURE H offers a slight alternative to this first map with Taylor-Montgomery LLC in place of Dutchess County RRA.

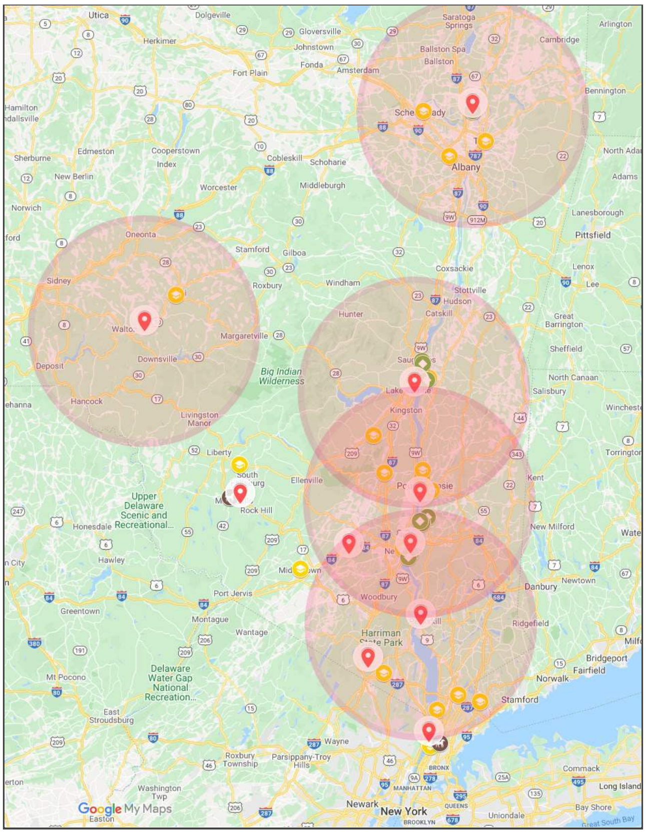


FIGURE G: ***5 Selected Proposals (Option A)***

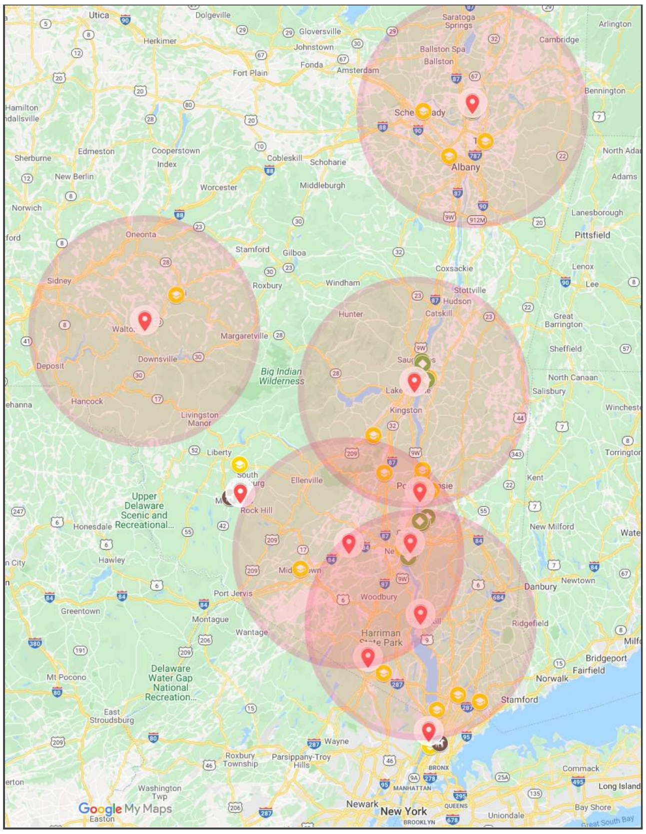
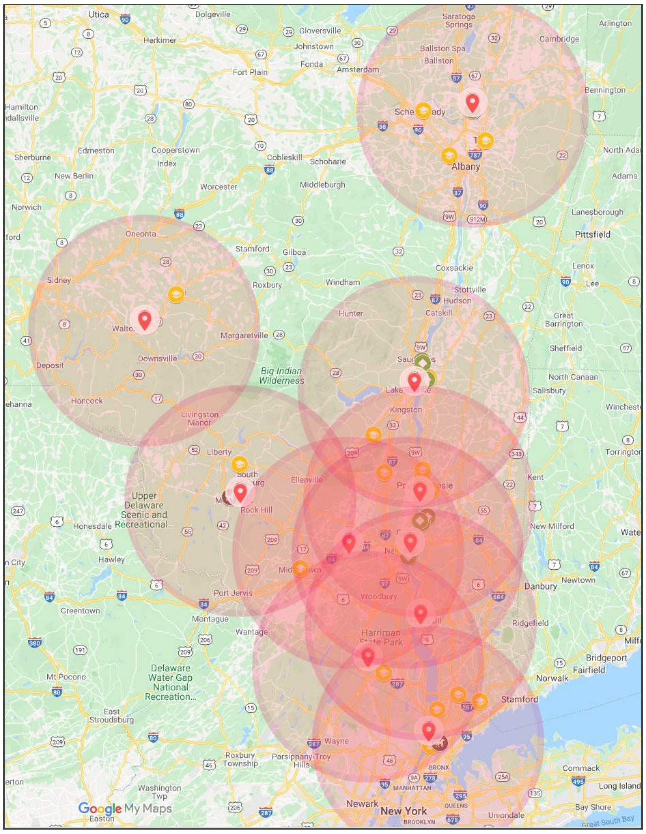


FIGURE H: ***5 Selected Proposals (Option B)***

With *Option A,* Ulster County RRA (Proposal 5) is located at the northern boundary of Dutchess County RRA's 25-mile radius. Meanwhile, Wheelabrator Westchester (Proposal 8) is located at the southern boundary of Dutchess County RRA's 25-mile radius. Therefore, maximum area coverage is achieved with roughly equal overlapping areas coverages to the north and to the south. This is not the case if the Dutchess County RRA proposal is replaced with the Taylor-Montgomery LLC proposal. Another factor of consideration pertains to the clamp infrastructures. Dutchess County RRA does not own the property to the north where their clamp would be placed, while Taylor-Montgomery LLC does own the property where their clamp would be placed. Thus, when considering long-lasting and resilient strategies for land restoration, Taylor-Montgomery LLC may be the better choice of the two proposals even though there appears to be more regional coverage if the Dutchess County RRA Proposal were to be implemented in its place.

Filling in the blanks

FIGURE I is the same map that is shown in FIGURE F with 25-mile radiuses drawn around each of the nine proposed locations. However, in search of solutions designed to create continuous coverage of service throughout the downstate region of NYS, there are some gaps. For instance, the center of the map is largely in the Catskill Mountain region and is preserved land in the form of state parks, wilderness, and forest. Because this area is relatively low in population density, for the purposes of this study, it will be disregarded and not considered to be an immediate region that requires coverage. There is also a gap to the south of the Town Of Colonie Landfill (Proposal 10).



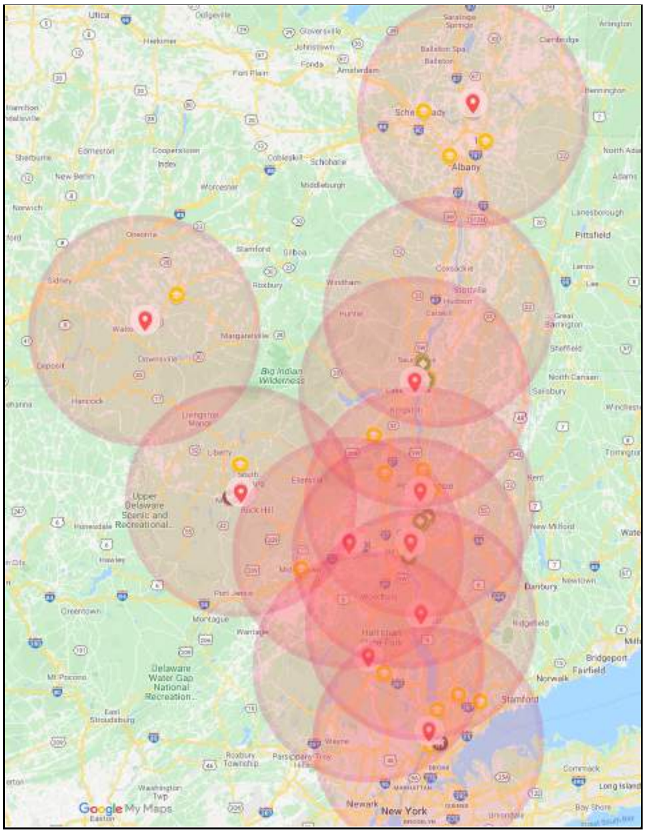


FIGURE I: 10 Proposal Regional Coverage

FIGURE J: Greene County Addition

The methodology for determining ideal locations for these circular biogas systems excluded typical transfer stations that are only serving as intermodal sorting and connection points. Yet, there is one location in Greene County that should be mentioned as the 'next-best' candidate because it can serve the role of offering this necessary overlap of service and would cover the gap between Ulster County RRA (Proposal 5) and Town Of Colonie Landfill (Proposal 10). The Catskill Transfer Station in Catskill, NY is located on the western side of the Hudson River shortly north of the Rip Van Winkle Bridge. FIGURE J displays the addition of a circle with a 25-mile radius with this location at the center. This facility serves as the main transfer station for all of Greene County's solid waste transportation. The flow of this network can be seen in FIGURE K with this facility represented by the yellow box in the center of the image. FIGURE L shows a satellite image of the location which reveals that there is sufficient space to host a number of shipping container digesters, but there doesn't appear to be sufficient quantities of available feedstock within this defined radius.

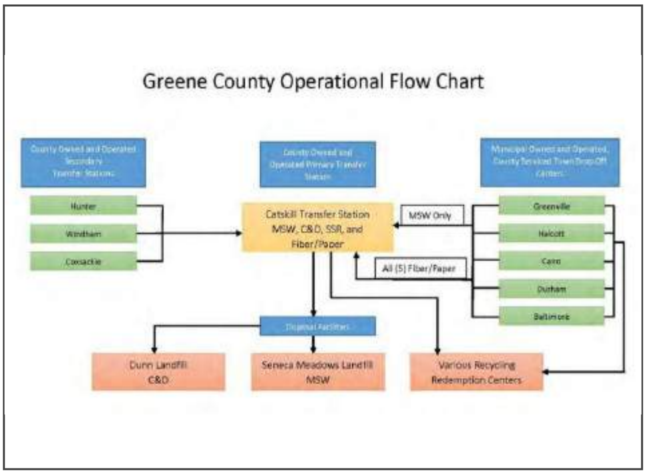


FIGURE K: Greene County MSW Flows

FIGURE L: Greene County Solid Waste

It is also worth mentioning that the Columbia County Solid Waste facility is located on the eastern side of the Hudson River a short distance north of the Rip Van Winkle Bridge in Hudson, NY. FIGURE M depicts both the Greene County Solid Waste Management and Columbia County Solid Waste Management with pink markers which reveal that these two facilities are relatively close to each. Therefore, they should be equally considered for the implementation of a biogas system in this region. FIGURE N shows a closer satellite view of the Columbia County facility which also depicts a mining operation immediately to the south of the location. One main differentiator between this site and the Greene County site is the nearby composting activity. There are two sites reported here with Cornell Waste Management Institute's compost survey which includes Greenport Transfer Station (which accepts combined yard waste from residents as well as commercial entities) and the Hudson Correctional Facility which generates approximately 1.6 tons of excess food waste per week, according to NYSP2I. Provided the small quantity of available feedstocks, it may make more economic sense to locate the operation at the correctional facility. A private owner currently manages a shipping container anaerobic digester solution in Hudson, NY. The most practical opportunity for development could therefore be to build upon and expand this existing resource.

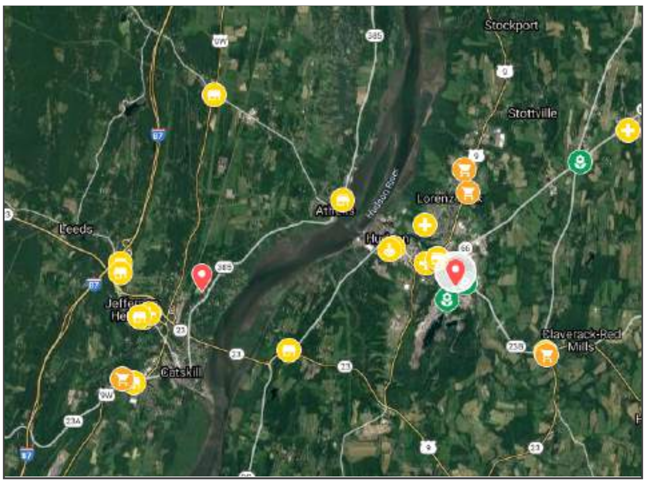


FIGURE M: Greene & Columbia Feedstocks

FIGURE N: Columbia County Solid Waste

Scaling to transfer stations

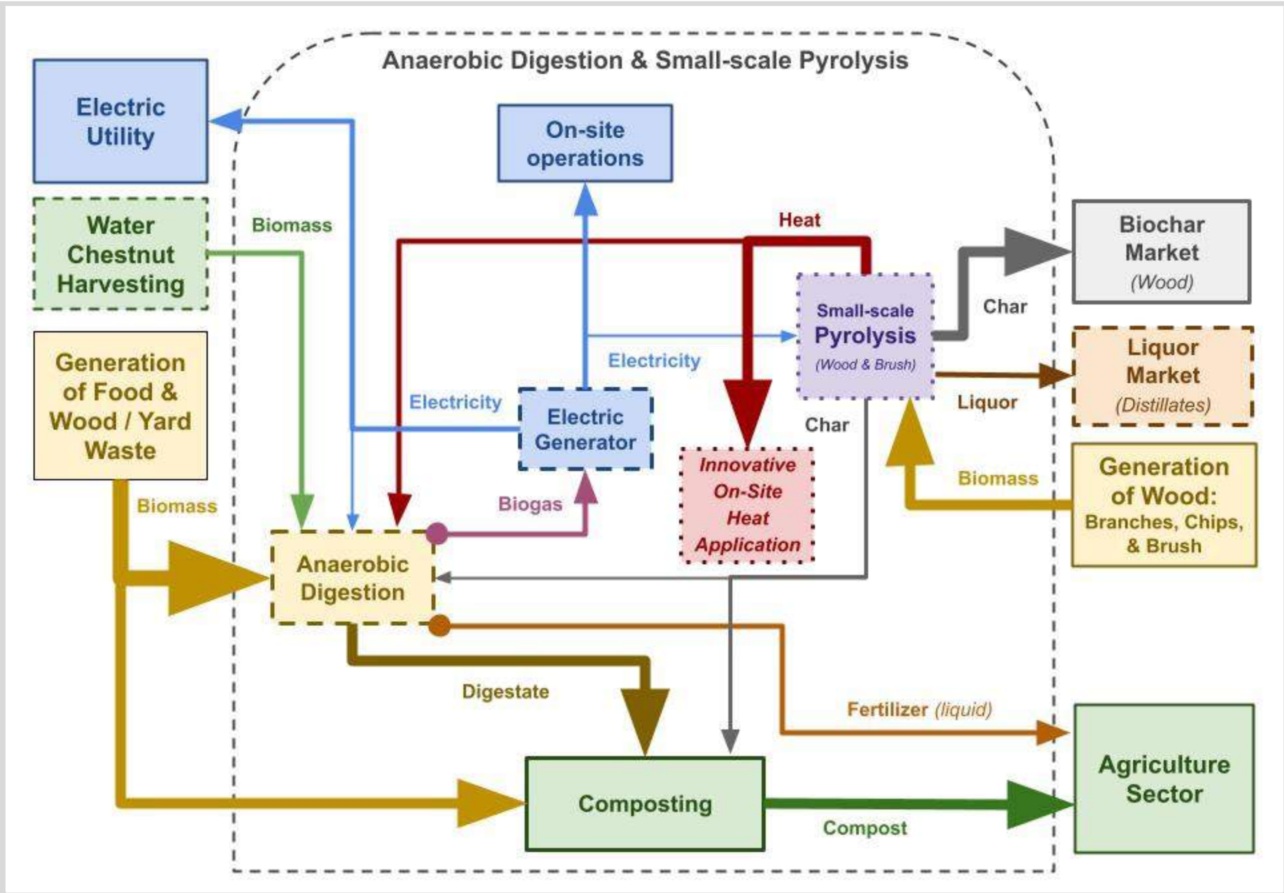
In the case for which biogas systems have been proposed at particular transfer facilities, it is because they are the primary county facility that manages the majority of waste streams throughout the local region. This is perhaps most apparent with Proposal 1 (Monticello Transfer Station) and Proposal 3 (Beacon Recycling & Transfer). Supportive reasoning for an installation at the Catskill Transfer Station could also be supported by this reasoning due to the aforementioned desire to attain continuous service coverage from NYC up through the capital district. Outside of these two special circumstances, local waste transfer stations (MSW, C&D, etc) were generally not considered because this study categorizes them as facilities limited to the function of redirecting and repackaging waste for transportation onto another location. Because the majority of these locations do not have a means of dealing with organic materials such as excess food waste and organics, other locations that already offer sorting of these waste streams as well as activities related to composting have been prioritized. In addition, requiring a site to become familiar with new technologies and logistics could represent a challenge to efficient adaptation, especially with multi-faceted implementation on a regional scale. However, with the anticipated development and maturity of organics diversion throughout the state, these local nodes of waste sorting and transportation should be scaled into their own biogas production operations to offer these services as a regional network solution. Until then, offering these services at the regional facilities will help to refine community transport and routing for a variety of these potential feedstock so that the proper pathways can be established at the right time.

Scaling into pyrolysis

Shipping container anaerobic digester solutions are available at a price point that could be considered attainable by many facilities looking to finance and introduce this type of technology into their operations. However, industrialized pyrolysis solutions for processing feedstocks such as sewage sludge require substantially more capital investment. Naturally, this difference can represent a financial barrier for resource and recovery facilities. For instance, the concepts and theories behind the economics of these multi-million dollar systems might be justified, however, general unfamiliarity with this sector's technology may prevent financing from ever being secured. In order to help communities and institutions adapt to this technology, one strategy is to explore smaller-scale, batch solutions, which, while not offering the same specifications as continuous high-volume equipment, can still provide a significant benefit to an organics recycling operation.

Low volume solutions typically operate at lower temperatures than their heavily industrialized alternatives and therefore are not likely to offer the same hazardous compound destruction qualities. In this respect, they would not be appropriate for managing sewage sludge or other organic material that are likely to be laden with contaminants and heavy metals. However, these machines are effective and very capable of processing organics material at their predescribed specifications. This means that the feedstock should be wood in the form of scrap lumber and small branches.

SYSTEM C offers one approach to introducing a small-scale pyrolysis unit into a facility aiming to offer a system solution with anaerobic digestion and composting. As in the previously proposed systems, the primary output is the carbonaceous char can serve the same three purposes as the larger solutions; an anaerobic digestion additive, a composting additive, and a biochar market. These pyrolysis units also produce a significant amount of heat which may be able to be applied to the anaerobic digestion process and reduce the electrical parasitic load and otherwise be required to maintain a healthy microbial environment. The remaining heat can also be applied to an innovative on-site heating application. For a small community environment, this energy could serve a range of beneficial uses from supplementing a nearby building's heating requirement to agricultural-related infrastructure such as green-houses and produce drying.



SYSTEM C: ***Anaerobic Digestion & Small-scale Pyrolysis***

There is one additional byproduct which emerges from this small-scale solution which is not available from the large industrial applications. 'Liquor,' sometimes referred to as 'Black liquor,' is a liquid distillate, or pyrolytic oil, which can be captured from the exhaust steam, condensed to a liquid form, and made available to a variety of markets. According to one manufacturer, it can be used as a natural preservative for lumber as well as an insecticide additive, fungicide additive, and soil fertilization amendment. It is an organic solution which would likely appease the needs of many regional farmers and sustainability enthusiasts. Beyond these applications, there is precedent for the material being used in various manufacturing processes, so respective markets should be investigated by each facility with any local markets being prioritized.

Drying biosolids for pyrolysis

The circular solution presented in SYSTEM C can be described as a potential precursor for installation for a larger-volume and more integrated pyrolysis solution. One aspect of sewage sludge pyrolysis which deserves more attention is the solid content of this feedstock that is imported into the system. Generally, input material with a high solid content is preferred because this means that less energy is required to heat, dry, and pyrolize the matter. This reduction directly correlates to the amount of excess heat energy that would be available for on-site utilization or, alternatively, the amount of syngas which would not have to be combusted and could be sold to market.

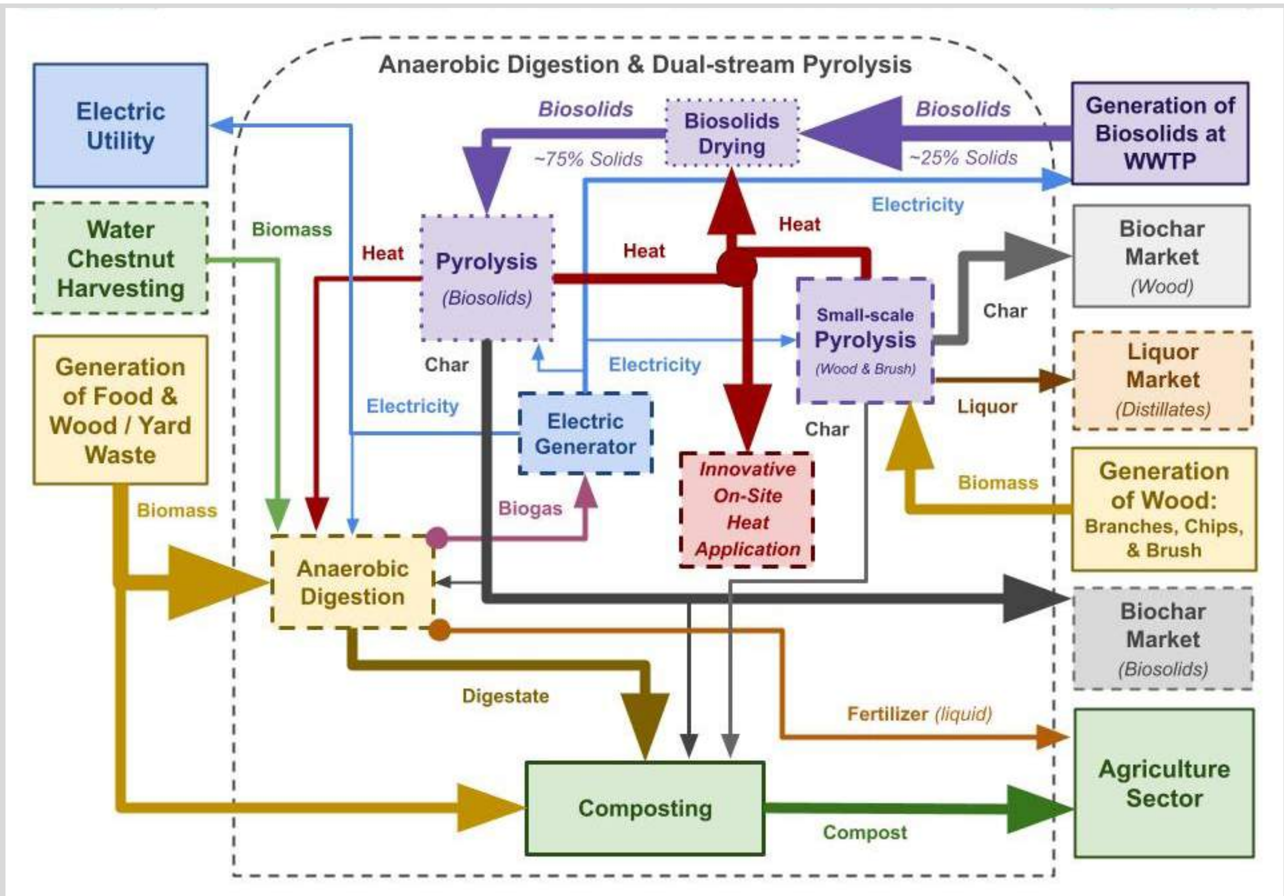
The 2015 NYS DEC WWTP Survey recorded that the Village of Delhi's WWTP outputs a wet ton sewage sludge that is approximately 11% solids. According to manufacturer specifications, this would not be suitable to pyrolyze and must first be dewatered. This percentage is not consistent with all WWTPs because there are a variety of different technologies employed throughout the Hudson Valley which would result in different dry to wet ratios. For instance, belt dryers and presses may be used to increase the solid contents substantially and even output the sludge in the form of a consolidated brick. Another process for dewatering can be found at the town of Marlboro's treatment plant where a large portion of the generated biosolids is directed into a specialized greenhouse. This arrangement, as shown in FIGURE O, houses a series of sections which are systematically filled, dried, and manually extracted to be exported to another management facility. The brown-colored area is a section that was recently loaded with biosolids. Meanwhile, the gray area of the image in the foreground is a section of biosolids which has dried. Notice how the material cracks and separates as the water evaporates. Once the biosolids reach this consistency, an employee shovels out the material and loads it into a hauler.

FIGURE O: Biosolid Greenhouse

While drying would be best to conduct at the physical location of the WWTP, thereby saving the energy and transport costs associated with the water portion, there may not be localized solutions available. One opportunity could be to collect and aggregate biosolids from different locations with a method that would collectively reduce the overall water percentage. For instance, biosolids with a high moisture content from one facility combined with sludge bricks that have a very low moisture content could produce a resulting product that is conducive for pyrolysis treatment. Otherwise, an alternative dewaterating mechanism would have to be installed at the site of the pyrolysis process and optimized for the greatest efficiency of energy use. This is how a smaller, community wood pyrolysis process may be able to be incorporated into the production process and implemented as a dual processing stream with synergistic industrial ecology attributes.

SYSTEM D offers a depiction of how this dual-stream pyrolysis operation could be designed. It contains all of the same processes that were displayed in SYSTEM C with four new additions; the biosolids generation, a new biosolids drying process, the biosolid pyrolysis process, and the potential biosolid char market. Notice that the heat output from the wood pyrolysis process in SYSTEM C has now been applied to the biosolids drying process. Ideally, this would result in a significant decrease in volume as well as a decrease in mass with a corresponding increase in the percentage of solids. While 75% solid content is likely to meet manufacturer specifications, a higher percentage is preferred in reference to the correlated energy savings. There are manufacturers which have designed drying units to use the heat generated from pyrolysis, so there is precedent for these types of designs that can be replicated and incorporated with new management methods.

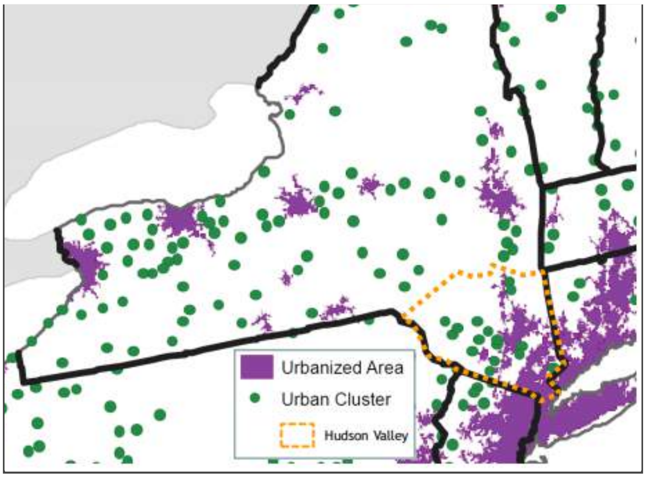
In the event that biosolid volume reduction is not possible with the heat from wood pyrolysis, there would still be some value in heating up the biosolids, via a heat exchanger, before they are fed into the sludge hopper for the same reason of aiming to reduce the parasitic heating load of the biosolid pyrolysis process. For one of the larger systems designed to produce syngas from the sludge, this configuration would permit a greater volume of renewable gas that could be sold to market because it would not have to be combusted for heat energy pertinent to this process. SYSTEM C & D are both theoretical, however, they offer an open-minded and unique approach to meeting the demands of a circular economy and implementing a commingled and regenerative production cycle.



SYSTEM D: ***Anaerobic Digestion & Dual-Stream Pyrolysis***

Environmental justice review

For each proposal, relevant NYS identified environmental justice areas have been highlighted and referenced. Corresponding regional maps have been displayed depicting the location and scope of these areas relative to the proposal's host county as well as close-up figures with detailed maps relative to the analogous municipalities. The Empire State Development (ESD) has provided a state-wide summary map of these identified areas which is shown in FIGURE P and built upon data sourced from the US Census Bureau. From this image, it is possible to perceive the overall mapped distribution of these urbanized clusters throughout the state. Notice that the area north of New York City, which is located in the lower-right of the image, depicts a significant amount of purple. There is also a dashed-yellow outline of the Hudson Valley which references 7 of New York's 62 counties. Meanwhile, FIGURE Q is from the Hudson Valley's Regional Economic Development Council and depicts this same outlined area with red circles that encapsulate identified 'Opportunity Zones.' These markings indicate that these areas are prime project candidates for CLCPA investments related to clean energy and efficiency initiatives. This is according to the legislation which has set a goal for at least 35% associated funding to be allocated to these areas.



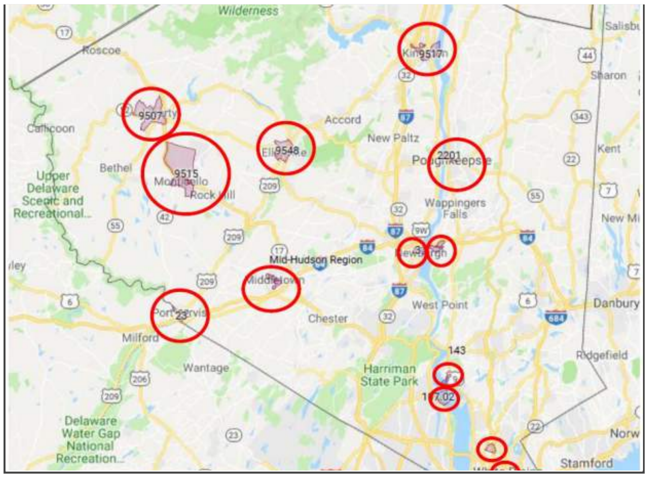


FIGURE P: ***Urbanized Areas (Census Bureau)*** **FIGURE Q:** ***Opportunity Zones (ESD)***

In FIGURE P, the base of this yellow-outlined region represents Rockland and Westchester Counties and includes Proposal 4 (WeCare Denali | Rockland County), Proposal 7 (Westchester County WWTP), and Proposal 8 (Wheelabrator Westchester). All transportation access to the northern parts of the state passes through this densely populated area along the Hudson River which is relatively narrow compared to the breadth of the rest of the state. The next northern cluster is within Orange and Dutchess Counties and includes Proposal 2 (Taylor-Montgomery LLC), Proposal 3 (Beacon Recycling & Transfer, and Proposal 9 (Dutchess County RRA). Further up the Hudson River, Proposal 5 (Ulster County RRA) is present in this purple area. Finally, the cluster outside and above of the yellow-outline (to the left of Massachusetts and Vermont) is where Proposal 10 (Town Of Colonie Landfill) is located. These environmental justice area maps can be compared to the mapped figures in the beginning of this discussion section to examine the coinciding regional placement of all 10 proposals within these state-wide identified areas.

Financial catalyst

Each of these proposals requires significant initial capital investment. While Proposal 1 at the Monticello Transfer Station, can install a 900-ton / year anaerobic digester for under $1 million USD, the multi-component systems such as Proposal 5 at the Ulster County Resource Recovery Agency can sum up to several million dollars USD even without the proposed plastics processing. However, investigatory discussions with the manufacturers of these existing products have revealed that these solutions are economically viable and can even offer a return on investment. The more advanced systems such as Proposals 8 and 9 which seek to incorporate operational synergies with the incinerator component of the existing facilities will obviously require more extensive engineering and integration specifications. Once carbon capture becomes part of the system, as in Proposal 10 at the Town Of Colonie Landfill, the complete system designed can be valued at well over $10 million USD, however, they still offer a viable economic return when constructed in the fashion that they have been proposed. This implies that circular system solutions are the only way to effectively address the Hudson Valley's green shift and construct infrastructure that is resilient for decades.

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. 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." 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). Another form of this arrangement is a power purchase agreement (PPA) which many communities, such as the Village of Wappingers Falls, have used to install renewable energy infrastructure such as solar panels. With this funding strategy, the customer of the electricity receives a stable, low-cost energy rate with no upfront fees. The owner also receives tax credits and income from this commerce as well as tax benefits associated with depreciated value. These models have also been supported by the CLCPA's Waste Advisory Panel.

Hudson Valley Biogas supports the use of these funding models to initially engage the support of key stakeholders and finance solutions from within each respective community. In this way, circular production systems can be introduced to the public in their simplest and most accessible forms. By establishing this regional education and engagement practice, communities will feel much more comfortable about pursuing larger, more ambitious, and much more capital intensive solutions that complete the entire regenerative production cycle.

Conclusion: Time for action

The greater Hudson Valley has an inspirational opportunity to face its challenges that relate to transitioning towards a circular economy. Closed-loop production models that focus on minimizing resource input, maximizing use of byproducts, and eliminating waste represent promising pathways to a sustainable future. Hudson Valley Biogas is introducing an instruction manual for a paradigm shift to reimagine, rebuild, and renew the local economy. The strategies exhibited by the 10 aforementioned proposals effectively discontinue many linear waste accumulation business models and welcome the implementation of installations that break down many of the economic barriers to prosperity that communities are facing today. This report has provided a series of circular biogas solutions for New York's greater Hudson Valley which address four significant categories of need; A) managing excess food waste according to legislation mandates, B) restoring ecosystems overburdened with the invasive aquatic water chestnut, C) achieving NY's CLCPA renewable initiatives aimed to mitigate climate change, and D) catalyzing environmental justice efforts to revitalize our impoverished communities. Through these four perspectives, the proposed installations will help the region accomplish its economic development goals in an environmentally just manner while setting the necessary foundations for scaling related infrastructure.

10 proposal summary

The area investigated for this report has spanned the 11 NY counties north of NYC; Albany, Delaware, Dutchess, Orange, Rockland, Sullivan, Ulster, and Westchester. This region covers approximately 7,700 mi^2 (~20,000 km), and is home to over 2.6 million people. NY's excess food waste legislative stipulation requires that all NYS DEC identified generators divert this biomass to beneficial use if they are within 25-miles of a respective recycling facility. Therefore, this constraint has outlined a condition that each installation be constructed approximately 25- to 50-miles from each to offer networked regional coverage. The number of proposals for each county has also been capped at 2 site installations to promote equitable distribution of investments throughout the Hudson Valley. The resulting proposals are within 8 counties (dark yellow in FIGURE R) of the 11 counties reviewed at the following site locations; 1) Monticello Transfer Station, 2) Taylor-Montgomery LLC, 3) Beacon Recycling & Transfer, 4) WeCare Denali | Rockland County, 5) Ulster County Resource Recovery Agency, 6) Delaware County Solid Waste Management Center, 7) Westchester County Wastewater Treatment Plant, 8) Wheelabrator Westchester, 9) Dutchess County Resource Recovery Agency, and 10) Town Of Colonie Landfill.

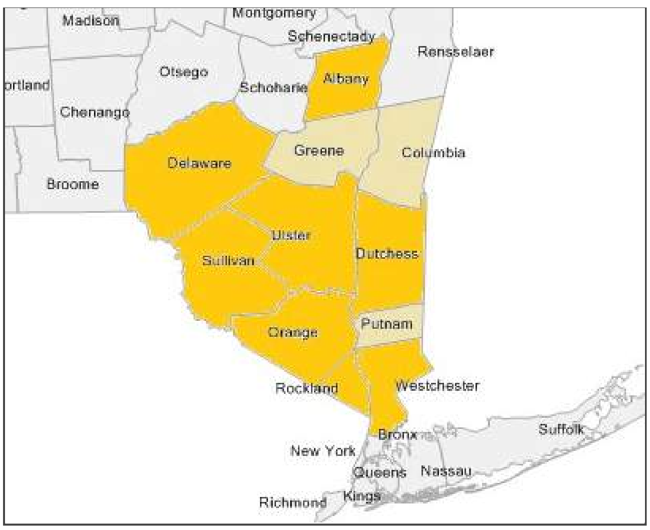


FIGURE R: NYS Counties With Proposals

Classification matrices

The systematic approach used to identify the potential and associated resources at each proposed location involved creating a series of classification charts. This strategy focused on four main categories to assess the current operations at the selected sites as well as to recognize the potential for future infrastructure installations. They are 1) industrial / commercial site with hauling activities, 2) variation of feedstock, 3) pyrolysis & biochar (production viability), and 4) space to host the proposed system (and scale with additional infrastructure). Each of the tables exhibits a series of subset qualities and attributes which are used to highlight more details about the elected location. The summation of these collective proposals is now shared to reveal the respective proportions of existing and potential operational infrastructure which are also extrapolated in APPENDIX 4.

TABLES C displays the number of commercial sites which have recycling facilities, energy production, and landfill operations. Of the 10 proposals, 8 are classified as having existing recycling operations with the other two having potential. Only 3 of these existing operations manage organics other than wood/yard waste while 5 conduct composting of general biomass. The 2 facilities that currently generate biogas are associated with Proposal 7 (an anaerobic digestion operation for biosolids) and Proposal 10 (a landfill which collects the gases produced from decomposing matter). Proposal 10 also represents one of two active landfills at the proposal site while there are 3 other proposals suggested on the site of 3 closed landfills. All of the remaining 8 proposals exhibit the potential for biogas production which reflects the purpose and intents of this report.

<table>
<tr><th colspan="7">EXISTING: Industrial / commercial site with hauling activities</th></tr>
<tr><td colspan="2">8 Recycling facilities</td><td colspan="3">4 Energy production</td><td colspan="2">4 Landfill</td></tr>
<tr><td>6 Organics</td><td>5 Composting</td><td>2 Biogas</td><td>2 Incinerator</td><td>0 Natural gas</td><td>2 Active</td><td>3 Closed</td></tr>
<tr><th colspan="7">POTENTIAL: Industrial / commercial site with hauling activities</th></tr>
<tr><td colspan="2">2 Recycling facilities</td><td colspan="3">6 Energy production</td><td colspan="2">0 Landfill</td></tr>
<tr><td>4 Organics</td><td>4 Composting</td><td>8 Biogas</td><td>Incinerator</td><td>Natural gas</td><td>0 Active</td><td>0 Closed</td></tr>
</table>

TABLE C: Industrial / Commercial Proposals Summary

With respect to available feedstocks for anaerobic digestion, there are five forms of biomass which have been considered irrespective of biosolids due to the previously reviewed concerns of possible contaminants. Only 1 of the reviewed facilities currently processes a diverted excess food waste stream while all remaining sites could be provided with this diverted wastestream. Proposal 6, Delaware County SWM separates food waste from select MSW with their industrialized sorter, however, this machinery mixes biosolids into this process and would make it ineligible as a feedstock for digestion from the perspective of Hudson Valley Biogas. However, there is still an opportunity for this facility to receive a separated waste stream and thus has been included with the number of proposed facilities assigned to this category. 4 proposals have wood / yard waste composting operations and only 1 of them incorporated livestock manure. 5 proposals could include invasives as a feedstock while 5 of the sites appear to be adequate for perennial grasses.

Variation of feedstock				
1 Excess food waste	4 Wood / yard waste	3 Invasive species	1 Livestock manure	0 Perennial grasses
Variation of feedstock				
9 Excess food waste	3 Wood / yard waste	2. Invasive species	3 Livestock manure	5 Perennial grasses

TABLE D: ***Anaerobic Digestion Feedstocks Proposals Summary***

Of the 10 facilities, 7 have sufficient quantities of biosolids that are either generated or transferred on-site and could be incorporated into a pyrolysis operation. (Proposal 5, UCRRA, is the only one of these sites which does not generate biosolids but has them transferred at their location.) Meanwhile, the remaining 3 proposals are near enough regionally generated biosolids to justify the implementation of a centralized pyrolysis process with a coordinated supply of feedstock from these outlying facilities. Also, 3 of the proposed locations process wood waste in sufficient quantities to justify a wood pyrolysis process. Proposals 8 & 9 are both incinerators that apply heat to their incoming MSW feedstock while Proposals 6 & 7 require heat for their compost processing operations. Only Proposal 7, Westchester County WWTP requires heat to keep their anaerobic digestion tanks warm for processing biosolids.

Pyrolysis & biochar		
7 Biosolids	3 Wood waste	5 Heat need
Pyrolysis & biochar		
3 Biosolids	1 Wood waste	2 Heat need

TABLE E: ***Pyrolysis Potential Proposals Summary***

9 of the 10 proposals appear to have sufficient space to support the proposed circular system. The one exception is Proposal 7, Westchester County WWTP which appears to already have a very high density construction footprint that has limited expansion feasibility due to the Hudson River on its west side and the railroad tracks to the east. 4 of the proposals seem to have additional space to scale-up the proposed system with an increased supply of feedstock while 6 proposals require further investigation due to the space constraints of the current infrastructure. Finally, 5 of the proposed sites seem to be excellent candidates for subsequent circular economy initiatives while the remaining 5 reveal potential for this category. This judgement has been made with general considerations based on the variety of feedstock availability, recognized regional partner candidates, susceptibility for a pyrolysis installation, and general proximity to densely populated areas. Regardless of this conclusion, new possibilities should continuously be explored.

Space to host the proposed system		
9 Sufficient to support proposal	4 Space to scale-up the proposed system with increased feedstock	5 Available area to introduce innovative circular economy initiatives
Space to host the proposed system		
1 Sufficient to support proposal	6 Space to scale-up the proposed system with increased feedstock	5 Available area to introduce innovative circular economy initiatives

TABLE F: ***Space & Circular Economy Proposals Summary***

Regional coverage

With respect to the NYS Food Donation and Food Scraps Recycling Law, each proposal has been mapped with a 25-mile radius to examine their relative proximity and overlapping area coverage. The collection of these 10-sites is depicted in FIGURE S (repeated from the map displayed in the discussions section of this report). Albany, Delaware, Orange, Rockland, Sullivan, Ulster, and Westchester Counties each have one site proposal while Dutchess County has two proposals. As per the 50-mile proximity goal outlined at the beginning of this research, all of the proposals, with the exception of one, are located within this distance to each other. Therefore, a great span of regional coverage has been successfully achieved. The outlier is Proposal 10 (Town Of Colonie Landfill), which presents a coverage gap between Proposal 5 (Ulster County RRA) to the south. As previously reviewed, this is due to the relatively low volume of feedstocks processed at centralized locations within the Greene and Columbia Counties. However, prospective future development sites have been explored and discussed accordingly. FIGURE T shows a second map with only 5 of the 10 proposals identified which was also previously shown in the discussions section. Proposals 6 (Delaware County SWM), Proposal 8 (Wheelabrator Westchester), 9 (Dutchess County RRA), and Proposal 10 (Town Of Colonie Landfill) are proposed as one strategy for implementation prioritization. While Proposal 1 (Monticello Transfer Station), in Sullivan County, would offer more regional coverage relative to the other selected sites than Proposal 2 (Taylor-Montgomery LLC), the population density is much higher near the Hudson River, so this choice is more practical with respect to how many people and communities could benefit from this regional approach.

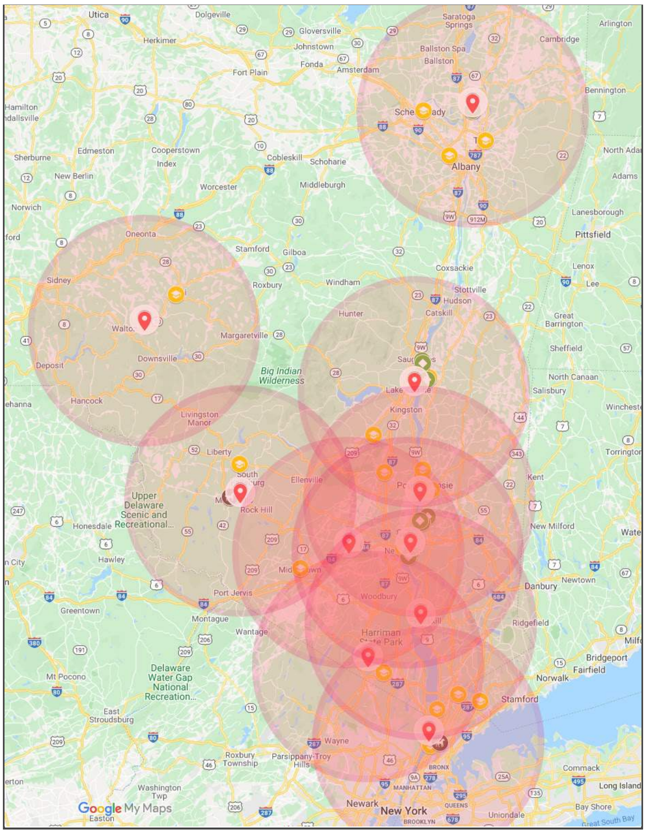


FIGURE S: 10 Proposal (~25-mile radii)

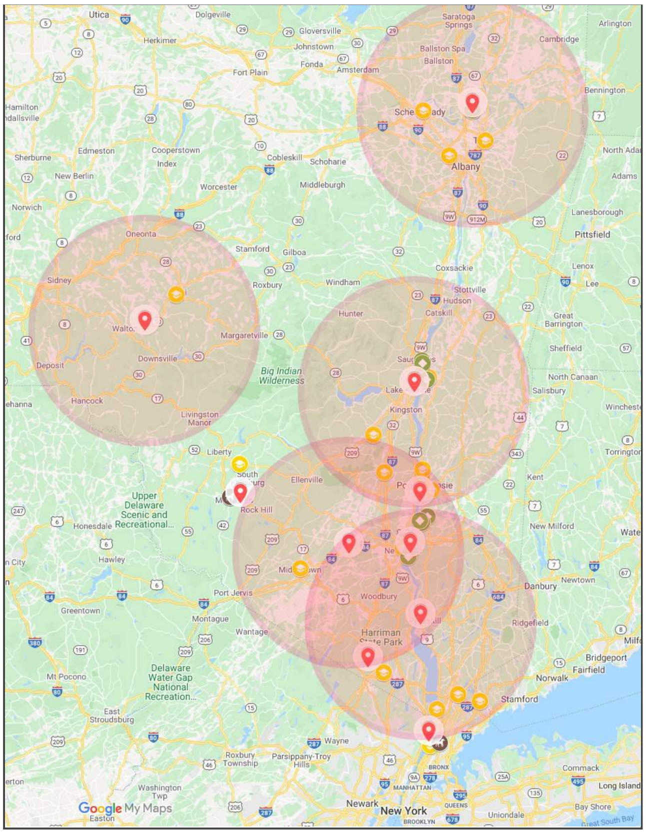


FIGURE T: *5 Selected Proposals (Option B)*

Compounded benefits

The individual component technologies reviewed for these 10 proposals are currently available in several forms from a variety of manufacturers. Correspondence with many of these companies has revealed that their products represent economically viable investments. However, these benefits can be compounded when multiple technologies are combined into a collective system. For example, anaerobic digestion can serve as a precursor to composting while valorizing additional energy through the capture and energy conversion of biogas. This renewable fuel can be combusted in an electrical generator to produce electricity and power on-site operations.

Meanwhile, pyrolysis, which is able to cleanse biosolids of all hazardous compounds (microplastics, pharmaceuticals, PFAS, etc), also produces heat which can be applied to the digesters' feedstock and keep the entire system warm throughout colder winter months. Perennial grasses can be cultivated as part of land restoration projects and be applied for co-digestion to help maintain a healthy and consistent microbial environment. In addition, the digestate and effluent fertilizer byproducts can be returned to the local agricultural sector to promote local sustainable farming cycles and avoid the importation of excess compounds that can lead to watershed eutrophication.

With large volume digesters, the carbon dioxide can be filtered from the renewable methane and captured for sale to local industry. However, this process only becomes economical with a significant heat source - one which is readily accessible through a complimentary pyrolysis process and is necessary for the compression aspect of the technology. Or, as in Proposal 10 (Town Of Colonie Landfill), the carbon dioxide can be captured from the electric generators' exhaust following biogas combustion and also be compressed and sold to industrial or food/beverage industries.

Mapping of these material flows and processes within a defined system boundary reveals how each technology can be integrated with the entire facility in a symbiotic manner to promote a resilient and self-sustaining production model. Hudson Valley Biogas has successfully depicted how these respective benefits contribute to a regenerative cycle that prioritizes reuse, repair, refurbishment, remanufacturing, and recycling. By embracing this mentality of developing multi-functional circular systems, the Hudson Valley can successfully embark on a sustainable pathway into the future.

Live, work, play

The NY Regional Economic Development Councils promotes 'WORK, LIVE, PLAY' as part of their marketing strategy for economic competitiveness and long-lasting growth. Each of the 10 proposals invite opportunities for additional infrastructure expansion and growth with community residents and new technologies. Training from the manufacturers is included with equipment installations and offers an attractive opportunity for unskilled workers to participate in on-the-job learning. This method of implementation and adaptation fosters a bridge with education and skill development that can be guided with the help of local institutions and learning centers.

The Regional Economic Development Councils can help to form these connections between the public and local governments while building capacity with critical stakeholders that includes the participation of businesses and higher education. FIGURE U shows the collection of high density urbanized areas located in the lower part of NYS in purple with urban clusters identified with green dots. The 10 Hudson Valley Biogas proposals align with this mapped distribution and can reinforce the ambitious initiatives set by NYS to inject capital and innovative developments into these designated regions with the CLCPA. Through these efforts, the state will take an active approach to increasing economic value within these respective communities and bring opportunities to residents who may be limited to work positions within the confines of their own city's boundaries.

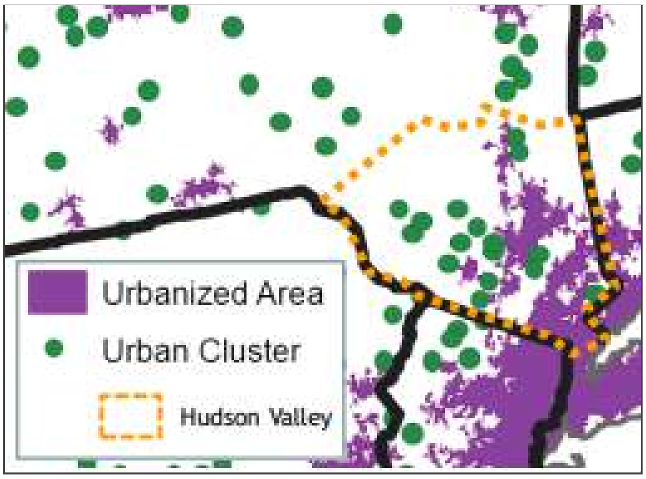


FIGURE U: ***Urbanized areas (US Census)***

Hudson Valley Biogas meets the WORK strategy through diversification of green jobs that are required to continuously grow with the success of communities. While many of NY's renewable energy initiatives related to installation of green infrastructure only create temporary jobs, these Hudson Valley Biogas proposals each generate long-term work requirements. This form of job security is necessary in order to achieve measurable economic development that can withstand the tests of time such as unexpected downturns and depressions in the local economy.

The LIVE strategy is met by creating centralized resource and recovery operations that can be scaled with a variety of add-on technologies. In this way, the locations will evolve into innovation hubs that breed even more resilient ideas and sustainable practices. Installations can become key destinations for community engagement especially with integration of agriculture and food security. These material flows are necessary for life and will exist as long as humans inhabit the Earth. Learning the most effective and responsible ways to manage human waste streams and body cycles is paramount to understanding the ecological balance and system designs of mother nature.

Finally, the PLAY strategy is achieved through the processes that help to restore and cleanse the local ecosystem. For instance, incorporating the invasive aquatic water chestnut as a feedstock into the production cycle creates an economic incentive to clean and restore priority water bodies. Another possible application of byproducts is to use the biochar to filter drinking reservoirs and immobilize hazardous compounds in contaminated soils. Reclaiming these spaces is critical to health and recreation as people seek to be more in touch with the environment. Beyond this aspect, clean and safe areas will invite tourism and related commercial developments into once deprived areas. Circular solutions are the foundation for all of these aspects and activities.

The next chapter

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 energy sources 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 network of systems can be deployed throughout the region to meet the demands of a circular economy in which all resources are reused and recycled. 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. This form of innovation welcomes entrepreneurship and cultivates community engagement with all ages.

Environmental, Social & Governance (ESG) strategies will continue to serve an important aspect of development between businesses, communities, and the environment. The 17 United Nations Sustainable Development Goals (UN SDGs) are designed to help guide these principles and offer an excellent system of checks and balances to ensure responsible growth and progress. This qualifiable approach permits decisions to be made with a continual conscious assessment relative to communities and nature. Tools such as Life Cycle Assessment (LCA), Risk Assessment, and Material Flow Analysis (MFA) are available to measure environmental impacts and provide quantifiable evidence of program success. These elements can be applied to each of the site installations to highlight and address any concerns while maximizing program effectiveness.

Implementing programs while building capacity between residents and their resources drives healthy living and empowers responsible minds. Managing regional operations with careful attention to inherent material value is the optimal and best practice for valorizing the Hudson River Valley's local resources (FIGURE V). These values have provided the foundational motivation for this greater Hudson Valley Biogas study and the resulting 10 Circular System Proposals have begun to write the next chapter of this region's environmental movement. Each individual component plays an indicative and strategic role in the overall mission of achieving national and international sustainability, and the greater Hudson Valley can set invigorating precedents capable of being scaled and replicated across the state, country, and world. This is a pathway that can truly empower the people, planet, and prosperity. Everyone can share in these initiatives and unite around a common goal of a responsible society. Hudson Valley residents are ready to take action and serve as a beacon of light for others to follow. Become part of this movement and learn to live, serve, and maintain the beauty of the Hudson River Valley.

FIGURE V: ***Esopus Island, Hudson Valley***

Appendices

APPENDIX 1: Background

County biosolid flows

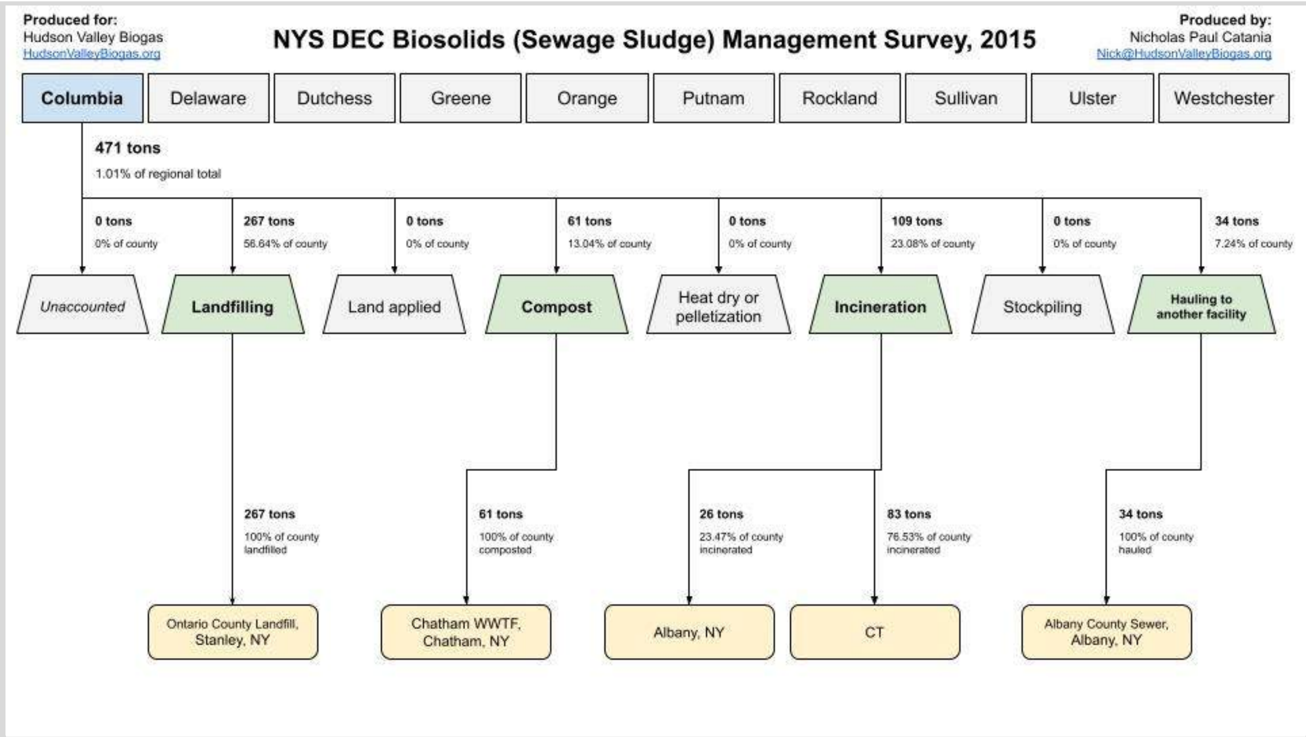


FIGURE AA: ***Columbia County Biosolid Flows, 2015 Survey***

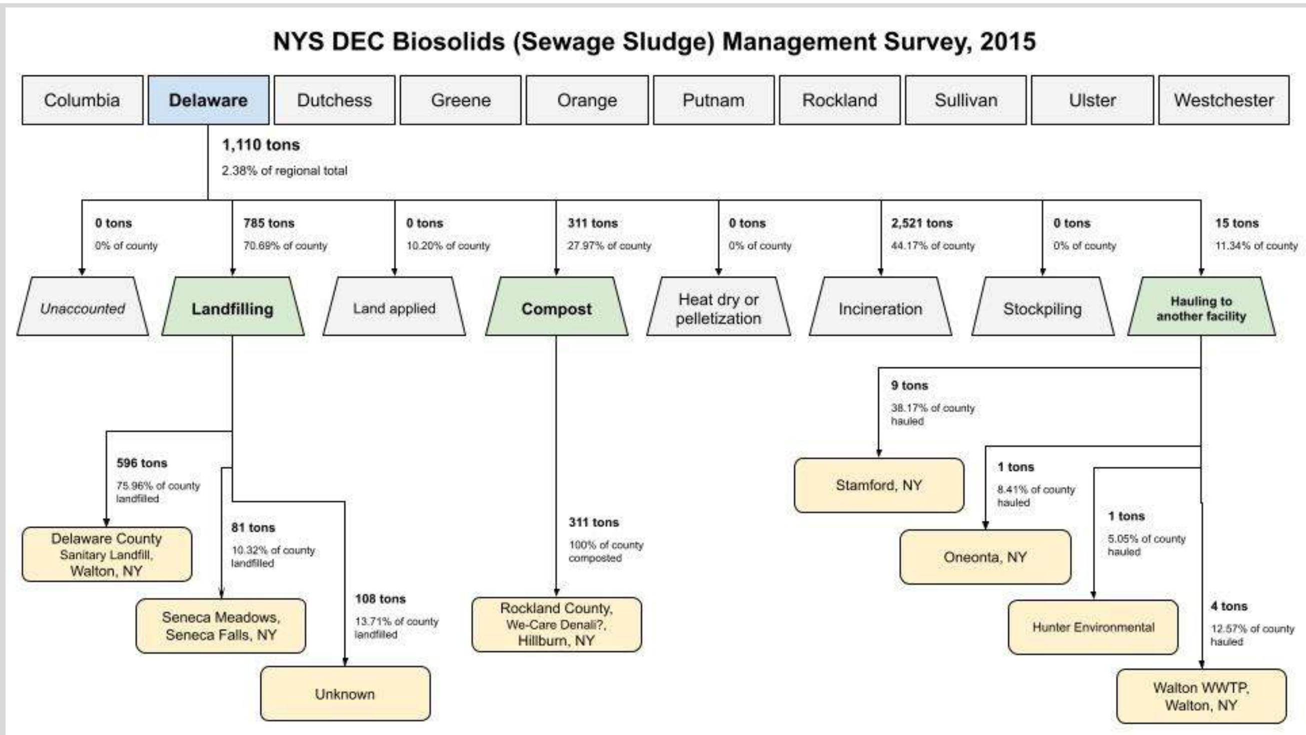


FIGURE AB: ***Delaware County Biosolid Flows, 2015 Survey***

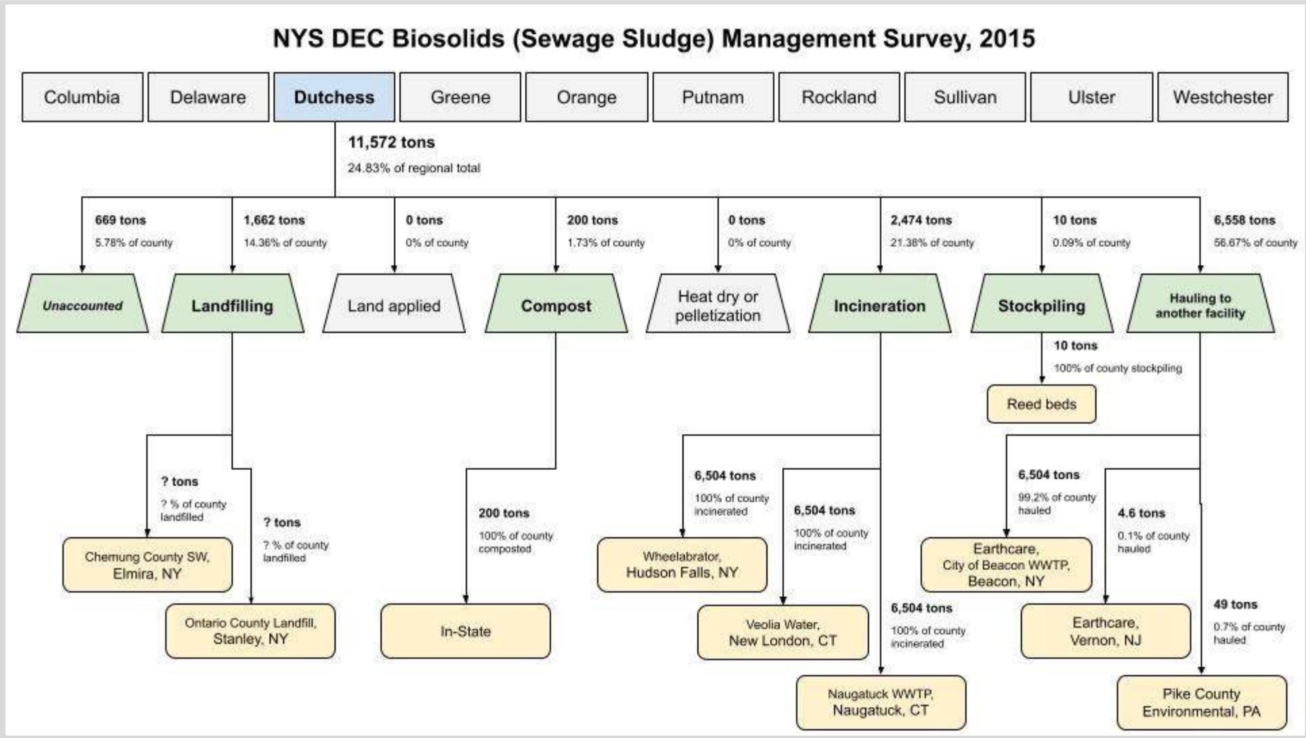


FIGURE AC: ***Dutchess County Biosolid Flows, 2015 Survey***

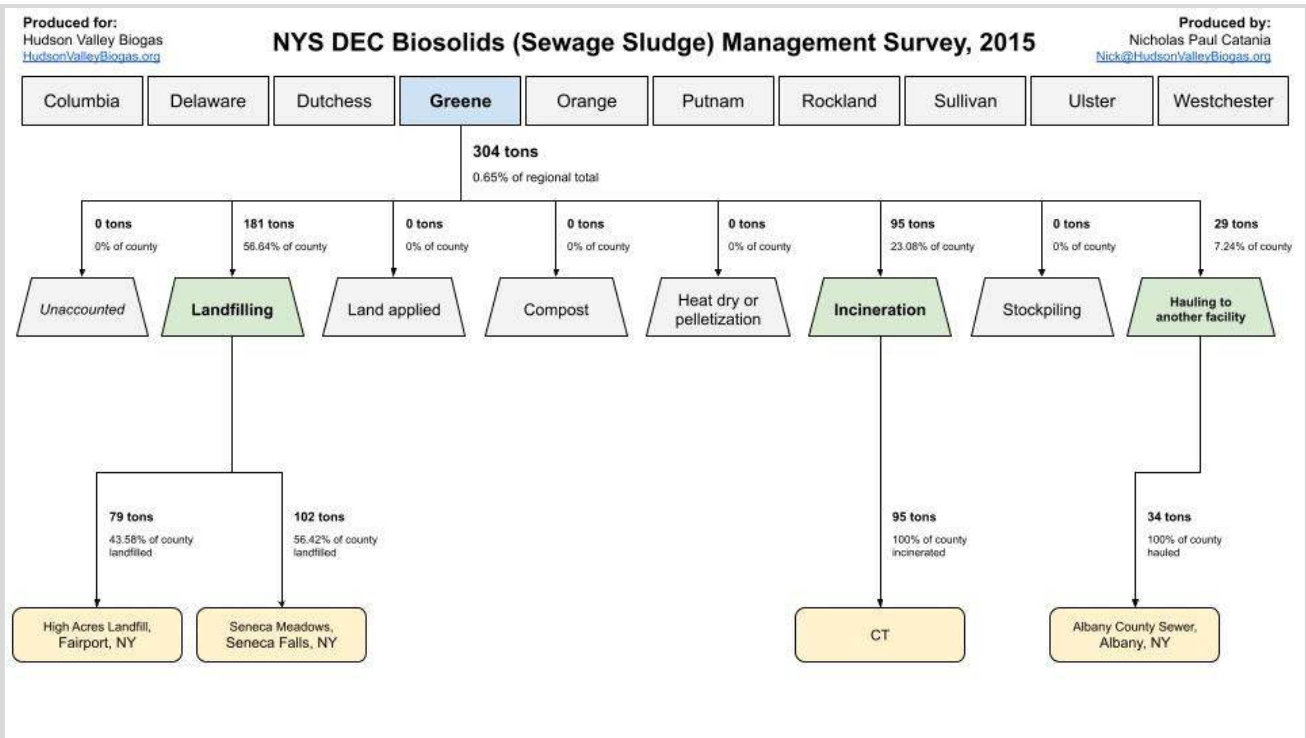


FIGURE AD: ***Greene County Biosolid Flows, 2015 Survey***

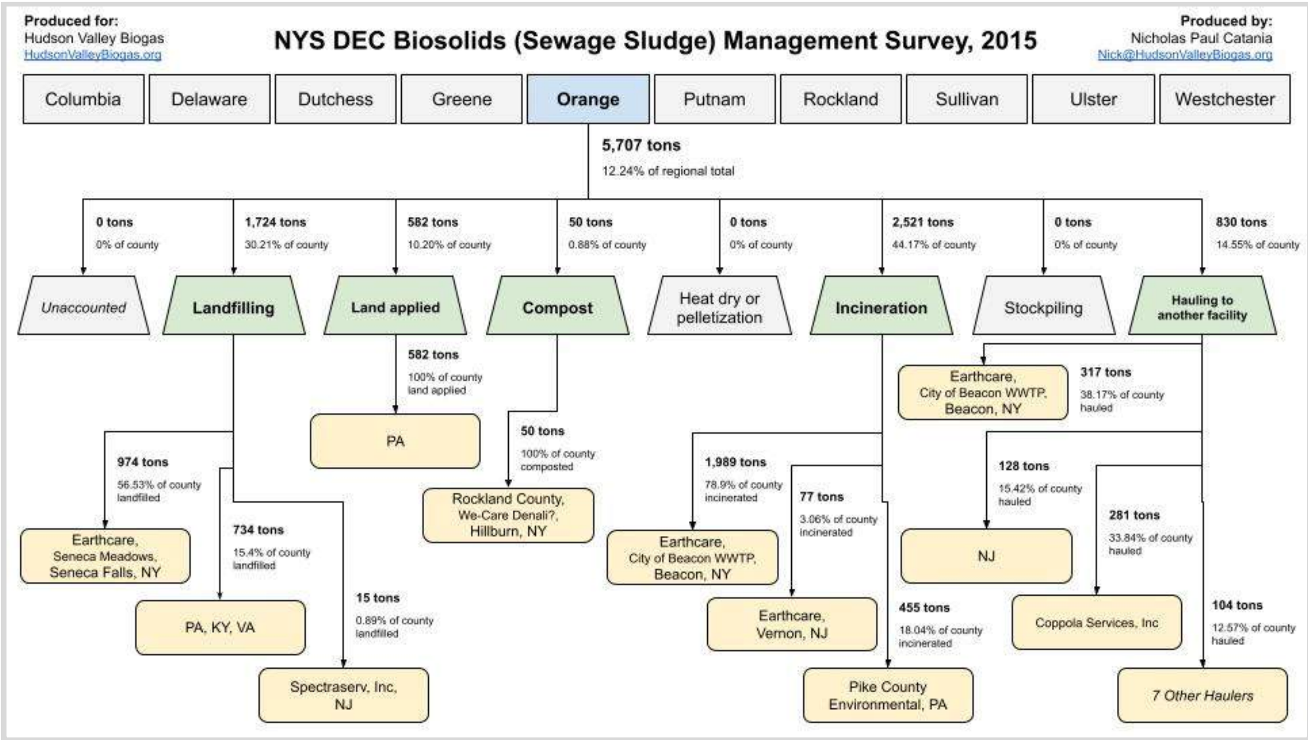


FIGURE AE: ***Orange County Biosolid Flows, 2015 Survey***

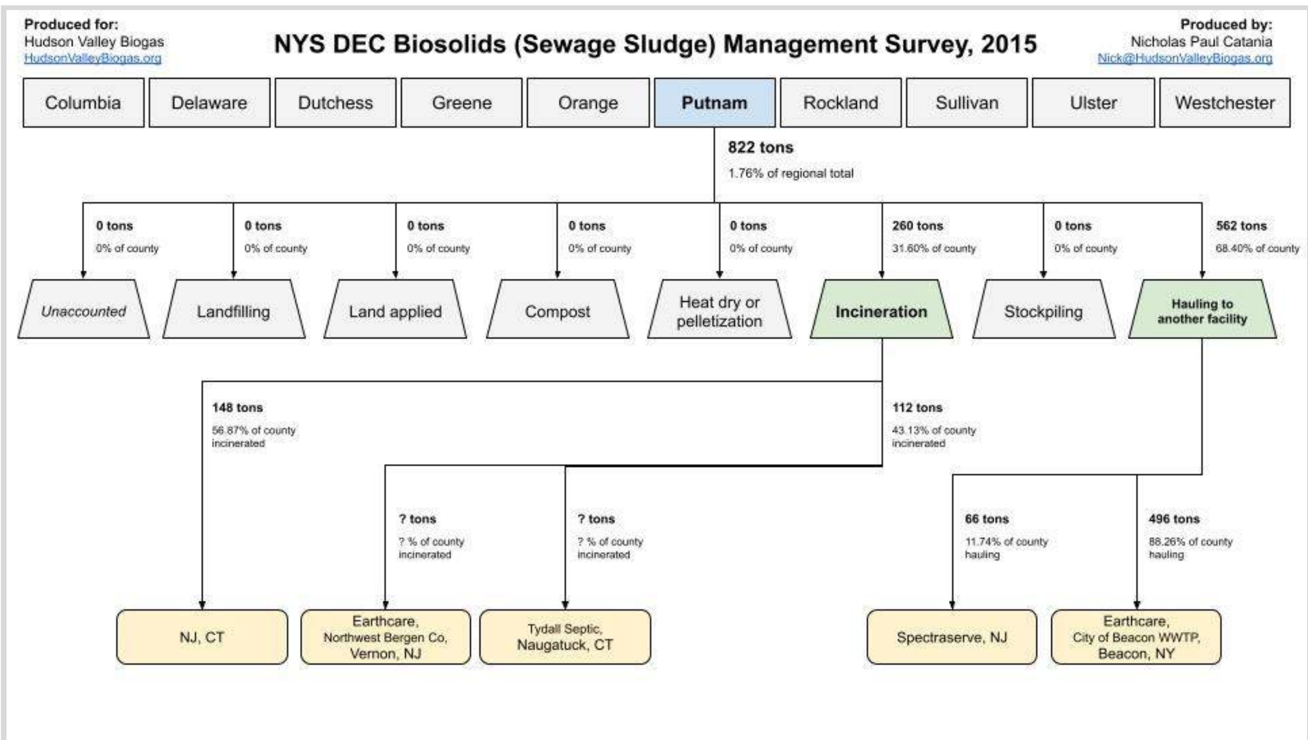


FIGURE AF: ***Putnam County Biosolid Flows, 2015 Survey***

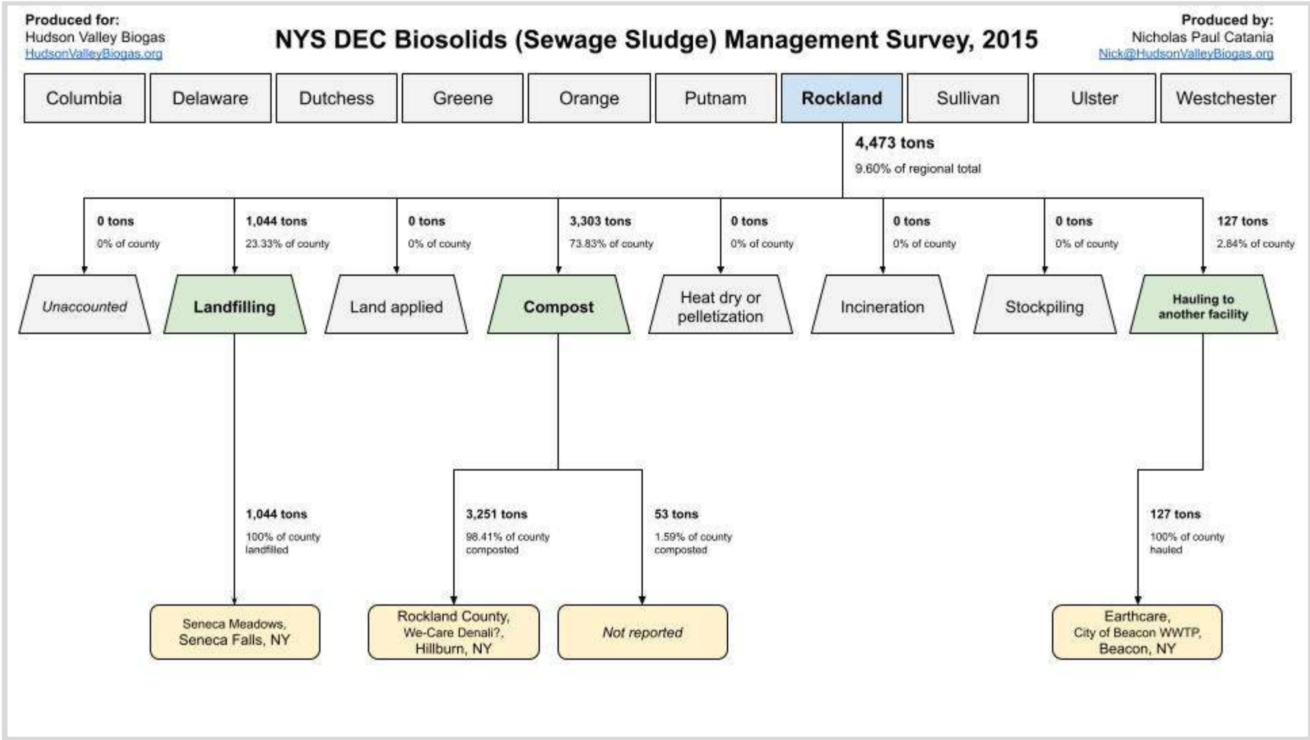


FIGURE AG: ***Rockland County Biosolid Flows, 2015 Survey***

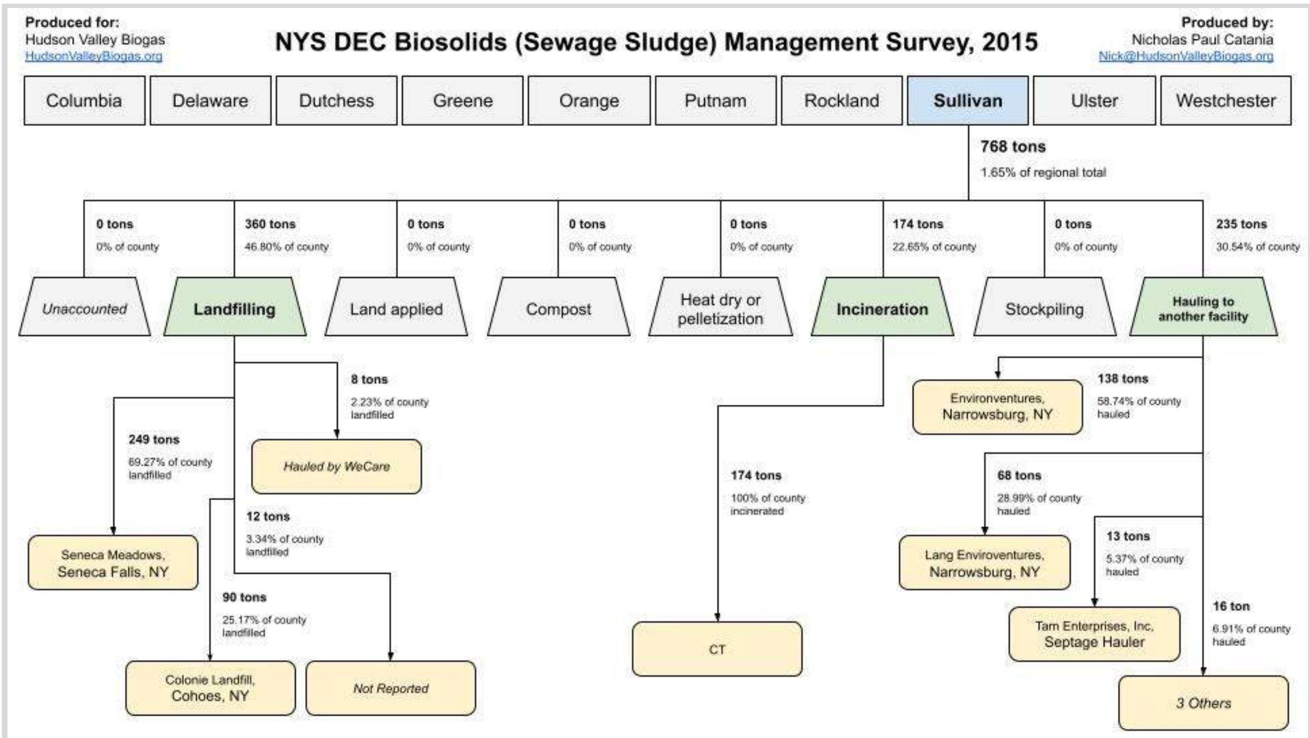


FIGURE AH: ***Sullivan County Biosolid Flows, 2015 Survey***

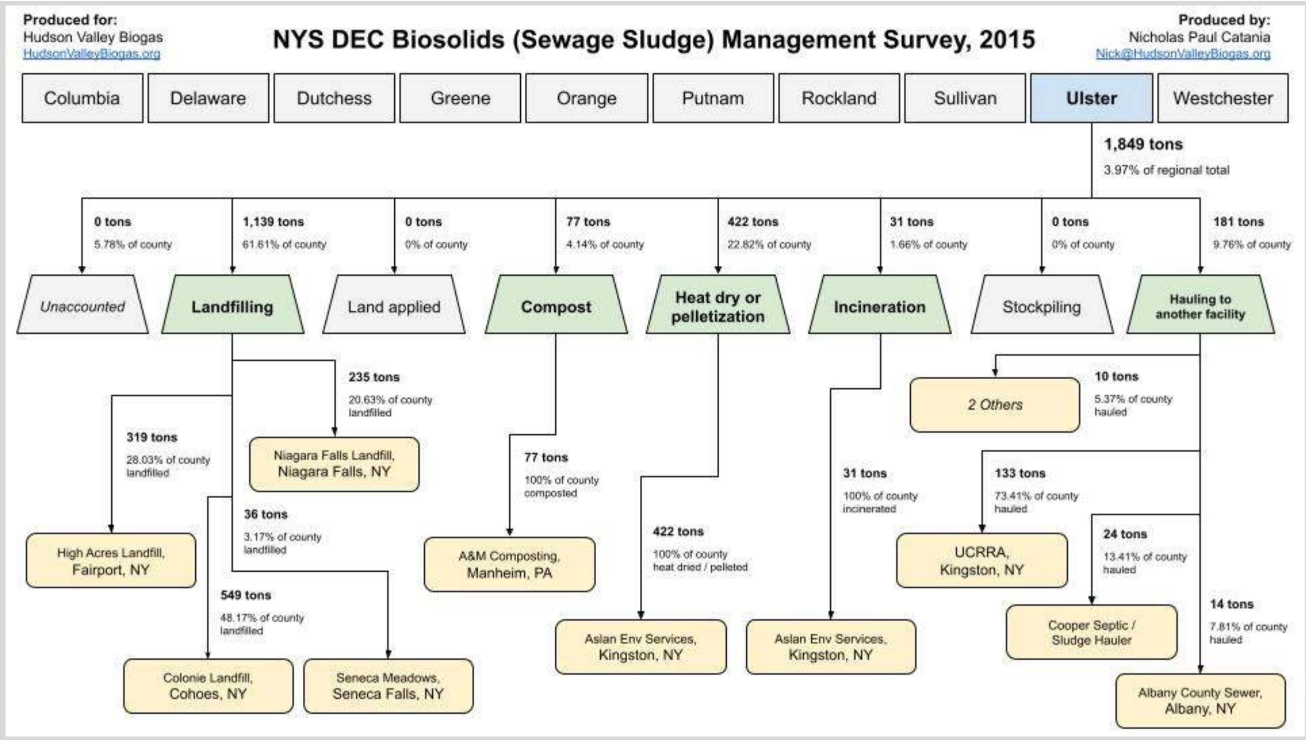


FIGURE AI: ***Ulster County Biosolid Flows, 2015 Survey***

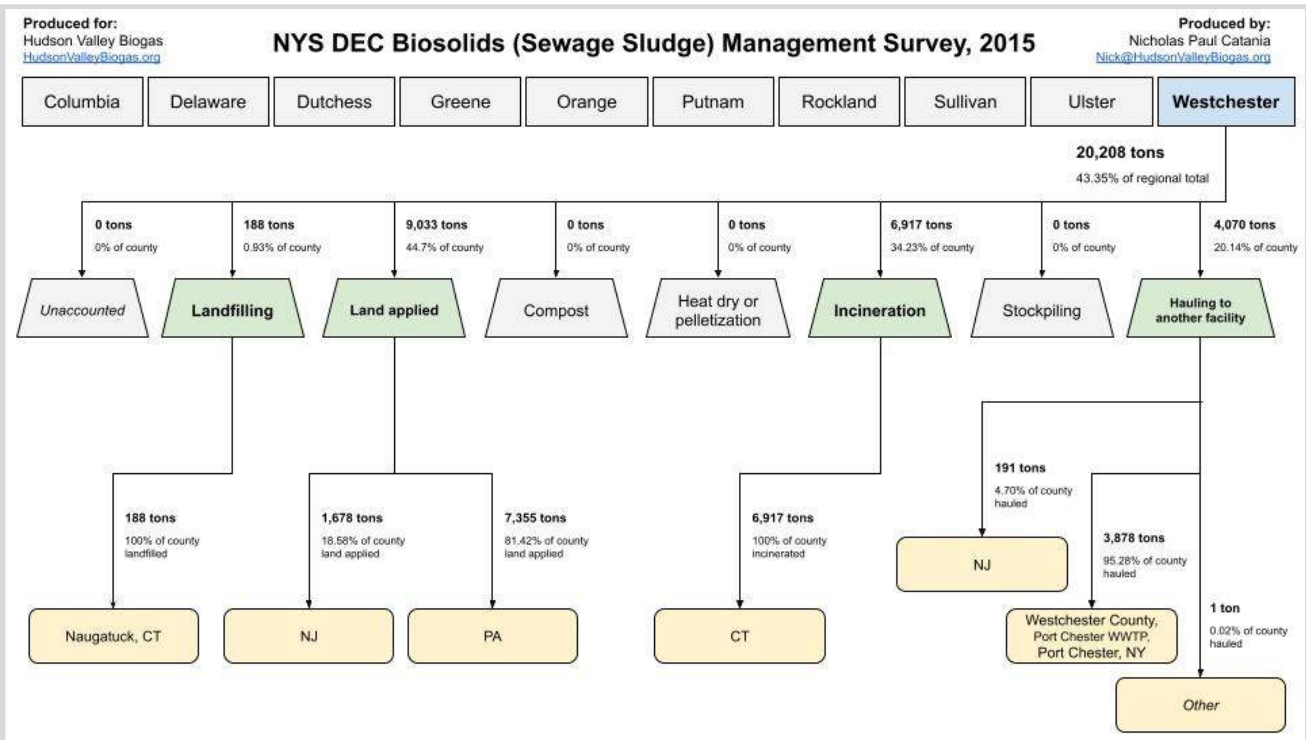


FIGURE AJ: ***Westchester County Biosolid Flows, 2015 Survey***

Regional biosolid landfilling flows

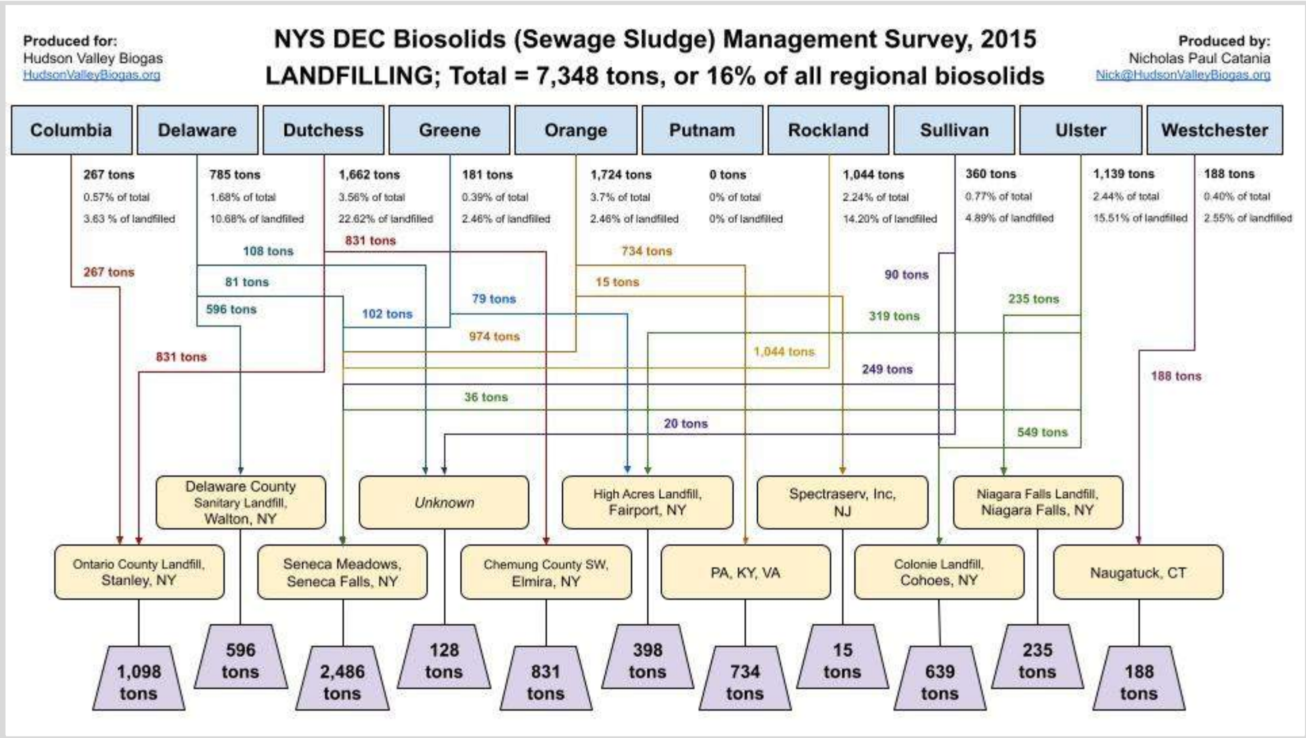


FIGURE AK: ***Regional Biosolid Landfilling Flows, 2015 Survey***

APPENDIX 2: Methods

Feedstock maps

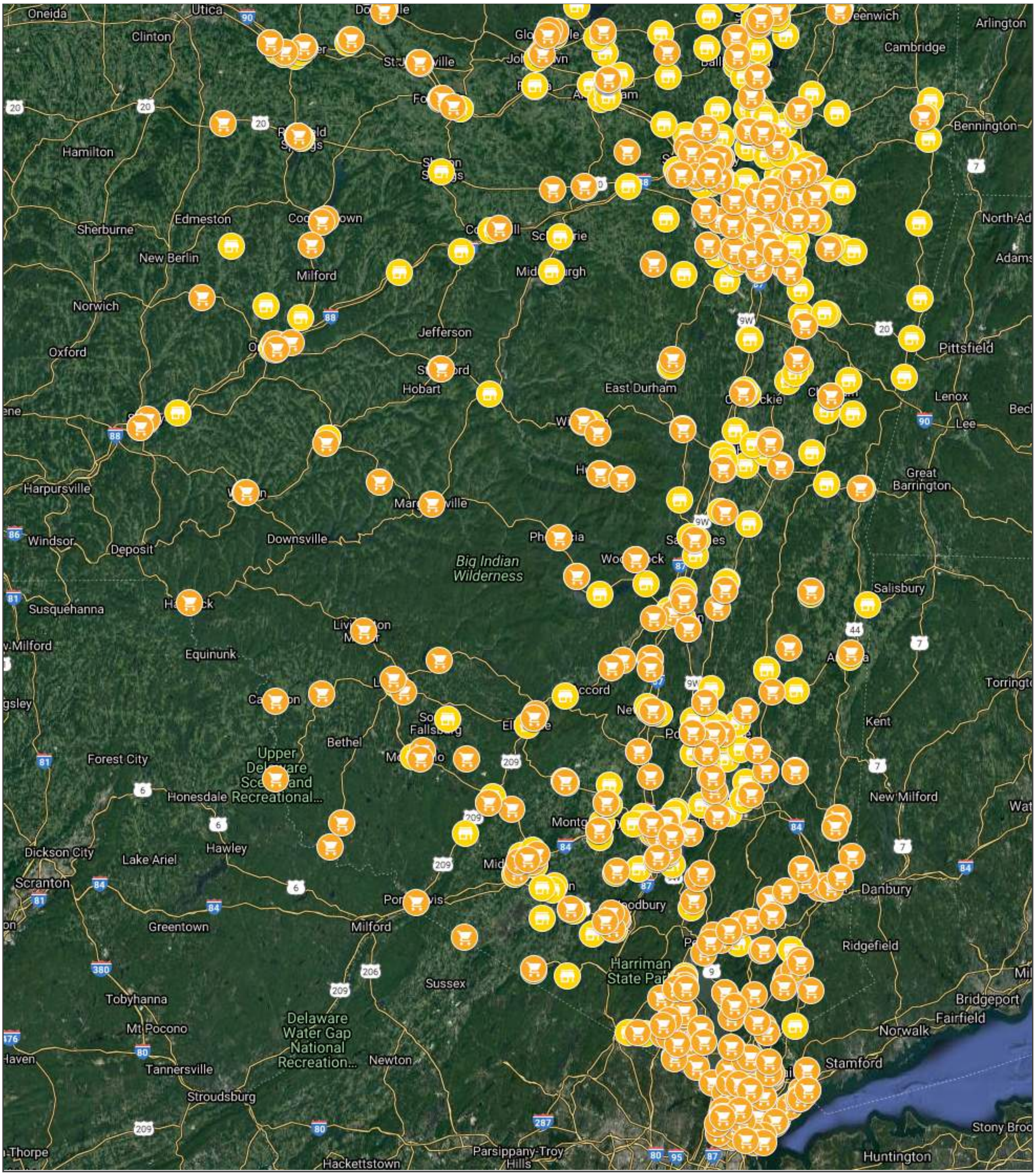


FIGURE BA: ***Excess Food Waste Generators (Limited)*** Source: NYSP2I

LEGEND

- Orange - Supermarkets
- Yellow - Convenience Stores

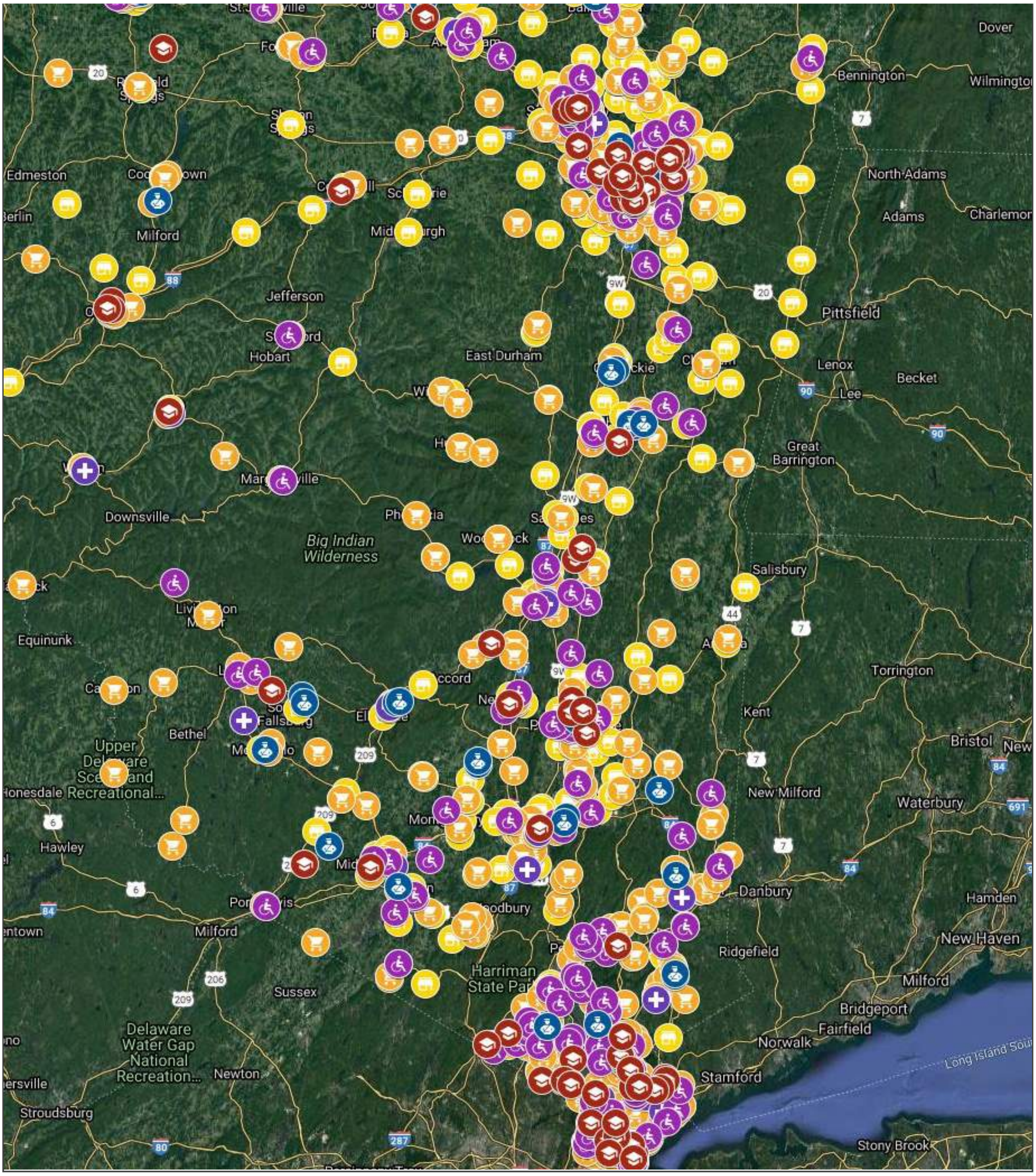


FIGURE BB: ***Excess Food Waste Generators*** Source: NYSP2I

LEGEND

- Orange - Supermarkets
- Yellow - Convenience Stores
- Pink - Nursing Homes
- Red - Colleges & Universities
- Blue - Correctional Facilities

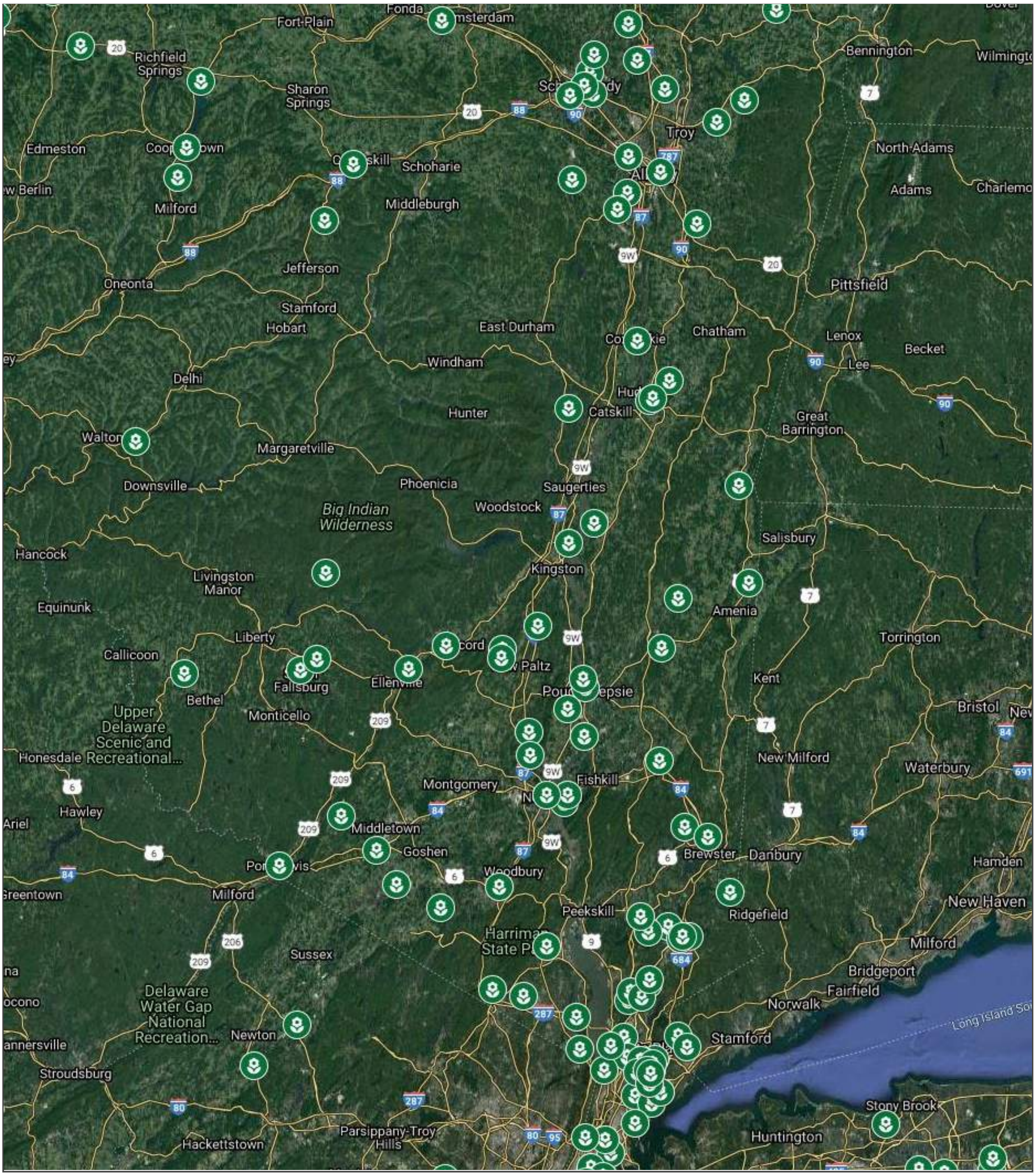


FIGURE BC: ***Compost Operations*** Source: Cornell WMI

LEGEND

- Green - Compost Operations

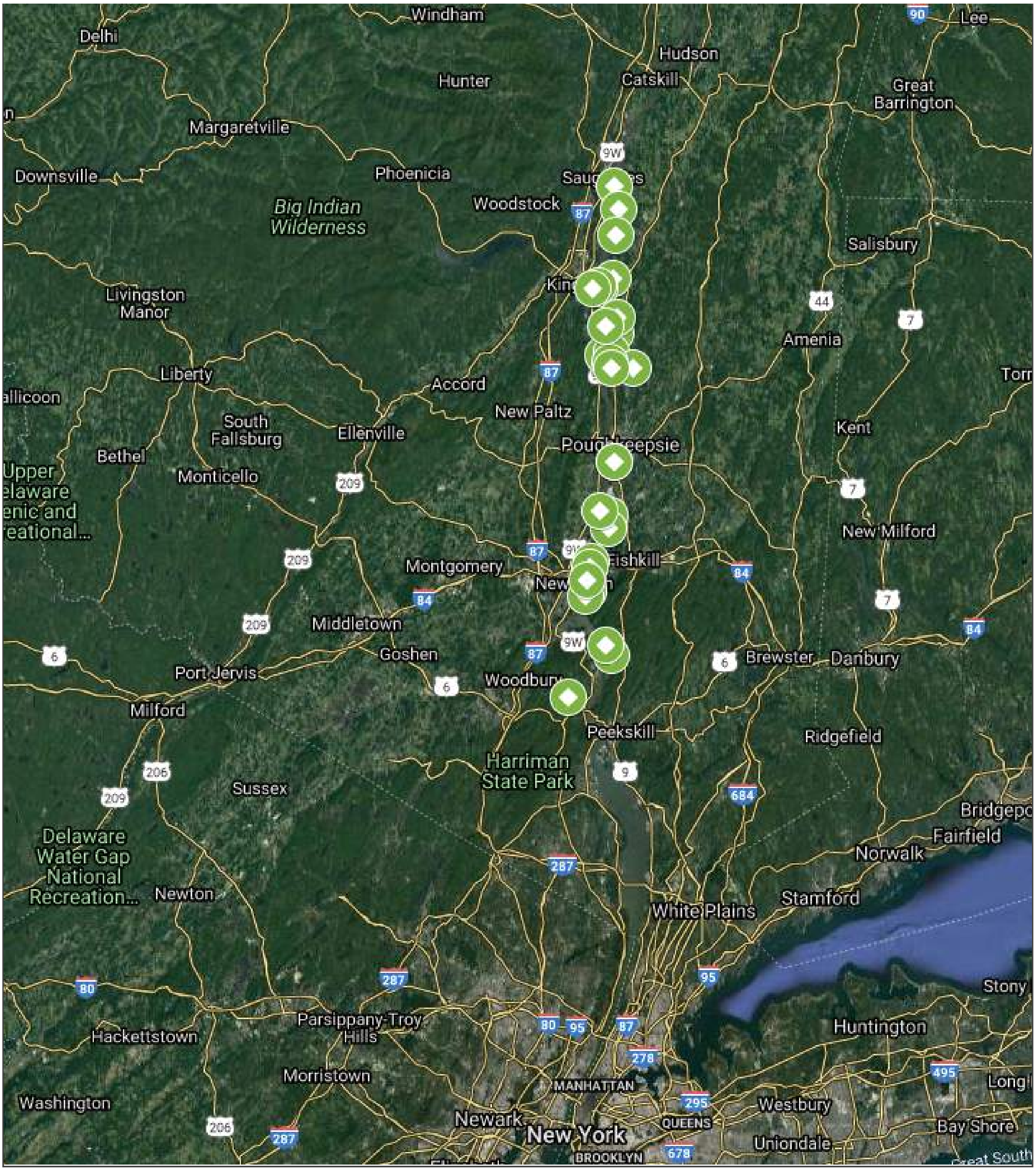


FIGURE BD: ***Water Chestnut (Trapas Natans) Infestations*** Source: Lowed Hudson PRISM

LEGEND

- Green - Water Chestnut *(Trapas Natans)*

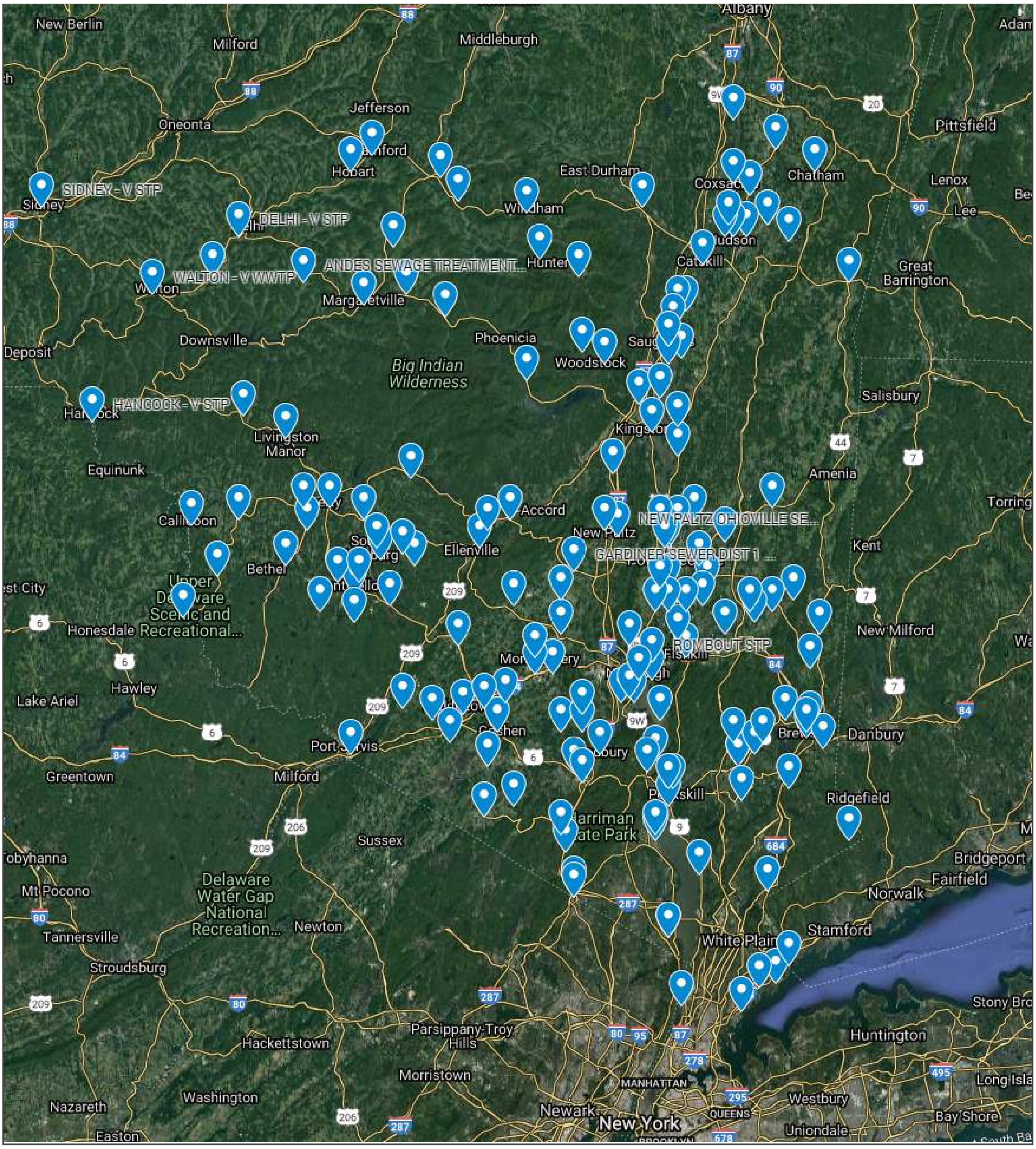


FIGURE BE: ***Wastewater Treatment Plants*** Source: NYS DEC

LEGEND

- ○ Blue - Wastewater Treatment Plants

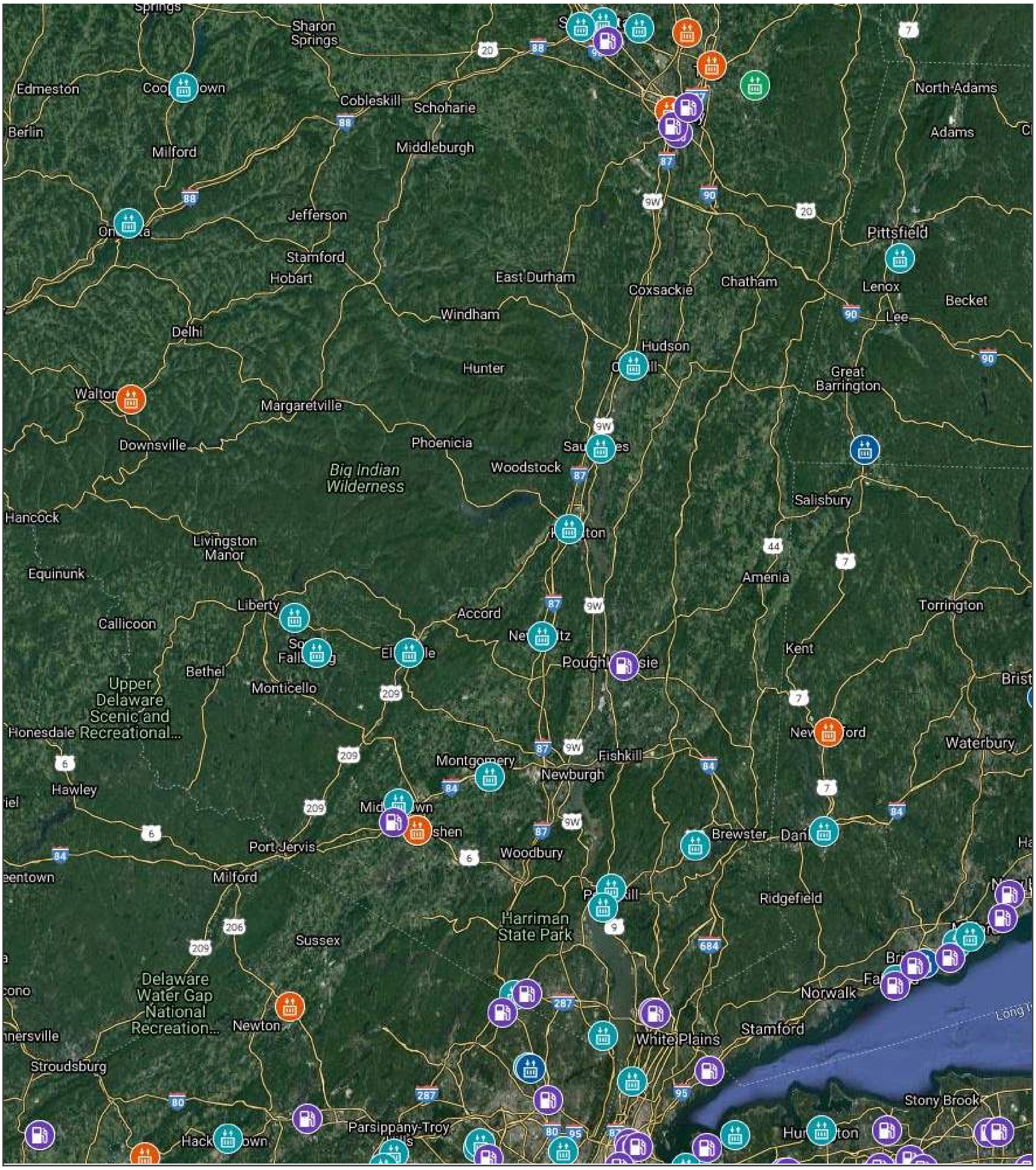


FIGURE BF: ***Operating NY Biogas Systems*** Source: USDA

LEGEND

- Purple - CNG Fueling Stations
- Red - Landfill Biogas Systems
- Teal - WWTP Biogas Systems
- Green - Agricultural Biogas Systems

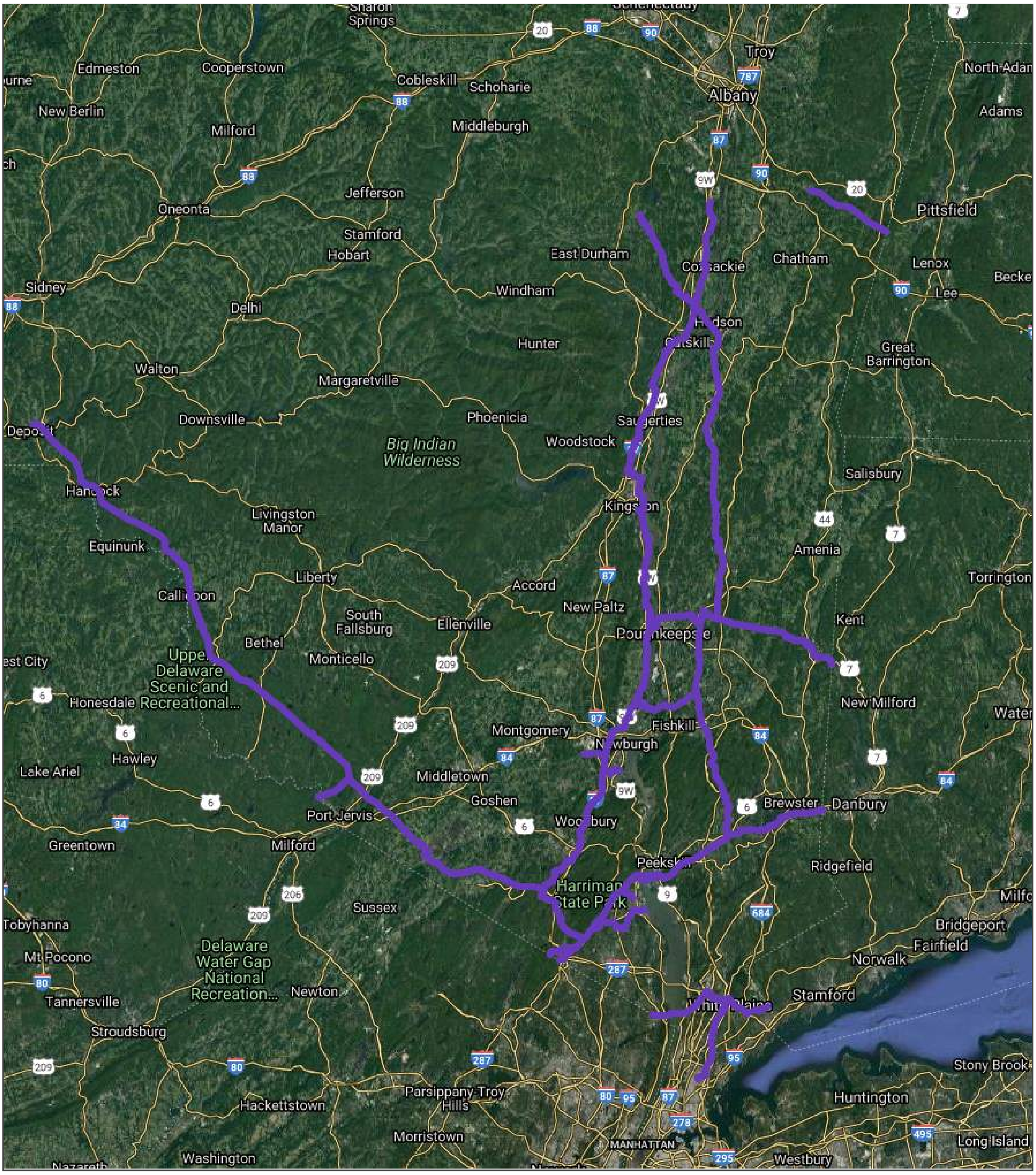


FIGURE BG: ***Natural Gas Pipeline Network*** Source: National Pipeline Map

LEGEND

- Purple - Natural Gas Pipeline Network

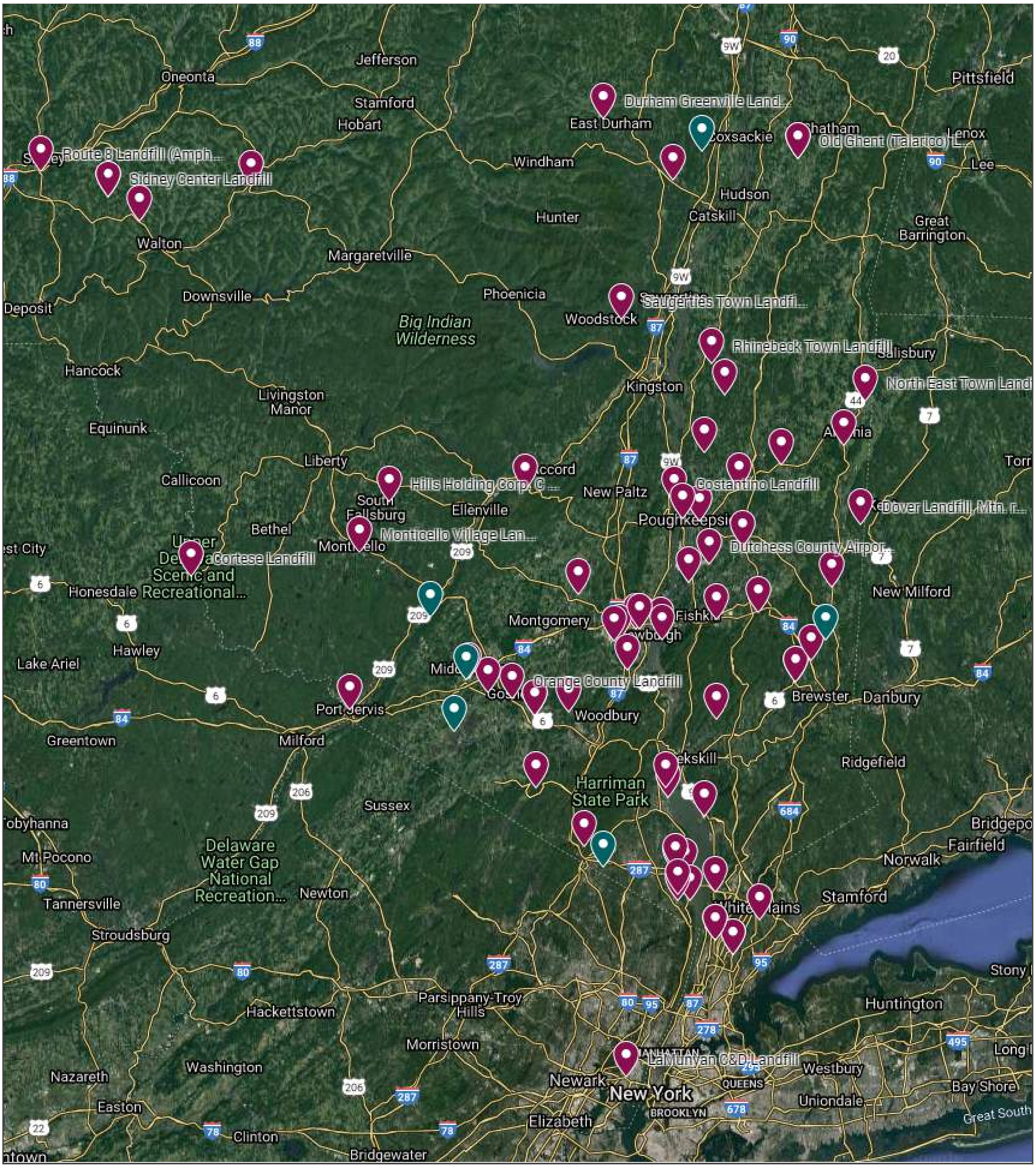


FIGURE BH: ***Landfills & Dump Sites*** Source: NYS DEC

LEGEND

- Burgundy - Landfill Sites
- Teal - Dump sites

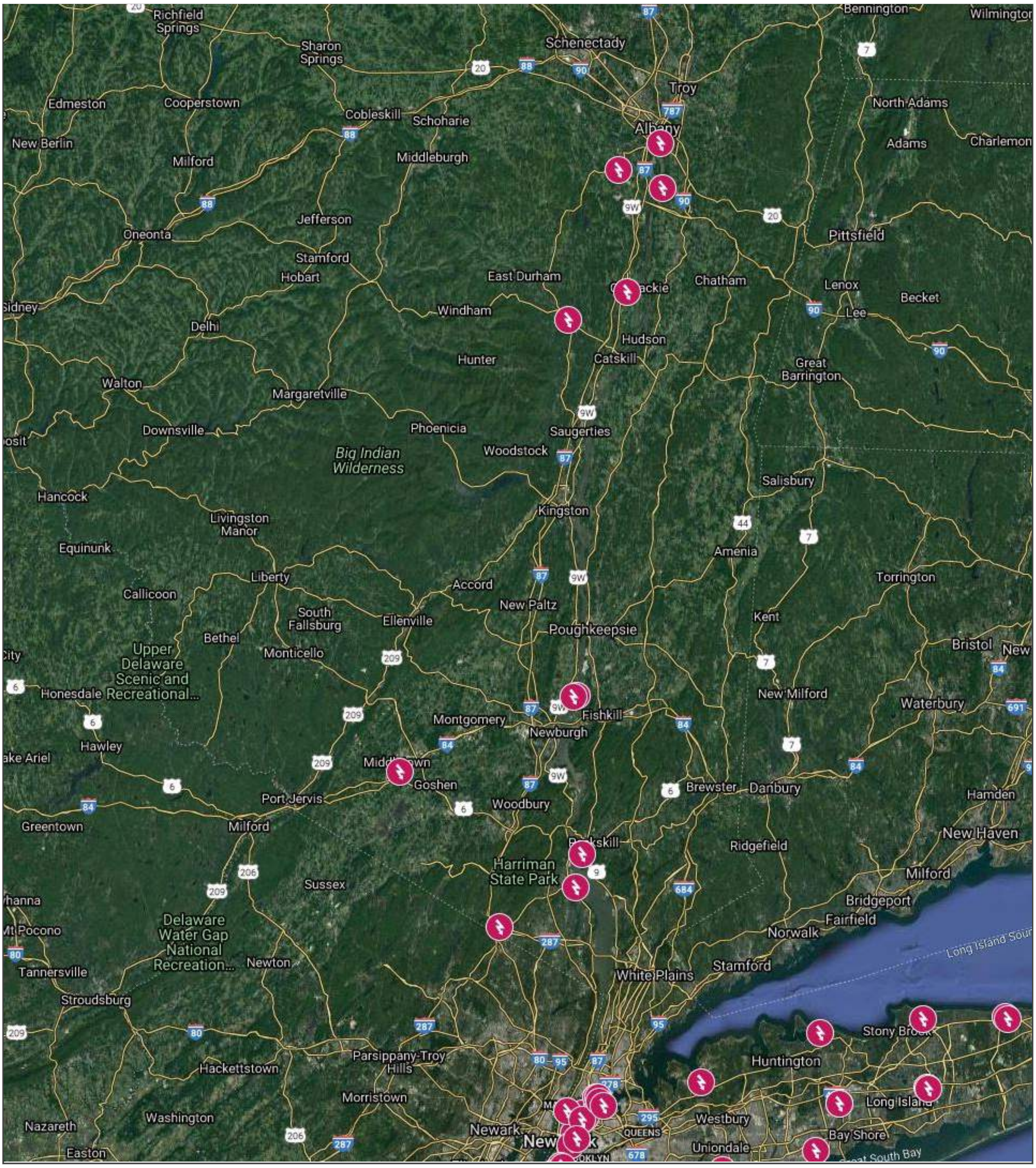


FIGURE BI: ***Power Plants*** Source: USDA

LEGEND

- Pink - Power Plants

Classification matrices

Industrial / commercial site with hauling activities						
Recycling facilities		Energy production			Landfill	
Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE BA: *Industrial / Commercial Operations*

Variation of feedstock				
Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE BB: *Anaerobic Digestion Feedstocks*

Pyrolysis & biochar		
Biosolids	Wood waste	Heat need

TABLE BC: *Pyrolysis Potential*

Space to host the proposed system		
Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE BD: *Space & Circular Economy (Area Overview)*

APPENDIX 3: Discussion

Mapping & prioritization

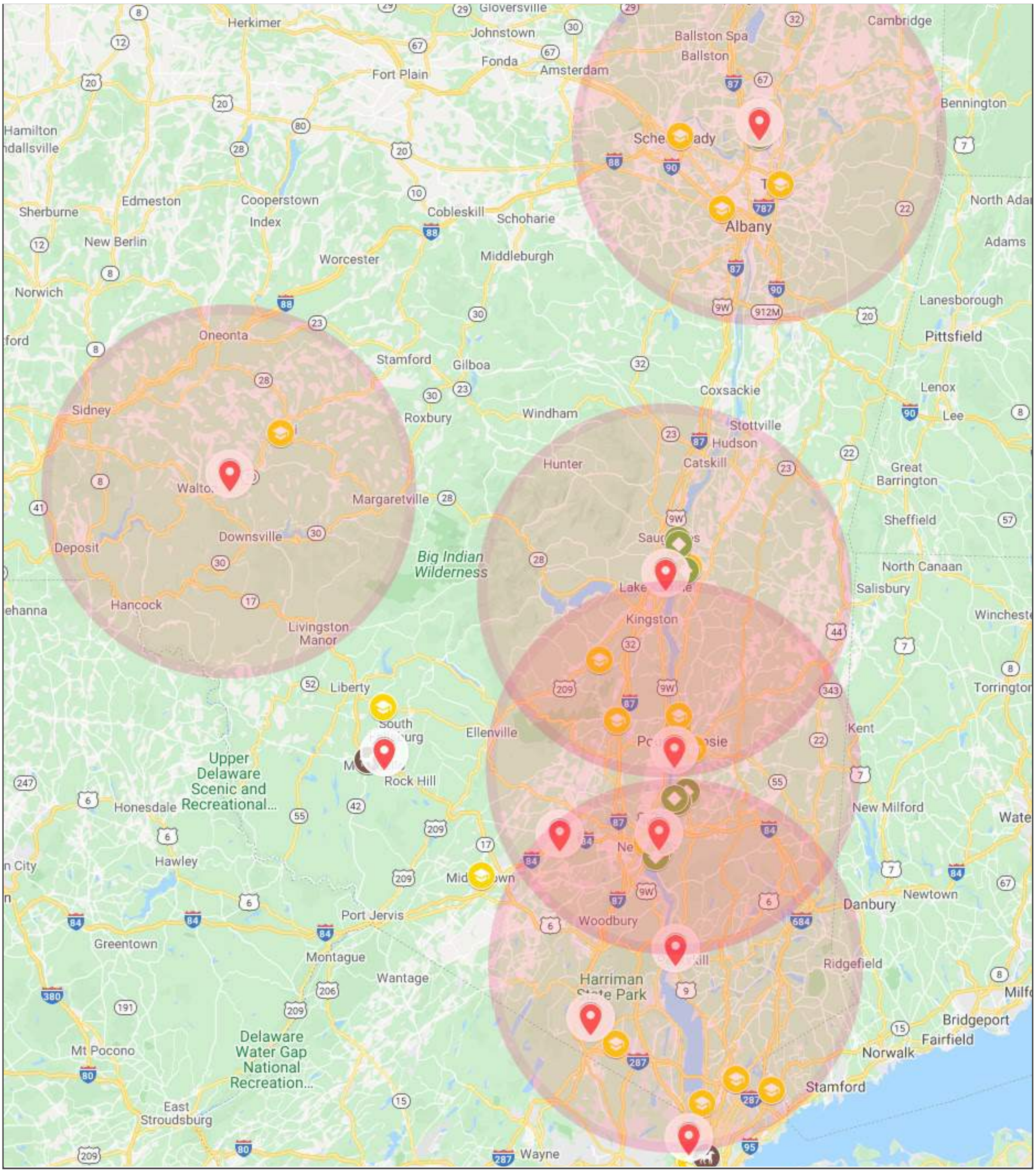


FIGURE CA: ***5 Selected Proposals For Maximum Area Coverage (Option A)***

- Proposal 5: Ulster County Resource Recovery Agency
- Proposal 6: Delaware County Solid Waste Management
- Proposal 8: Wheelabrator Westchester
- Proposal 9: Dutchess County Resource Recovery Agency
- Proposal 10: Town Of Colonie Landfill

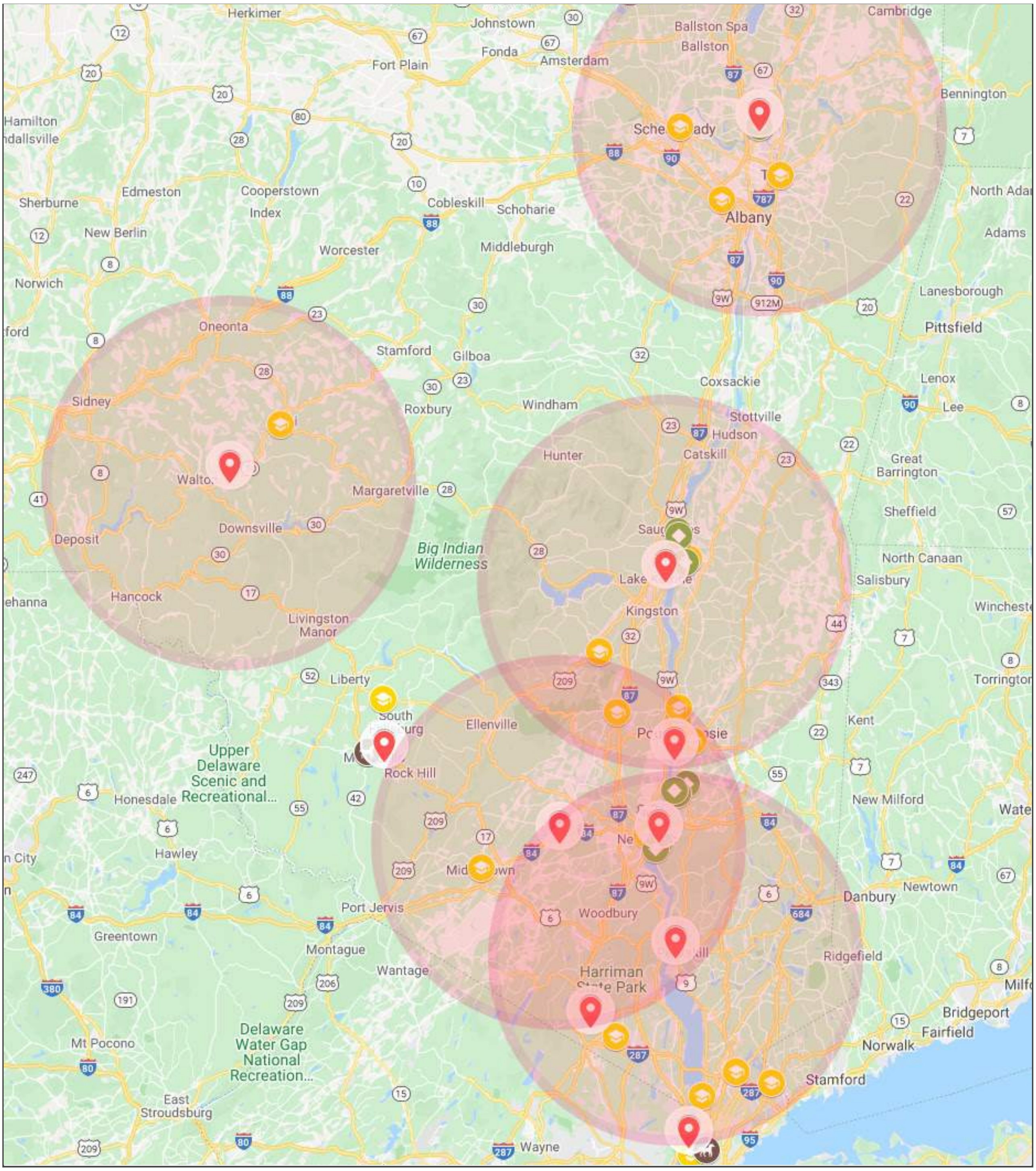


FIGURE CB: ***5 Selected Proposals For Maximum Area Coverage (Option B)***

- Proposal 5: Ulster County Resource Recovery Agency
- Proposal 6: Delaware County Solid Waste Management
- Proposal 8: Wheelabrator Westchester
- Proposal 2: Taylor-Montgomery LLC
- Proposal 10: Town Of Colonie Landfill

Environmental justice & opportunity zones

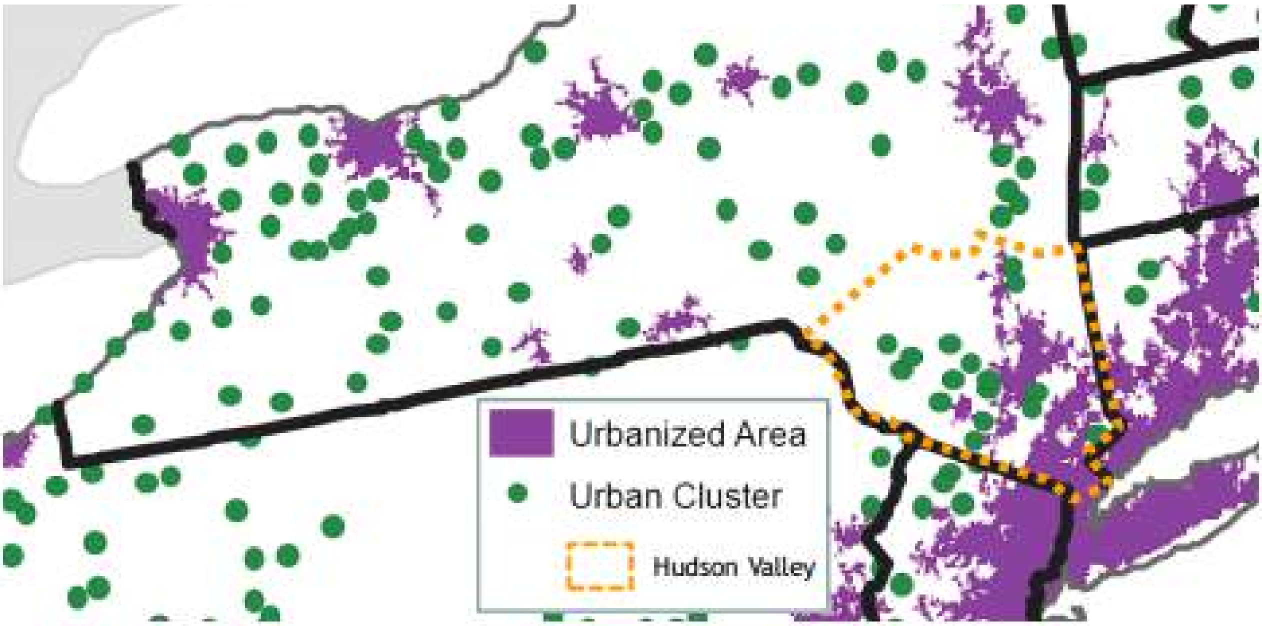


FIGURE CC: ***Urbanized Areas & Clusters (US Census Bureau)***

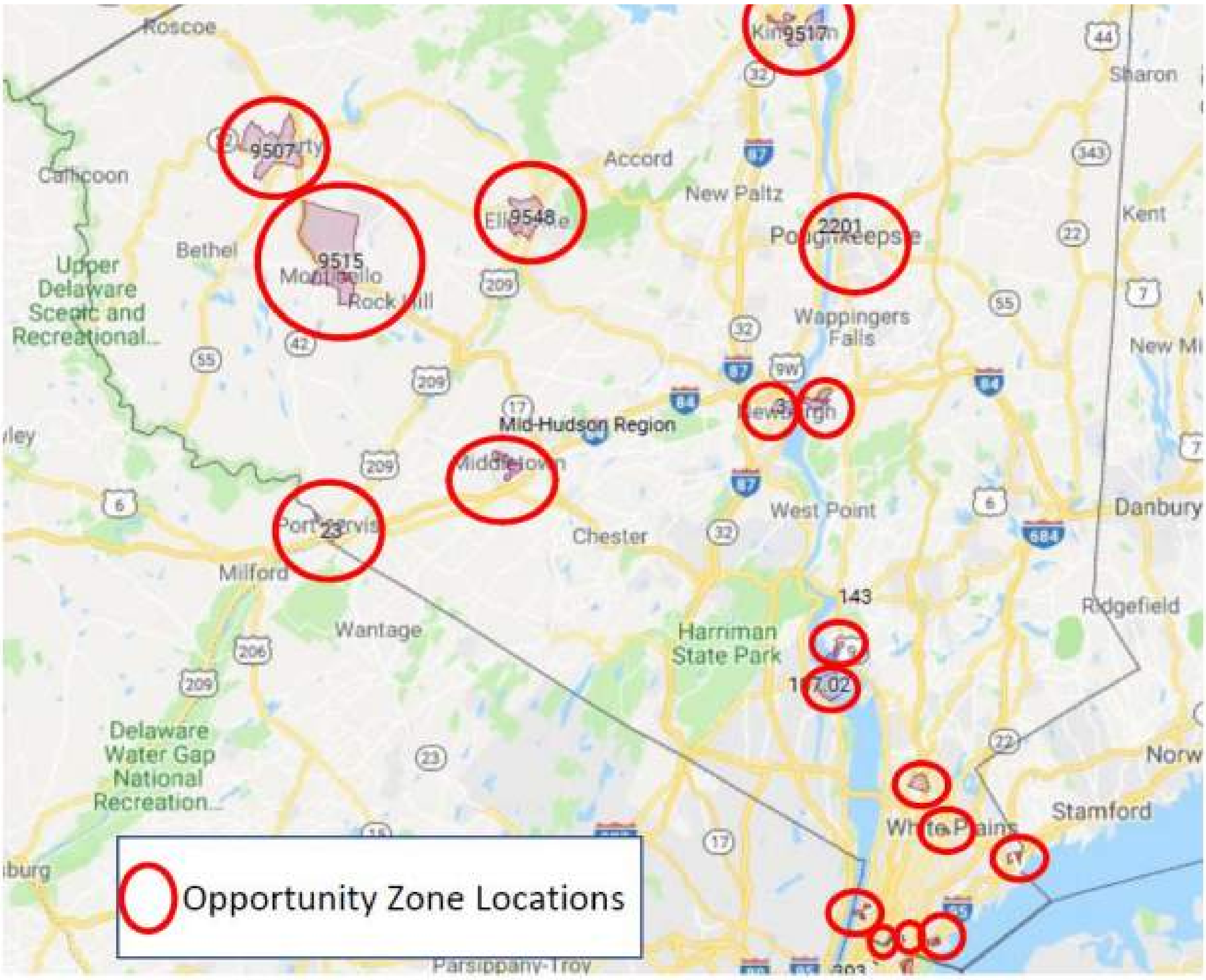


FIGURE CD: ***Opportunity Zones (NY Economic Development Strategy)***

APPENDIX 4: Conclusion

10 Proposals mapped

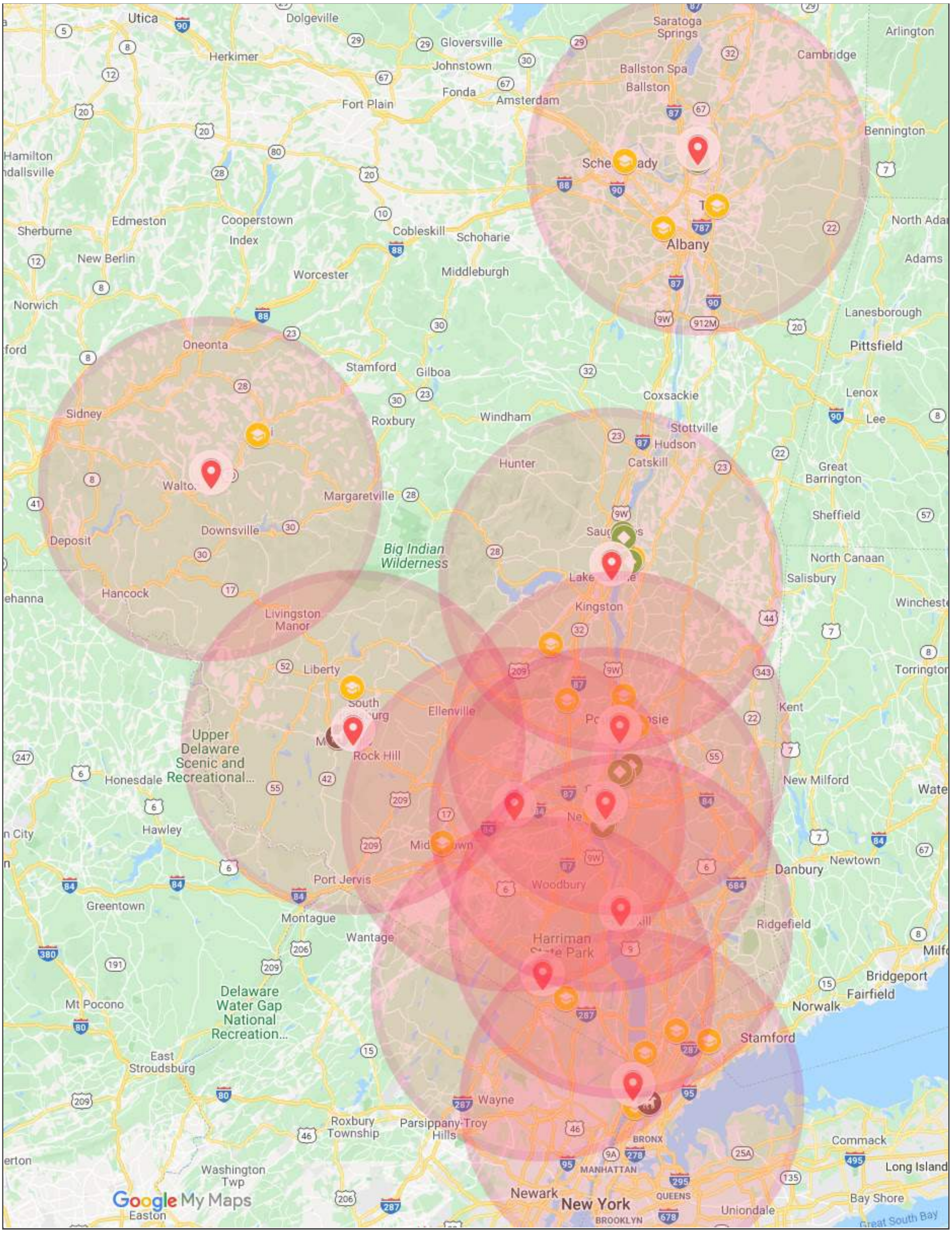


FIGURE DA: ***10 Proposals Mapped With ~25-Mile Radii***

Classification summary 1

		Industrial / commercial site with hauling activities						
		Recycling facilities		Energy production			Landfill	
1	Monticello Transfer Station	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
2	Taylor-Montgomery LLC	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
3	Beacon Recycling & Transfer	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
4	WeCare | Denali Rockland	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
5	Ulster County RRA	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
6	Delaware County SWM	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
7	Westchester County WWTP	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
8	Wheelabrator Westchester	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
9	Dutchess County RRA	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed
10	Town Of Colonie Landfill	Organics	Composting	Biogas	Incinerator	Natural gas	Active	Closed

TABLE DA: Industrial / Commercial Proposals Summary Extrapolated

Classification summary 2

		Variation of feedstock				
1	Monticello Transfer Station	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
2	Taylor-Montgomery LLC	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
3	Beacon Recycling & Transfer	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
4	WeCare | Denali Rockland	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
5	Ulster County RRA	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
6	Delaware County SWM	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
7	Westchester County WWTP	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
8	Wheelabrator Westchester	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
9	Dutchess County RRA	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses
10	Town Of Colonie Landfill	Excess food waste	Wood / yard waste	Invasive species	Livestock manure	Perennial grasses

TABLE DB: Anaerobic Digestion Feedstocks Proposals Summary Extrapoated

Classification summary 3

		Pyrolysis & biochar		
1	Monticello Transfer Station	Biosolids	Wood waste	Heat need
2	Taylor-Montgomery LLC	Biosolids	Wood waste	Heat need
3	Beacon Recycling & Transfer	Biosolids	Wood waste	Heat need
4	WeCare | Denali Rockland	Biosolids	Wood waste	Heat need
5	Ulster County RRA	Biosolids	Wood waste	Heat need
6	Delaware County SWM	Biosolids	Wood waste	Heat need
7	Westchester County WWTP	Biosolids	Wood waste	Heat need
8	Wheelabrator Westchester	Biosolids	Wood waste	Heat need
9	Dutchess County RRA	Biosolids	Wood waste	Heat need
10	Town Of Colonie Landfill	Biosolids	Wood waste	Heat need

TABLE DC: *Pyrolysis Potential Proposals Summary Extrapolated*

Classification summary 4

		Space to host the proposed system		
1	Monticello Transfer Station	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
2	Taylor-Montgomery LLC	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
3	Beacon Recycling & Transfer	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
4	WeCare | Denali Rockland	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
5	Ulster County RRA	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
6	Delaware County SWM	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
7	Westchester County WWTP	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
8	Wheelabrator Westchester	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
9	Dutchess County RRA	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives
10	Town Of Colonie Landfill	Sufficient to support proposal	Space to scale-up the proposed system with increased feedstock	Available area to introduce innovative circular economy initiatives

TABLE DD: *Space & Circular Economy Proposals Summary Extrapolated*

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Circular Biogas Systems For NY's Greater Hudson Valley

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